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Overview of District Heating and Cooling Markets and Regulatory Frameworks under the Revised Renewable Energy Directive

Main Report

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District Heating and Cooling in the European Union

Overview of Markets and Regulatory Frameworks under the Revised Renewable Energy Directive

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Table of contents

List of acronyms

ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie (French agency for environment and energy management)
AGFW	Energieeffizienzverband für Wärme, Kälte und KWK (German energy efficiency association for heating, cooling and CHP)
APG	Algemene Pensioen Groep (Dutch Pension Fund)
Art	Article
ATES	Aquifer Thermal Energy Storage
AVBFernwärmeV	Verordnung über Allgemeine Bedingungen für die Versorgung mit Fernwärme (Ordinance on General Terms and Conditions for the Supply of District Heating Germany)
BTES	Borehole Thermal Energy Storage
CAPEX	Capital Expenditure
CAPM	Capital Asset Pricing Model
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
COC	Condensable Organic Compounds
COP	Coefficient Of Performance
CoP	European Statistics Code of Practice
COx	Oxides of Carbon
CPC	Compound Parabolic Collector
CSP	Concentrated Solar Power
CTR	Centralkommunernes Transmissionsselskab I/S (Metropolitan Copenhagen Heating Transmission company)
DC	Distrcit Cooling
DCS	District Cooling Systems
DH	District Heating
DHC	District Heating and Cooling
DHW	Domestic Hot Water
DN	Nominal Diameter (in mm)
EC	European Commission
ECJ	European Court of Justice
EED	Energy Efficiency Directive
ELAN	Evolution du logement de l'aménagement et du numérique (Evolution of housing, development and the digital environment)
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Coefficient
EPCC	Engineering, Procurement, Construction and Commissioning
ESIF	European Structural and Investment Funds

ESP	ElectroSubmersible Pump
ESS	European Statistical System
EU	European Union
EWRC	Energy and Water Regulatory Commission (Bulgaria)
GHG	GreenHouse Gases
GW	GigaWatt
GWB	Gesetz gegen Wettbewerbsbeschränkungen (Act against Restraints of Competition in Germany)
GWh	GigaWatt hour
HC	Heating and Cooling
HeizkostenV	Verordnung über Heizkostenabrechnung (Ordinance on the Settlement of Heating Costs)
IHP	Independent Heat Producer
kW	KiloWatt
kWh	KiloWatt hour
L-CNG	Liquid to Compressed Natural Gas
LNG	Liquefied Natural Gas
MID	Measuring Instruments Directive
MS	Member State
MW	MegaWatt
MWe	MegaWatt electric
MWh	MegaWatt hour
MWth	MegaWatt thermal
na; n/a	not available
NCC	National Commission on Energy Prices (Lithuania)
NECP	National Energy and Climate Plan
NERC	National Energy Regulatory Counci (Lithuania)
Nm3	Normal cubic meter
No.	Number
NOx	Oxides of Nitrogen
NRA	National Regulatory Authority
NUP	National Urban Policy
nZEB	nearly Zero Energy Building
OPEX	Operational Expenditure
ORC	Organic Rankine Cycle
P2P	Point-to-Point
PEC	Primary Energy Consumption
PM	Particulates Matter
pp	Percentage Points
RED	Renewable Energy Directive

RES	Renewable Energy Sources
RES-HC	Renewable Heating and Cooling
SCR	Selective Catalytic Reduction
SNCR	Selective Non-Catalytic Reduction
SOx	Oxides of Sulphur
TO4	Thematic Objective 4
TPA	Third Party Access
TPS	Third Party Supplier
TSO	Transmission System Operator
UK	United Kingdom
URE	Energy Regulatory Office Electricity (Poland)
URSO	Úrad pre reguláciu sieťových odvetví (Office for Regulation of Network Industries Slovakia)
VAT	Value Added Tax
VEKS	Vestegnens Kraftvarmeselskab I/S (DH Company Copenhagen)
VOC	Volatile Organic Compounds
VST	Vilniaus Šilumos Tinklai (DH Company in Lithuania)
WWTP	WasteWater Treatment Plant

Acknowledgments

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Abstract

This study contributes to an enhanced knowledge of European District Heating and Cooling (DHC) markets, needed to develop policies, initiatives and projects contributing to achieving the decarbonization targets set by the European Green Deal. In particular, the study aims at providing, through a detailed investigation led for all EU Member States as well as the UK, Norway, Iceland and Ukraine, a deep analysis of the DHC market (Block A), as well as the policy framework (regulation and support measures) and urban regulations affecting DHC use in buildings and industries (Block B). It also aims at studying the various technical possibilities to further integrate renewable and waste heat and cold sources in local energy systems. To illustrate current best practices, ten European case studies of DHC systems using renewable energy, waste heat and waste cold sources are analysed, through a holistic approach, aiming at identifying virtuous, replicable, cost-efficient DHC developments in various environments (Block C). The results are based on a thorough literature review, surveys and interviews with national and local stakeholders as well as internal knowledge and experience of the consulting team.

Executive summary

Policy context

Through its European Climate Law and Green Deal, the EU has set itself the objective to achieve **climate neutral economy by 2050**, and set an intermediate targets for 2030 to achieve at least 55% greenhouse gas reduction by 2030. The 'Fit for 55 package' adopted in July 2021 proposes to raise the EU renewable energy target from 32% to 40% and the EU energy efficiency target from 32,5% to 39% (a 9% energy consumption reduction, if expressed against the 2020 baseline). One of the key challenges and contributor to achieve those objectives will be the **decarbonisation of the heating and cooling (H&C) sector,** currently representing half of the EU's final energy consumption and mainly relying on fossil fuels.

In the last decades, most of the European energy transition policies focused on renewable electricity and were mainly addressed at EU and national levels. The lack of policy focus on H&C decarbonisation by most Member States together with the local nature of **H&C markets** has resulted in a **significant data gap** on their characteristics, preventing the design of effective and efficient H&C decarbonisation policies. Developing those policies has now become an EU priority.

From the different H&C solutions, **district heating and cooling (DHC) is one of the main infrastructures allowing decarbonisation by integrating renewable and carbon neutral energy sources and technologies and participating in energy system integration**[1]. It allows to combine a variety of energy efficiency and decarbonisation solutions and leverage them to yield high greenhouse emissions reduction and energy savings. These solutions include the efficient integration of **local renewable energy sources** and the use of various forms of **excess heat and cold sources** (also called waste heat and cold[2]) that otherwise would remain untapped. Modern and efficient district heating and cooling is well-placed to benefit from and implement an overall multi-energy system approach, including in connection with city planning. It can also provide **flexibility on the electricity market** via power-to-heat solutions such as electric boilers or large-scale heat pumps, especially when coupled with thermal storage, or via combined heat and power (CHP) plants, to accommodate renewable electricity production for example. However, in many countries, the statistical office does not (yet) publish statistical data on DHC, and the visibility of the DHC situation in each country is limited at the European scale.

Despite the wide consensus on the **general interest of a broader deployment of modern and efficient DHC systems**, this solution represents only 12% of the EU's heating market[3], and the public awareness of its benefits remains low, especially in emerging DHC markets.

Purpose and Approach

This study contributes to an **enhanced knowledge of European DHC markets**, needed to develop policies, initiatives and projects contributing to achieving the decarbonisation targets set by the European Green Deal. At the EU level, it has supported the 2021 revisions

[1] For the role of district heating & cooling in energy system integration, please see the EU Energy System Integration Strategy, COM(2020) 299 final, July 2020

[2] Waste heat and cold is the terminology used in the Renewable Energy Directive (2018/2001/EU) and the Energy Efficiency Directive (2012/17/EU as amended by 2018/2002/EU)

[3] in the residential and service sectors (2018 data)

of the Renewable Energy Directive (RED), Energy Efficiency Directive (EED) and Energy Performance in Buildings Directive (EPBD).

In particular, the study aims at providing a detailed vision, for all EU Member States as well as the UK, Norway, Iceland and Ukraine, and a deep analysis of the DHC market (Block A), as well as the policy framework (regulation and support measures) and urban regulations affecting DHC use in buildings and industries (Block B). It also aims at studying the various technical possibilities to further integrate renewable and waste heat and cold sources in local energy systems. To illustrate current best practices, ten European case studies of DHC systems using renewable energy sources (RES), waste heat and cold sources are analysed, through a holistic approach, aiming at identifying virtuous, replicable, cost-efficient DHC developments in various environments (Block C).

The results are based on a thorough literature review, surveys and interviews with national and local stakeholders as well as internal knowledge and experience of the consulting team.

Main Findings

The study tackles the existing DHC market data gaps and contributes to an **enhanced knowledge of the European DHC markets. The data collection and analysis performed for this study contributes to the evidence base needed to develop effective policies on DHC and ensure that it contribute to achieving the decarbonisation targets for H&C** set under the 'Fit for 55' package and the European Green Deal.

Block A: Detailed market overview of DHC in Europe

The latest data regarding Europe's **DHC supply, its share in final energy consumption, technology and energy mix** per country and region have been integrated into an online dynamic visualisation tool (PowerBi), publicly accessible under the link below. In 2018, **district heating (DH) final energy consumption in the EU-27 was ca. 445 TWh** (representing, for the residential and services sectors, 12% of the final energy consumption for space heating and hot water), mainly in the residential sector (52%), while **district cooling (DC) represented 3,1 TWh**, mostly in the service sector.

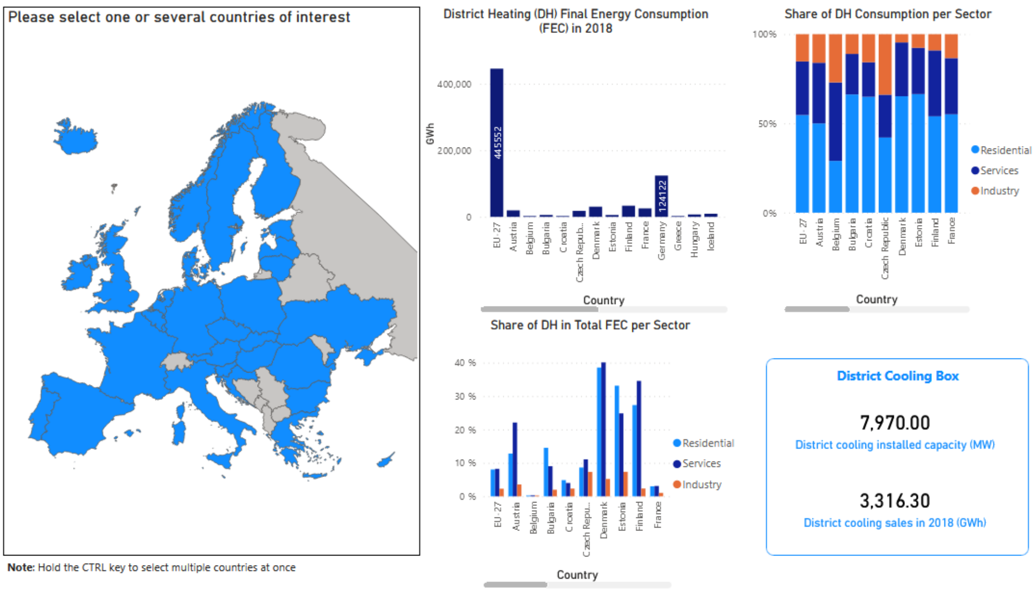


Figure 1: Interactive tool with DHC statistics (own production, https://irees.de/2021/10/18/district-heating-and-cooling-trend-interactive-report/)

Market situations vary strongly amongst the analysed countries, especially in terms of DHC deployment and energy mix. In the EU-27's residential sector, the highest share of DH in the heating and domestic hot water consumption is observed in the **Scandinavian and Baltic countries** (e.g., Sweden 50%, Denmark 46%, Lithuania 40%, Estonia 39%), while the DH market share in several Member States is below 1% (e.g., Belgium, Ireland, Spain). In the EU-27, DH production mainly comes from **cogeneration** plants (63%). **Two-thirds of this DH supply is generated with fossil fuels** (mainly natural gas), while **biomass, biofuels and renewable waste** are the main low-carbon fuels, accounting for ca. 27%. Interestingly, Scandinavian and Baltic countries, combining a high share of DHC in the H&C sector and a high share of low-carbon fuels in DHC, are currently Europe's best performers in H&C decarbonisation, with more than 45% RES-H share.

The **DHC regulatory situation, supervising authorities and support schemes** in each country are also very diverse and have been documented through country factsheets. A detailed analysis of the impact and efficiency of these different policy frameworks is provided in Block B.

Most European DH systems were developed during the 20th century, even if the first DH system dates back to the 14th century, at Chaudes-Aigues (France). The features of DHC systems have significantly evolved from the so-called First Generation DH systems (mostly steam systems supplied by coal-fired boilers or waste incineration units) to **modern Fourth Generation DH systems** (4GDH), characterised by a high share of local renewable and waste H&C technologies (beyond biomass and renewable waste), lower operating temperatures and higher interaction between consumers and producers within a smart local energy system. However, in many European countries, the weighted average specific heat consumption is above the suitable 4GDH threshold of 50 to 150 kWh/m²/y (depending on climate conditions), preventing the reduction of the DH supply temperature and thus the development of these systems. **Improving energy efficiency in buildings can therefore contribute to a higher deployment of 4GDH systems**, especially if these initiatives are coordinated between municipalities and DHC utilities, e.g., in the frame of a **municipal comprehensive heat planning** process.

Today, DH networks in Europe are mainly owned and operated by public entities, even if all kind of governance modes are in place (private, PPP, etc.), including consumer-owned networks. **Numerous DHC suppliers** have been identified and listed for each country, including international players present in most countries. However, national **DHC markets are highly concentrated** (i.e., a few suppliers control more than 70% of the market).

Consumers' perception and satisfaction are key aspects of DHC and some of the identified challenges of the sector. The study of the situation in each of the analysed countries shows that **a positive perception results from high transparency of prices**, **high quality of heat supply without interruptions** and **good customer service.** The most common complaints are about high prices, followed by billing issues.

Block B: Overview of the regulatory regimes applied to DHC

DHC systems are natural monopolies and are therefore subject to some kind of regulation in most countries (cf. examples in Figure 2 below). Unlike other energy grids (i.e., electricity and natural gas), most EU Member States consider DH to be an **integrated service** in which generation, grid operation and distribution are operated in an integrated manner by one company. Indeed, several studies from Finland, Sweden, Germany, or the UK imply that **unbundling DH might lead to higher heating prices.** In Lithuania, on the other hand, market liberalization on the production side led to lower retail prices.

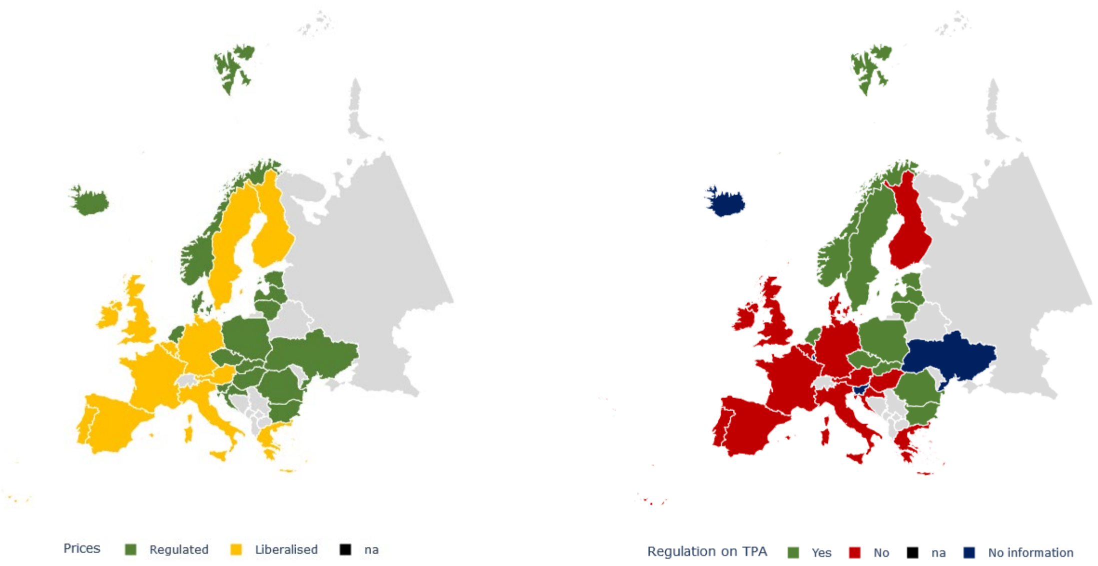


Figure 2: Maps of price (left) and TPA (right) regulations (source: own production from survey data)

In more than half of the analysed countries, DH prices, as well as the mechanism for setting prices, are regulated. The depth of regulation differs substantially. The price formation mainly depends on the fundamental principles the sector is regulated upon (profit-orientation vs. non-profit principle) and the specific design of the regulatory framework. The **two main models** in place for price regulations are: i) **liberalised DH prices** with ex-post price control on request (e.g., Finland, Germany, Sweden); and ii) **regulated DH prices** with mandatory price control (e.g., Bulgaria, Denmark, Lithuania, Poland, Slovakia, or the Netherlands). In countries with explicit price regulation, a cost-plus method is usually applied, while in countries with liberalised DH prices, prices are formed on the market.

In about half of the analysed countries, Third Party Access (TPA) is regulated in some form. However, there are significant differences in the regulation depth, and TPA can usually be denied whenever technical or economic reasons prevent it (e.g., capacity bottlenecks or generation costs). TPA is often also permitted in countries that do not explicitly regulate it (**voluntary TPA**) and is generally **limited to the producer side** (producer TPA or single-buyer approach). The study provides a guidance on key principles and elements to be reflected in the **contract between a third party supplier and a DHC operator**.

Moreover, **the analysis from this study reveals that there is no obvious correlation between the share of renewables or excess/waste heat and the degree of market opening of DH systems.** TPA may be a necessary condition, but in any case, it is not a sufficient one.

Subsidies and financial incentives targeting DHC grid infrastructure as well as renewable and efficient energy generation are largely available in most EU Member States, while support to research and innovation and connection of end-users to DHC networks is less common. Besides, in the majority of European countries, there is no legal nor regulatory framework regarding waste energy sources and no direct incentives to their use.

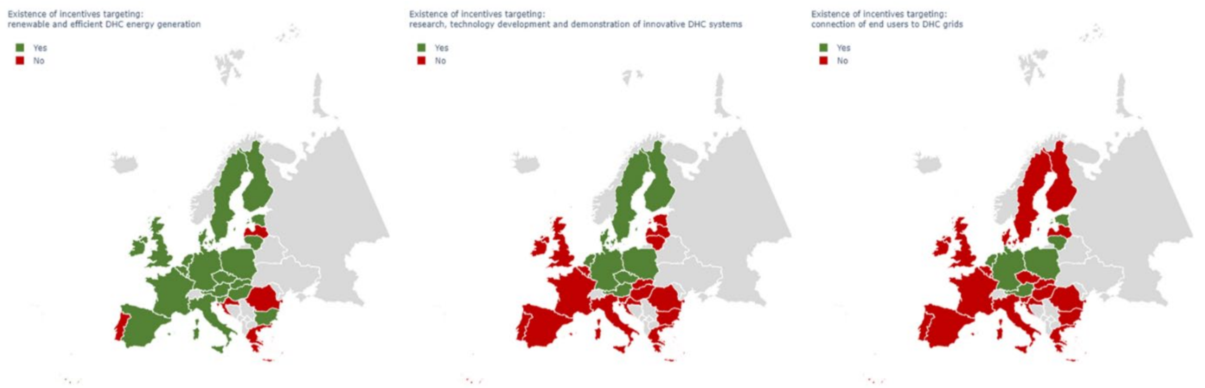


Figure 3: Maps on available incentives to DHC (own production)

The **building codes have a strong impact on the introduction of renewable H&C technologies.** In particular, nearly-zero energy buildings (nZEB) requirements have multiple impacts on DHC systems, mainly triggered by i) **primary energy consumption requirements**; ii) a **minimum share of RES**; and iii) the **primary energy factors of DHC systems** to be applied for the calculation of primary energy demand. The rigorous analysis of these factors for each country within scope revealed a **significant variety of values**. And even more, the **applied methods** also **strongly vary**, as well as the competitive position of DHC with respect to other H&C solutions. **Defining a few standardized procedures for identifying any of above tools** could lead to a more accurate comparison of energy sources and technologies and subsequently, to a better introduction of effective policies.

Finally, **urban planning** appears as a powerful **decarbonisation lever allowing energy savings and the deployment of renewable H&C solutions,** including DHC. Indeed, the potential for decarbonising the H&C sector highly depends on spatial planning issues for **optimal interlinking of demand and supply.** The analysis of H&C planning and DHC development within 13 city case studies concludes that mainstreaming **urban H&C planning requires national commitment via regulations** while, currently, explicit National Urban Policies (NUP) are found only in 10 EU Member States and do not address H&C planning specifically.

Block C: Overview of available technologies enabling the use of renewable and waste energy sources in DHC

DHC systems can play a key role as backbones for the integration of the various local renewable and waste energy sources, using mature technologies largely available on the market. The study presents a comprehensive assessment of the technologies associated to the use of renewable and waste energy sources in DHC systems, their respective opportunities and limits, as well as their techno-economical characteristics and complementary.

Indeed, **a wide palette of local and low-carbon energy sources can be integrated in DHC systems**, provided a number of technical and operational requirements are met. The study describes the technical conditions for the **optimized and efficient integration** of **renewable energies sources** (biomass, geothermal, biogas, solar thermal, ambient energy, and renewable electricity) and **waste energy sources** (power generation, industrial production, tertiary buildings, data centres, and underground railways), as well as their impact on the operation of DHC systems. **Thermal storage** can contribute to a higher uptake of these low-carbon energy sources, while increasing flexibility.

The use of these energy sources in ten **flagship European DHC systems** has been investigated through holistic case study analyses, identifying **key success factors (KSF) for H&C decarbonisation through DHC** and providing operational feedback that can inspire and guide policymakers, municipalities, DHC operators, urban planners and even citizens willing to foster H&C decarbonisation.

The main KSF at local level include the **support of municipalities**, a suitable and robust business model, **strategic (long-term) technical choices** for DHC supply and addressing the **DHC-building nexus,** as well as the implementation of **collaborative and innovative** approaches including consumer empowerment.

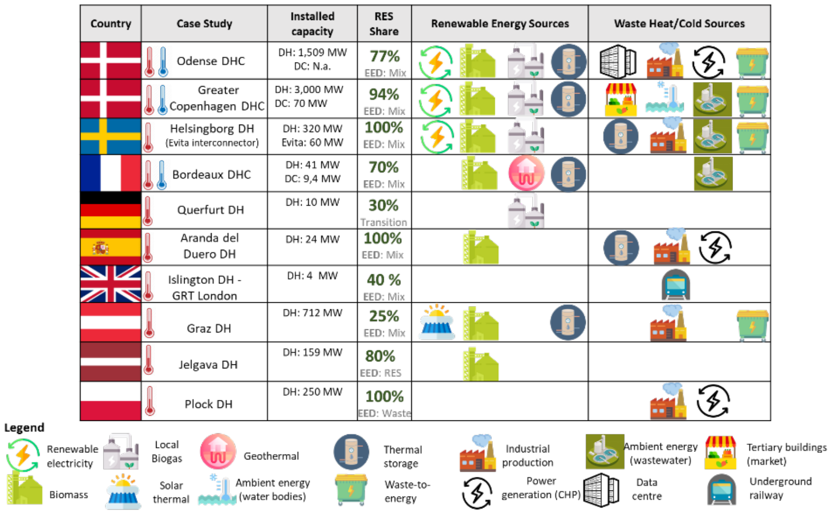


Figure 4: Best practices in DHC - Case studies analysed

Recommendations for H&C decarbonisation through DHC systems

- ✓ Quantified sustainable DHC targets at national level
- ✓ Stable and sufficiently strong price signals (e.g., CO2 taxes for fossil fuels, taxes on non-recovered waste heat, reduced VAT)
- ✓ Support schemes to facilitate the initial development of sustainable DHC systems and help them to overcome long pay-back time
- ✓ Mainstreaming strategic long-term local/urban heat planning, identifying district heating generation potential, sector synergies, etc.
- ✓ Obligation to DHC companies to develop long-term decarbonisation plans
- ✓ RES and waste heat quota obligations for DHC companies
- ✓ Incentives to facilitate the use of waste heat
- ✓ Incentives for higher customer participation and energy communities in DHC systems
- ✓ Improved transparency (e.g., information obligations)

Introduction

Context

Through its European Climate Law, the EU aims to become the first climate neutral continent by 2050. To this end, the European Union (EU) published in December 2019 the European Green Deal, the EU's ambitious climate policy whose goal is to achieve a modern, resource-efficient and competitive economy where economic growth is decoupled from resource-use [1]. One of the key challenges to achieve will be the decarbonisation of the heating and cooling (H&C) sectors, currently representing half of the EU's energy consumption and still mainly relying on fossil fuels [2].

District heating and cooling (DHC) is one of the main infrastructures allowing decarbonisation through smart sector integration. It enables the efficient integration of large-scale renewable energy sources like biomass, geothermal energy or solar thermal, and the use of various forms of excess heat and cold, often providing the strongest leverage, at the local level, to achieve decarbonisation. It can also provide flexibility on the electricity market via power-to-heat (PtH) solutions with either direct electric heating or large-scale heat pumps to accommodate renewable electricity production peaks for example. Because of their various advantages, DHC systems appear, in many respects, as a potential backbone for coherent local energy transition strategies, mainly due to the fact that they enable local authorities and other local stakeholders to combine a variety of energy efficiency and decarbonisation leverages within an overall multi-energy system, in connection with city planning. These networks also connect with national and European energy grids through sector integration solutions, linking heat, electricity and gas systems, providing energy storage and by using waste heat and waste streams. **In the last years and decades, the share of renewable energy sources (RES) in DHC has increased, positioning DHC as a powerful and cost-efficient enabler to develop low-carbon and resilient local multi-energy systems, which can evolve and be optimised over the time**. In particular, there are meaningful European examples of innovative integration of renewable energy sources and waste heat and cold into DHC systems. Some cities like Tartu, Copenhagen, or Stockholm have managed to gradually decarbonise their DHC systems, switching from fossil to RES and waste heat and cold sources. In parallel, flagship new efficient DHC systems have been developed in cities like Paris (Paris-Saclay), Milan or Hamburg (HafenCity). In these and other cases, the combination of fuel decarbonisation and optimised consumption proved to be a powerful cost-efficient leverage for deep local decarbonisation, which also stimulates local economic activity and paves the way to more balanced, resilient energy systems [64].

The analysis of the above examples suggests that business **models for DHC development have radically changed**. New modern DHC models follow different goals and development paths, as presented in the figure below.

Traditional DHC model (70s-90s)	New models
Long term concessions linking large scale production, supply and grid management within a unique contract	**Mid term concessions + service contracts**, often separating production contracts and supply from grid operation
Vertical integration, **no transparency on embedded costs**	Full **transparency on the value chain** at various levels
Centralised production, often coal or gas based, with or without CHP, unchallenged during the contract	**Decentralised production**, constantly reshaped with respect to environmental targets and cost effectiveness
Grid as a closed, **"one way" system**	Grid as enabler to **energy exchanges**
Mandatory connection, regardless of efficiency of alternative supply proposals	Conditional connection, can be challenged by efficient standalone solutions
Supply driven development	**Demand driven** development
Low consumer information, no cooperative dialogue to stakeholders	**Customer/stakeholder information as enabler to the model**

Figure 5: New models and new challenges for the development of DHC systems (Source: own assessment)

Acknowledging the potential system benefits of a higher deployment of efficient DHC[4], the renewable energy directive and its recast (RED and revised RED, or REDI and REDII)[5], the energy efficiency directive (EED)[6] and the energy performance of buildings directive (EPBD)[7] include explicit and implicit provisions and implications on the future use and extension of district heating and cooling. The 2018 recast of the **RED** (REDII) does not only include a newly established target of an annual increase of the percentage of renewable heating and cooling (Art. 23 of revised RED), but also a target for annually increasing the share of renewable district heating and cooling (Art. 24 of revised RED) . In addition, Member States are encouraged to implement regulations that allow producers of energy from renewable sources and from waste heat and cold (third party suppliers) to access district heating and cooling grids (Art. 24 revised RED). The **EED** includes provisions for developing the economic potentials of efficient district heating (Art. 14 EED and its Annex VIII and IX, as amended by Commission Delegated Regulation 2019/826[8]). Last but not least, the **EPBD** requires Member States to include the concept of nearly-zero-energy

[4] Efficient district heating and cooling is defined in Article 2(41) of EED. The same definition is applied under Article 2(20) of REDII, which includes this definition by reference. Efficient district heating and cooling is defined as: district heating systems using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat

[5] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (REDI); revised by Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (REDII)

[6] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC; amended by Directive 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency

[7] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings; amended by Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

[8] Commission Delegated Regulation (EU) 2019/826 of 4 March 2019 amending Annexes VIII and IX to Directive 2012/27/EU of the European Parliament and of the Council on the contents of comprehensive assessments of the potential for efficient heating and cooling

buildings (nZEBs)[9] in their building codes and regulations, which requires to cover the remaining low level of energy use mostly with renewable energy, with corresponding implications on the accounting of district heating and cooling in these nZEB definitions (Art. 9 EPBD). The requirement to ensure a minimum level of renewables in buildings is explicitly enshrined in the revised RED, and this level can also be fulfilled with renewable heating from efficient district heating and cooling systems (Art. 15(4) of revised RED).The national implementations of these directives are different and need to be considered thoroughly in the assessment of district heating and cooling policy and regulatory frameworks as well as their expected short- and mid-term developments.

At the local level, municipal regulation can also influence the development of DHC systems. In particular spatial planning and zoning of district heating priority areas have a strong impact on the achievable economic effectiveness of district heating grid infrastructure. Denmark, for example, has shown since several decades how municipal heat planning can have a positive impact on the economic effectiveness of district heating infrastructure and subsequently on the expansion and use of district heating. More recently, examples in Switzerland and the Netherlands showed that indicating district heating priority zones is an important signal, as well as regulatory measures supporting district heating.

Despite the wide consensus on the general interest in a broader deployment of efficient DHC systems, there is still a significant data gap on DHC markets and regulations in Europe. In the last decades, most of the energy transition policies have been focused on renewable electricity, and even if the EU is the most advanced continent in renewable heat policy development [3], one of the main challenges of the European Green Deal will be to develop a comprehensive set of policies enabling a deep decarbonisation in heating and cooling. The first step to design these policies consists in developing a comprehensive understanding of heating and cooling markets, addressing the current data gap.

Objective

This study aims at providing a detailed vision, for all EU Member States as well as the UK, Norway, Iceland and Ukraine, of the market and regulatory framework of DHC systems, and urban regulations affecting its use in buildings and industries (building regulations, urban planning, etc.), and the various technical possibilities to further integrate renewable and waste heat and cold sources in local energy systems. To illustrate current best practices, ten European case studies of DHC systems using RES, waste heat and cold sources or both are analysed, in a holistic approach, aiming at identifying virtuous, replicable, cost-efficient best practices in various environments.

By doing so, the study contributes to an enhanced knowledge of European district heating and cooling systems, needed to develop efficient policies, initiatives and projects contributing to achieving the decarbonisation targets set in the European Green Deal. At EU level, the study is expected to contribute to the 2021 revisions of the RED, EED and EPBD.

[9] The definition of nZEB is not undertaken at European level, but is subject to national implementation. Though, national definition must in any case consider nZEB as a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources.

Report Structure

The report is composed of three main blocks (A to C), followed by a conclusion in block D:

- **Block A provides a detailed market overview of DHC** in each country within the scope, and a summary description of the European Union as a whole, including:
  - DHC supply share, technology and fuel use (section A.1)
  - DHC historical developments, size and type of networks (section A.2)
  - DHC regulatory framework, market actors and customer satisfaction (section A.3)

- **Block B provides an overview of the regulatory regimes applied to DHC** in each country within the scope, and a summary description of the European Union as a whole, in particular with regard to:
  - Measurement methods and reporting (section B.1)
  - Pricing regimes and support schemes (section B.2)
  - Regulatory regimes on access to DHC and associated contractual modalities (section B.3)
  - Overview of national building regulations, urban planning and other urban regulations affecting the use of DHC in buildings (section B.4)

- **Block C provides an overview of available technologies enabling the use of renewable and waste heat and cold sources in DHC**, illustrated through ten case studies of European best practices.
  - Technologies enabling to integrate renewable energy sources (section C.1)
  - Technologies enabling to integrate waste heat and cold sources (section C.1)
  - Case study analysis of 10 DHC networks in Austria, Denmark, France, Germany, Latvia, Poland, Spain, Sweden and the UK (section C.2)

A. District Heating and Cooling in the EU – Market Overview

The first part of the study (block A) provides a detailed market overview of district heating and cooling (DHC) in each European Member States, the UK, Norway, Iceland, and Ukraine and a summary description of the European Union as a whole. By focusing on the technical parameters of existing DHC networks, regulatory frameworks and consumer perception, the tangible objectives of this task can be classified in the following categories:

- Quantification, description and graphical representation of the energy supply, consumption shares by sector, fuel, and technology mix of the existing DHC networks.
- Quantification, description and graphical representation of the historical developments and size of the DHC networks. Additional assessment and classification of the existing networks types based on the average specific heat demand, heat source and integration with the electricity sector.
- Assessment and description of the current regulatory framework and identification of the relevant market actors.
- Additional research on the current market satisfaction based on the available literature and existing case studies.

To achieve these objectives, the task is divided into three chapters as presented in Figure 6. The **first chapter A1** shows the final district heat consumption in the residential, service, and industrial sectors. Furthermore, it defines the installed capacities of the different heat supply technologies, the cogeneration share and the fuel used for the heat production. The **second chapter A2** strives to classify the existing networks in the four generation groups based on the heat supply technologies and the thermal condition of the supplied building stock. Additionally, it defines size of the networks and the historical developments and investment approaches. The **third** chapter **A3** provides an analysis of the main suppliers and the level of market concentration and competition. Moreover, it provides an overview of the regulatory frameworks, relevant authorities, and statistical reporting methods. This chapter provides input and serves as a starting point of block B, which analyses the applied regulatory regimes. Additionally, this chapter provides and overview of the consumer perception and satisfaction of DHC networks.

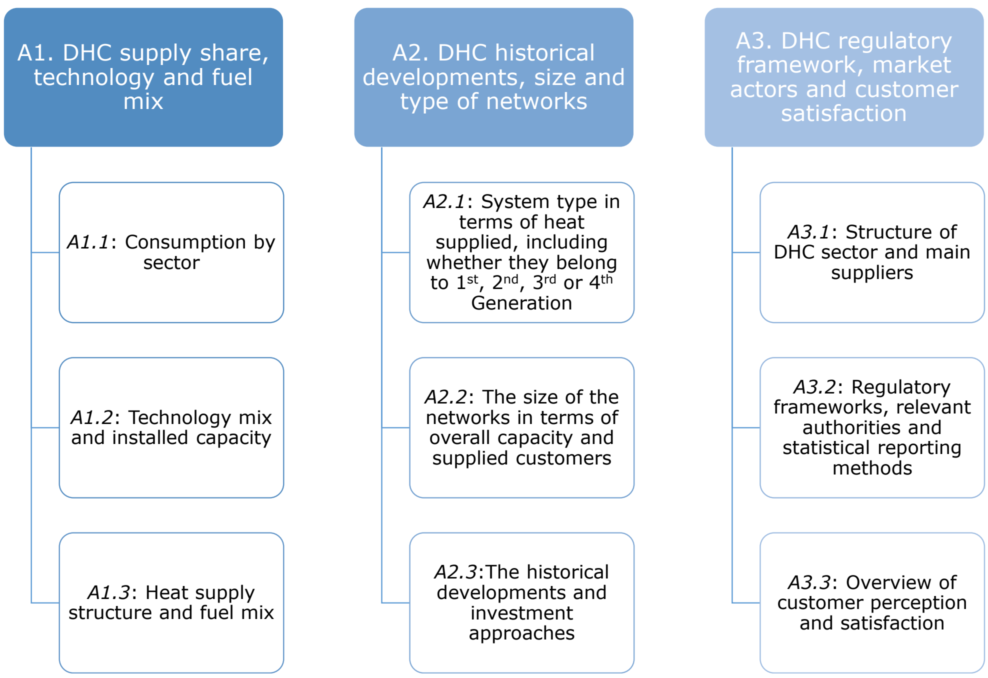


Figure 6: Block-A overview of chapters and subtasks

The results and analysis gathered in this part are based on a comprehensive literature review as well as a survey addressed to the main DHC stakeholders in the 31 countries within the scope of the study (except Malta and Cyprus where there is no DHC market today). The contacted stakeholders have been identified as key actors in the DHC field in their country, and come from national regulatory bodies (Ministry, Energy Agency, City Authority, etc.), DHC national associations, DHC operators, research institutions or consulting.

The survey has been conducted by an online questionnaire and built to collect precise information that were not available in the literature. The quality control of the answers has been carried out by cross-checking the information collected from the different participants of a same country as well as the information already collected through the literature review. The results of the survey have been used to complete some sections of blocks B and C as well. Specific information collected from country experts through this survey are referenced as such in the report.

A.1 DHC supply share, technology, and heat supply mix by country

Figure 7 presents the structure of chapter A1. The goal of the first section A.1.1 is to derive the final energy consumption of district heating and cooling per sector. In section A.1.2 the installed capacities by technologies are presented. The objective of section A.1.3 is to provide an overview of the heat supply structure by type of heat production (cogeneration or heat only) and energy carrier.

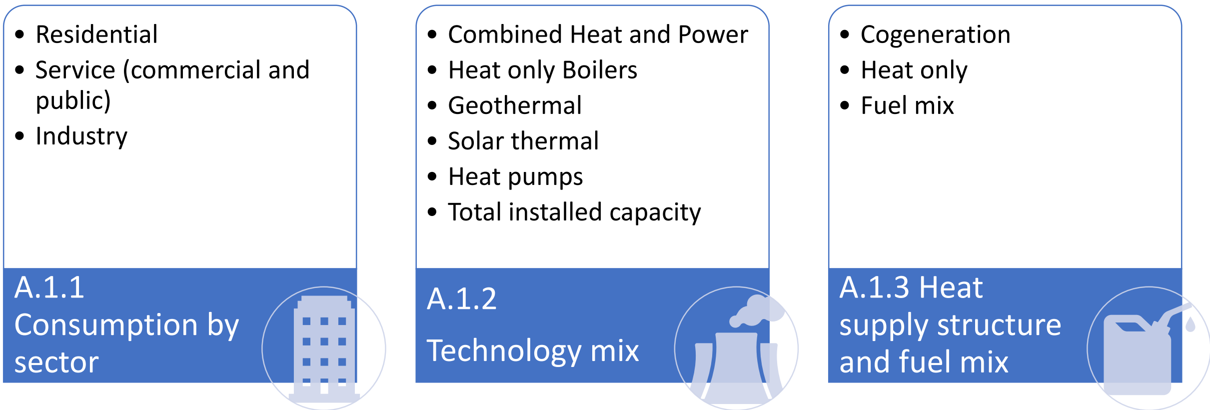


Figure 7: Overview of chapter A1 and its structure

A.1.1 DHC consumption by sector

The approach to define the consumption of district heating per sector consists of two steps:

- Analysis of heating and cooling demand per sector and country according to the official energy balances
- Compilation and analysis of country specific data

First of all, the complete energy balances data set from Eurostat [1] is used to analyse the final energy consumption of heating and cooling for each sector. In the second step, country-specific data is analysed and compared with the data from Eurostat.

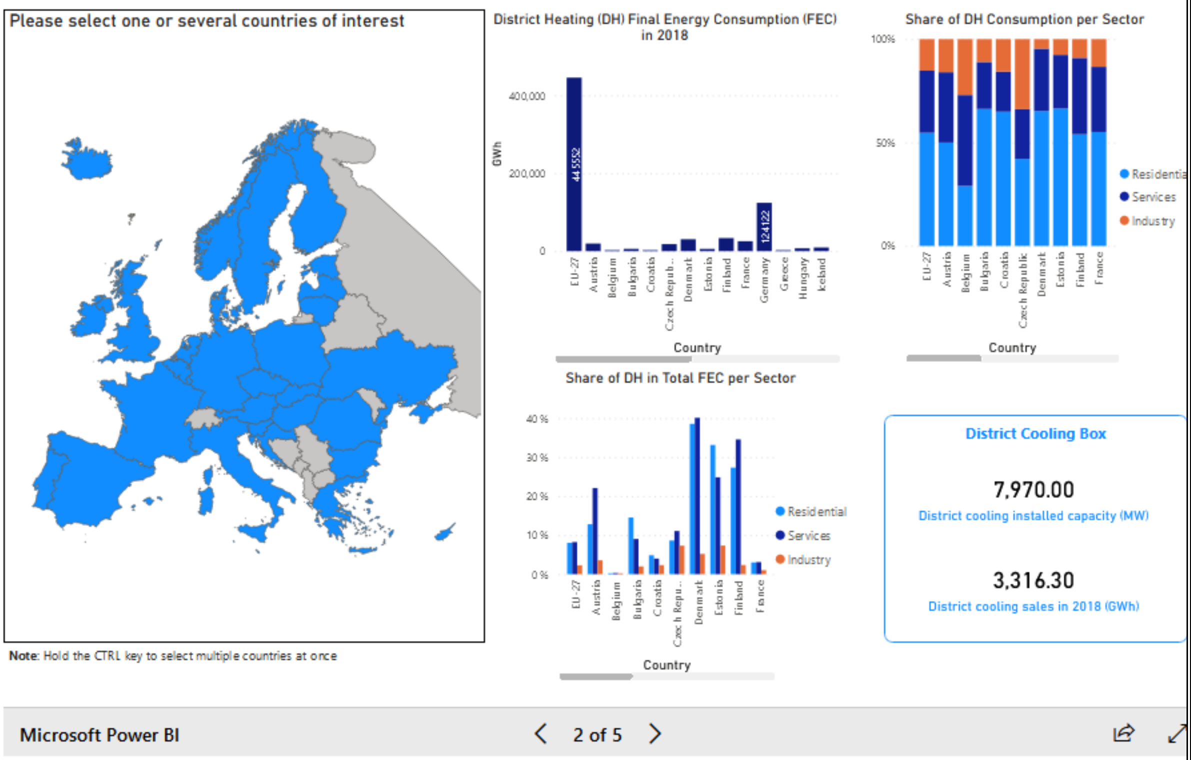
As one of the most complete statistical dataset of energy products, the Eurostat complete energy balances (nrg_bal_c) offers a view on the energy situation of a country in a compact format and divides the energy consumption of the whole economy in individual sectors. With regard to heating and cooling consumption, the residential sector (FC_OTH_HH_E), service (commercial and public) sector (FC_OTH_CP_E), and industry (FC_IND_E) has been included in the analysis. Final energy consumption from district heating is denoted as Heat[10] in the Eurostat statistics.

The compiled country-specific data comprises of different reports from relevant regulatory agencies, district heating associations and the 2019 Country by country reports from Euroheat & Power [2]. The list of the relevant country-specific regulatory authorities and the statistical sources are presented in Annex 2 and Annex 3.

[10] Heat (Current Eurostat dissemination code:H8000) refers to all heat produced, except for heat produced by autoproducers for their own use. All other forms of heat are reported as use of products from which the heat is produced. Hence, the heat reported is not necessarily used for space heating and hot water preparation, particularly relevant for the heat consumption in the industrial sector.

Dynamic web-application as an attachment to the report

Part of the results are compiled in an excel file as an attachment to the report as well as a dynamic web-application which can be access on the following website: https://irees.de/2021/10/18/district-heating-and-cooling-trend-interactive-report/.



The comparison of additional country-specific data on DHC with Eurostat statistics on Heat shows that the results for the residential and services sectors match for most of the countries[11]. Nevertheless, there are also significant deviations for some countries, especially in the industry sector. Therefore, the results presented in Table 1 are based not only on the Eurostat dataset but also on the additional country specific literature and statistics.

[11] Some deviations are due to the fact that data points are continuously updated, and have a different extraction dates

Table 1: District heating final energy consumption (GWh) by sector in 2018 (Source: Country-specific sources as presented in the excel attachment)

Country	Residential	Services	Industry	Total*
Austria	9,750	6,630	3,120	19,500
Belgium (Flanders region)	103	156	96	355
Bulgaria	3,769	1,293	629	5,691
Cyprus				
Croatia	1,297	387	314	1,998
Czech Republic	7,072	4,029	5,693	17,986
Denmark	19,933	9,211	1,410	30,554
Estonia	3,627	1,417	416	5,583
Finland	18,090	12,375	3,035	33,500
France	14,000	8,000	3,400	25,400
Germany	42,525	37,856	22,043	124,122
Greece				340
Hungary	5,417	1,790		7,206
Ireland				
Italy	5,900	3,100	289	9,289
Latvia	4,315	1,500	942	6757
Lithuania	5,580	2,065		7,645
Luxembourg	80	773	6	860
Malta				
Netherlands	2,967	2,065	1,300	6,333
Poland	43,611	11,614	9,624	64,849
Portugal	12	31		43
Romania	7,346	2,540		9,887
Slovakia	4,383	4,348	5,540	14,271
Slovenia	853	688	356	1,897
Spain	160	256	117	535
Sweden	30,130	14,761	6,060	50,951
EU-27	**230,920**	**126,885**	**64,390**	**445,552**
United Kingdom	6,500	5,500	-	12,000
Iceland	4,478	3,829	261	9,369
Norway	1,513	3,364	766	5,870
Ukraine	26,418	17,345	11,246	55,009

*The total includes heat to other sectors (energy, agriculture, etc) if applicable

In Figure 8 the DH share of the space heating and hot water final energy consumption in the residential and services sector in 2018 is presented. The highest shares of DH in the residential sector are observed in the Scandinavian and Baltic countries with shares above 30%. In the commercial and public services apart from the Scandinavia and Baltic countries, significant shares of DH can be observed in Austria, Slovakia, Slovenia, and

Ukraine. For the industrial sector, due to the missing statistical data of energy consumption by type of use, it is not possible to determine the share of space heating and hot water consumption from the total final energy consumption, and therefore the share of DH as well.

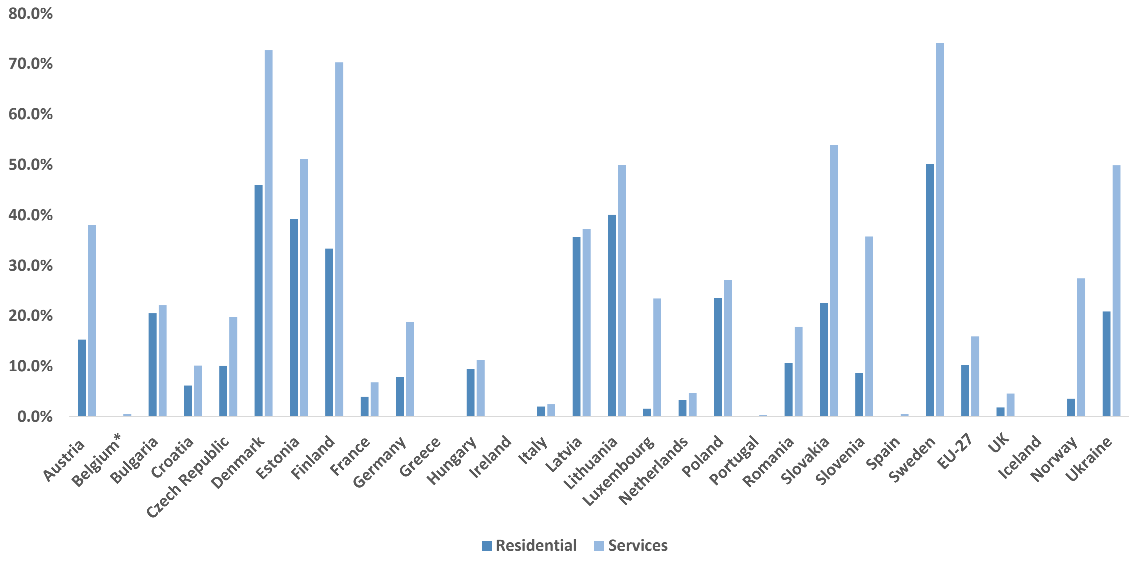


Figure 8 : District heating share of the space heating and hot water final energy consumption in the residential sector and services in 2018 (Source:[3],[4] data from Table 1)

Figure 9 presents the share of DH from the total final energy consumption in each sector in the year 2018. In the industrial sector, DH consumption plays a minor role, where shares above 5% of the total final energy consumption in the industrial sector can be observed in Denmark, Estonia, Latvia, Poland, Slovakia, and Ukraine.

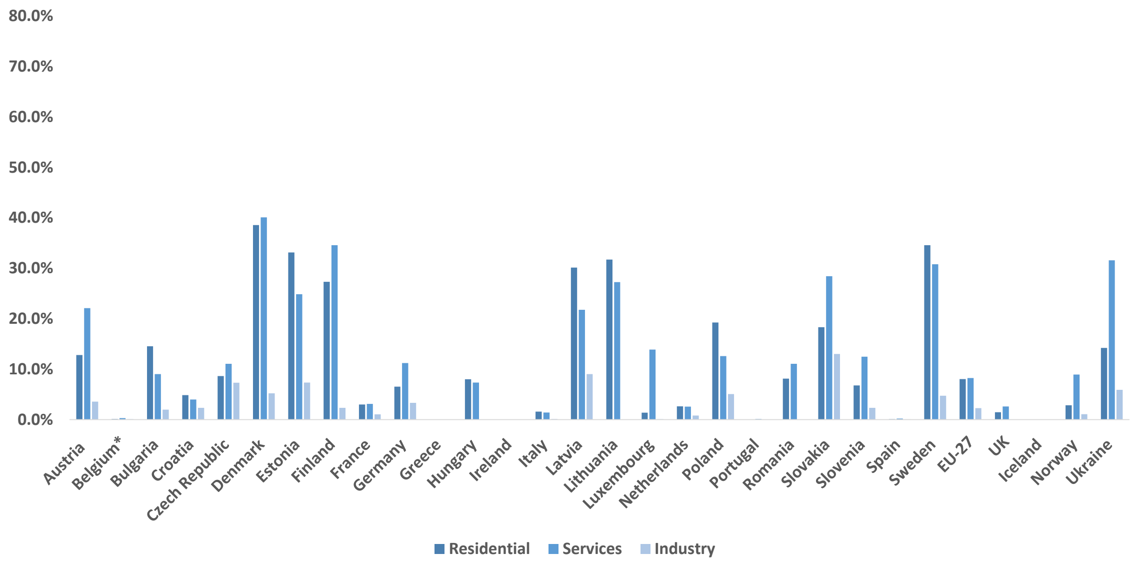


Figure 9 : District heating share of the total final energy consumption in the residential, services, and industrial sector in 2018 (Source:[3], data from Table 1)

Regarding district cooling, there is no comprehensive statistical dataset available. To determine the final energy consumption from district cooling and installed capacities of district cooling networks, individual reports of member states are compiled and analysed (presented in Annex 2 and Annex 3 section). In addition to country specific reports and statistics, annual reports and other company specific data from utilities and companies active in the district cooling market are included in the analysis such as reports from Wien Energie[12], EVN Bulgaria[13], Veolia ČR[14], Hofor[15], Fortrum[16], Engie – Climaespaço[17], Districlima[18] and many more. In the second step, the data were compared with an existing dataset on district cooling [5].

The results presented in the Table 2 show for district cooling an installed capacity in the EU27 of around 7.8 GW and for cooling consumption of almost 3.1 TWh in 2018. The district cooling consumption is not divided per sector as most of the sales are in the service sector (shopping centres, hospitals, trade fairs, office buildings etc.) with a very small part and site-specific share of residential buildings (mostly new buildings) as the connection of existing residential buildings, unlike district heating networks, is not feasible due to the absence of cooling distribution systems.

Table 2: District Cooling installed capacities and sales in 2018

Country	Installed Capacity (MW)	District cooling sales (GWh)
Austria	130.0	142.5
Belgium	0.6	0.5
Bulgaria	0.5	0.1
Cyprus		
Croatia	6.9	2.0
Czech Republic	34.6	18.5
Denmark	21.8	4.1
Estonia	13.0	13.0
Finland	283.0	211.4
France	761.0	1,061.6
Germany	241.0	307.5
Greece		
Hungary	1.2	0.7
Ireland		
Italy	202.0	126.7
Latvia		
Lithuania		
Luxembourg	19.0	22.9
Malta		
Netherlands	23.0	19.6
Poland	43.0	45.8

[12] Wien Energie (website accessed on: 22/05/20)
[13] EVN Bulgaria (website accessed on: 22/05/20)
[14] Veolia Czech Republic (website accessed on: 22/05/20)
[15] DBDH - Hofor Experience (website accessed on: 22/05/20)
[16] Fortum - reports and presentations (website accessed on: 22/05/20)
[17] Engie, the Lisbon DHC (website accessed on: 22/05/20)
[18] Districlima, "A consolidated DHC" (website accessed on: 22/05/20)

Country	Installed Capacity (MW)	District cooling sales (GWh)
Portugal	40.0	69.4
Romania		
Slovakia		
Slovenia	4.9	1.5
Spain	122.0	67.9
Sweden	5,787.0	914.3
EU-27	**7,734.4**	**3,030.2**
United Kingdom	75.5	64.3
Iceland		
Norway	160.0	222.0
Ukraine		

A.1.2 Technology mix

This section presents installed capacity of the generation technology. The results have been identified using country specific data and reports. The generation technologies feeding into DH networks are differentiated in:

- CHP plants (fossil and bioenergy)
- Heat Only boilers
- Geothermal plants
- Solar thermal DH
- Heat pumps
- Excess heat

The capacities of **CHP plants** are based on the Eurostat statistics. According to the energy efficiency directive 2012/27/EU each Member State has to collect data on the existing CHP units and submit them to Eurostat [6]. This dataset includes different CHP technologies (i.e. Table 1 from the reporting CHP instructions) and it represents the most comprehensive dataset of CHP generation units, installed capacities and fuel used. Since the Eurostat CHP dataset includes also decentralised generation units that are providing heat only for on-site industrial application and are not connected to a district heating network, the reported CHP capacity has to be corrected. To identify the thermal capacity of CHP plants connected to district heating networks, the heat supplied from cogeneration to DH networks (see section A.1.3) is divided with the full load hours calculated from the Eurostat CHP dataset. Therewith, an approximation of the installed DH CHP capacity is estimated for those countries where this data is not available in the national reports.

$$\text{DH CHP heat capacity (MWth)} = \frac{Cogeneration\ from\ supply\ mix\ (MWh)}{Full\ load\ hours\ (h)}$$

Eurostat statistic does not include **Heat only Boilers** (HoB) which are mostly installed to cover peak demands and for backup capacities. The installed capacities for HoB in this report are obtained by calculating the residual from the total installed DH capacity and the identified capacity of all other technologies (CHP plants, excess heat and RES-heat generations). The installed capacities of **geothermal units** are derived from the European

Geothermal Energy Council (EGEC) market report [7] and the proceedings of the 2019 European Geothermal Congers (EGC) [8]. For **solar thermal district heating**, the plant database from the SDH project is used [9]. As the status of the database is end of 2017, additional data are retrieved from the IEA Solar Heat Worldwide 2019 report [10]. With regard to **large-scale heat pumps**, the *Heat Roadmap Europe* study [11] and its supplementary materials are used to identify the installed capacities in each of the analysed countries. The total installed capacity of DHC plants is extracted from Euroheat & Power 2019 Country by country report, data from individual MS reports published by the authorities listed in Annex 2 and national statistical offices listed in Annex 3. Table 3 summaries the used data sources for the different technology categories.

Table 3: Data source used for specific technologies additional to the country specific reports presented in the excel attachment

Technology	Data sources
Combined Heat and Power (CHP)	Eurostat CHP data 2005-2018 Mapping and analyses of the current and future (2020-2030) heating/cooling fuel deployment [12]
Heat only Boilers (HoB)	No unique dataset was identified
Geothermal	EGEC Geothermal Market Report 2018 EGC 2019 Proceedings
Solar thermal	SDH database IEA Solar Heat Worldwide 2019
Heat pumps	Heat Roadmap Europe
Excess heat	Country-specific sources as presented in the excel attachment
Total installed capacity	Country-specific sources as presented in the excel attachment

The results are shown in Table 4. Within the group of RES-Heat non-combustion technologies, geothermal plants have the highest shares, followed by large-scale heat pumps and solar thermal units. The latter still represent a marginal share of the installed DH capacities. Higher significant capacities can be found only in selected countries such as Denmark (solar thermal) and Sweden (heat pumps). Non-combustion heat units currently face the challenges of high supply temperatures in district heating networks. Additional analysis of the type of networks and the potentials for reducing the supply temperatures are presented in chapter A.2.1.

Table 4: Total installed heat capacity per technology type (MW_{th}) (Source: Own representation based on sources in Table 3 and country specific source in the excel attachment)

Country	CHP [MWth]	Heat Only Boilers [MWth]	Geo-thermal [MWth]	Solar thermal* [MWth]	Heat pumps [MWth]	Excess heat [MWth]	Total capacity [MWth]
Austria	3,855	7,266	76	30	3		11,200
Belgium			17				
Bulgaria	2,888	3,253				232	6,373
Croatia	1,568	589	42				2,199
Czech Rep.	12,801	29,884	7		6		42,697

Country	CHP [MWth]	Heat Only Boilers [MWth]	Geo-thermal [MWth]	Solar thermal* [MWth]	Heat pumps [MWth]	Excess heat [MWth]	Total capacity [MWth]
Denmark	9,836	15,268	33	1,089	671	362	25,104
Estonia	520	4,914			20		5,434
Finland	8,328	15,206		1	155		23,534
France	4,351	18,036	430	13	23	237	23,067
Germany	49,781	45,315	335	56			95,487
Greece	312			10			312
Hungary	5,914	2,213	230	14			8,371
Ireland							
Italy	2,871	5,812	134	2	45	44	8,908
Latvia	3,247	2,360		15			5,622
Lithuania	1,832	6,850	18				8,700
Luxembourg							
Netherlands	1,595	4,046	208	11	1		5,850
Poland	18,081	37,054	74	16			55,209
Portugal							34
Romania	4,058	3,679	158				7,737
Slovakia	2,484	12,492	22		2		15,000
Slovenia	528	1,164	47				1,739
Spain	-	1,187	3	6			1,190
Sweden	7,902			27	1,244		
EU-27	**142,751**	**216,588**	**1,833**	**1,290**	**2,170**	**875**	**353,767**
UK	1,000		3				
Iceland	351		1,980				2,331
Norway	908	2,407		9	85		3,400
Ukraine	13,155		1				

*MWth for solar thermal plants only as indicative values for statistical reasons

A.1.3 Heat supply structure and fuel mix

The approach to define the heat supply structure and fuel mix of district heating supply consists of two steps:

- The Eurostat energy balances data is used to determine the gross heat production and used fuel per type of producer
- Compilation and analysis of country specific data to determine the district heat supply

Figure 10 presents and overview of the analysed data and methodology in determining the heat supply structure and fuel used for each country.

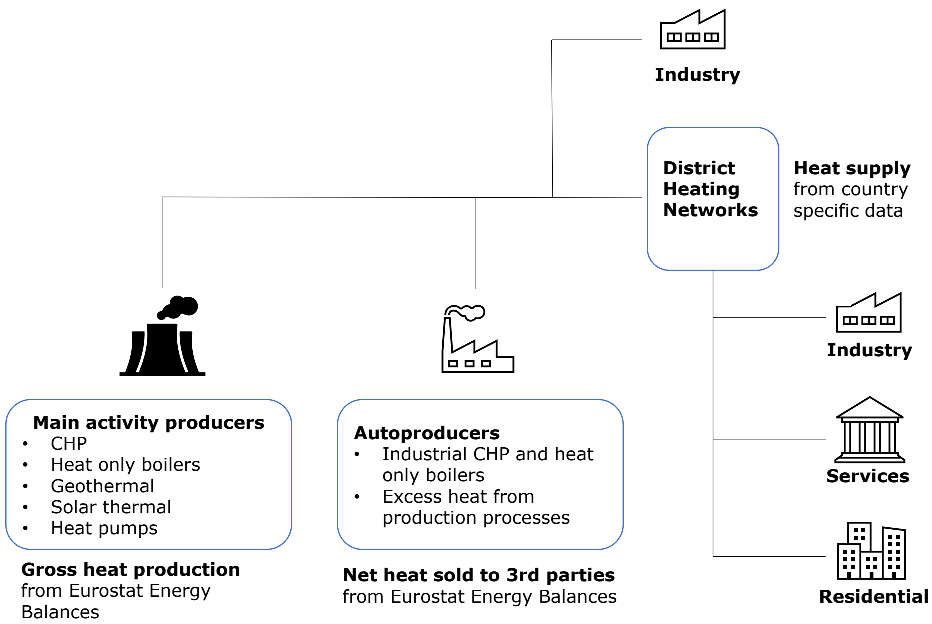


Figure 10: Overview of analysed data and methodology

The district heat supply structure and used fuel for DH are derived based on the Eurostat energy balances subset [3] which defines the production of electricity and derived heat by type of fuel used (nrg_bal_peh). The different fuel products are included in the analysis and aggregated to fossil and renewable fuels, respectively.

The following datasets and fuel types from Eurostat are used:

- Type of producer (NRG_BAL):
  - Gross heat production - main activity producer combined heat and power
  - Gross heat production - main activity producer heat only
  - Gross heat production – auto-producer combined heat and power
  - Gross heat production – auto-producer heat only

- Type of fuel (SIEC code):
  - Fossil fuels: Solid fossil fuels, Natural gas, Oil and petroleum products, Fuel oil, industrial waste (non-renewable), non-renewable municipal waste, non-renewable waste
  - Renewables: Biogases, solid biofuels, other liquid biofuels, geothermal, solar thermal, ambient heat, renewable industrial waste, renewable municipal waste

For the analysis in this report, it is essential to extract the amount of heat reported in the energy statistic that can be allocated to a use in district heating networks. The primary activity of the *main activity producers* is to generate electricity or heat for sale to third parties. *Main activity producers* are required to report the total amount of gross heat produced and fuel input. On the other hand, the *autoproducers* generate heat which is mostly used for self-consumption and the net heat reported in the statistic comprises only heat sold to third parties such as industrial customers or district heating network providers. Thus, the statistic also include heat which is not feed into utility operated district heating networks but directly sold to other industrial companies using direct connections, e.g. within an industrial park. Therefore, the results from the Eurostat energy statistic are compared with data derived from country specific reports in the following in order to identify the share of heat from auto-producers which can be allocated to district heating supply.

Figure 11presents the gross heat production from *main activity producers*. The gross heat production includes the total heat produced by the installations including the heat used by the auxiliary installations which uses heat for space heating, fuel heating, etc. and includes the losses in the installation and heat exchangers. Almost 70% of the heat produced in the EU-27 is supplied from cogeneration processes. The total share of fossil fuels in CHP plants is about 75%, whereas for heat only units, the share is lower accounting for 66% of heat supply.

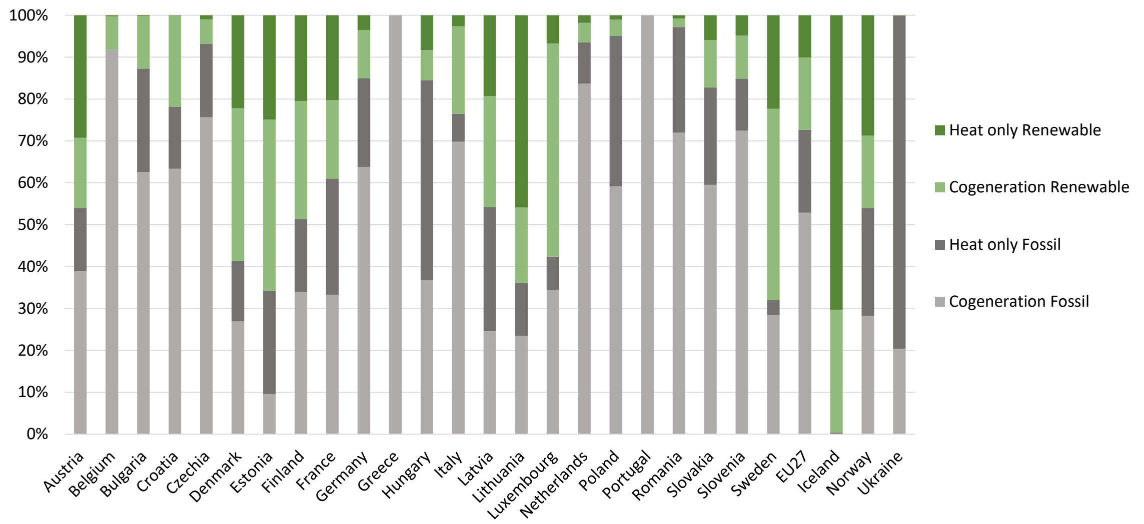


Figure 11: Share of gross heat production from main activity producers in 2018 per type of fuel and generation (Source: [3])

In Figure 12 the net heat production from autoproducers is presented. The net heat production is the heat supplied to the distribution system as determined from measurements of the supplied and returned flows. The share of heat produced in cogeneration process is around 75% and very similar to the gross heat production. On the other hand, the amount of fossil fuels within the heat only units is much higher in comparison to the heat produced by the main activity producers with a share of around 83% of the total heat produced by heat only units.

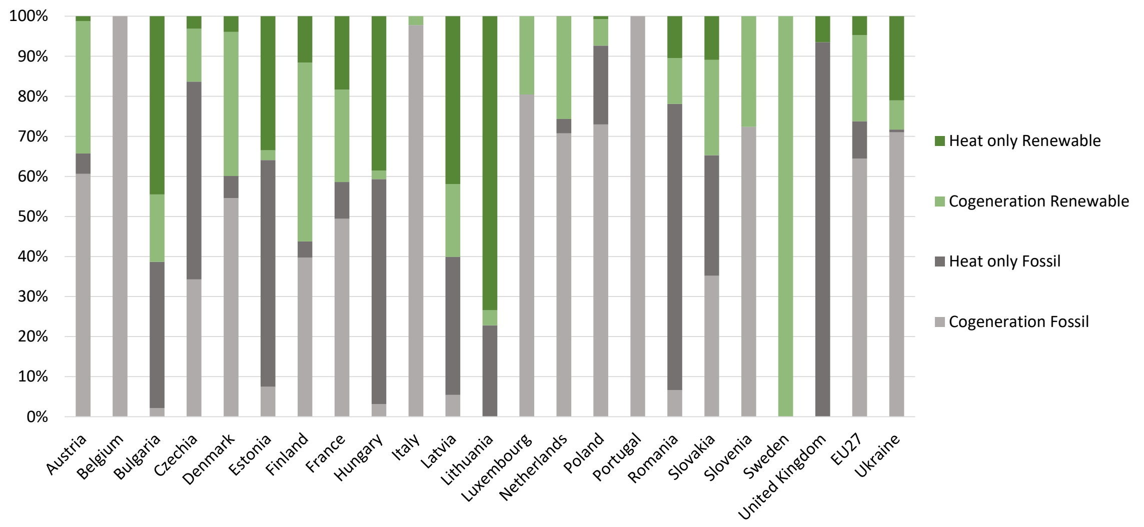


Figure 12: Net heat production from autoproducers in 2018 per type of fuel and generation (Source: [3])

In the second step of the analysis, country specific reports are included in order to determine the heat supply by district heating utilities. Table 5 compares the derived gross heat production from Eurostat energy statistic with the country specific market data. The results show that most of the countries the differences among the data sources are in the expected magnitude which shows the heat losses between heat production and supply, except for few selected countries such as France, Italy, the Netherlands, and Slovakia. For these countries it can be assumed that parts of the heat production analysed from the Eurostat dataset first supply heat to local industrial sites before supplying the district heating companies.

Table 5: Total heat production and district heating supply in 2018

Country	Total gross and net heat production from Eurostat [GWh]	Total district heating supply form country specific reports [GWh]
Austria	25,133	22,500
Belgium		
Bulgaria	9,866	7,513
Croatia	3,577	2,463
Czech Rep.	30,890	24,597
Denmark	39,888	37,481
Estonia	5,825	5,331
Finland	42,153	37,100
France	53,068	33,460
Germany	140,247	137,119

Country	Total gross and net heat production from Eurostat [GWh]	Total district heating supply form country specific reports [GWh]
Greece	605,000	340,000
Hungary	12,147	9,436
Ireland		
Italy	65,412	11,231
Latvia	8,250	8,246
Lithuania	9,833	9,000
Luxembourg		
Netherlands	29,612	7,667
Poland	79,603	74,228
Portugal	-	-
Romania	20,352	14,080
Slovakia	8,244	15,204
Slovenia	2,629	2,392
Spain	-	-
Sweden	55,716	53,672
EU-27	643,050	513,060
UK	18,777	13,200
Iceland*	8,461	9,369
Norway*	6,159	6,474
Ukraine*	96,570	

*Data for 2017

The resulting district heating supply mix and cogeneration shares are presented in Figure 13. In most of the EU-27 countries cogeneration shares are above 50% and in 2018, 63% of the district heating supply relied on it. Natural gas is the major source of heat used and in many countries with shares of 60% or more in member states such as Bulgaria, Croatia, Hungary, Italy, Netherlands, and Romania. Biomass, biofuels, and renewable waste are the second most used source of heat in the EU-27 member states with significant shares in many countries such as Austria, France, Scandinavian and Baltic countries. Coal and peat, as a third most used source of heat has a high share in Poland, Czech Republic, Greece, Germany, Slovakia, and Slovenia.

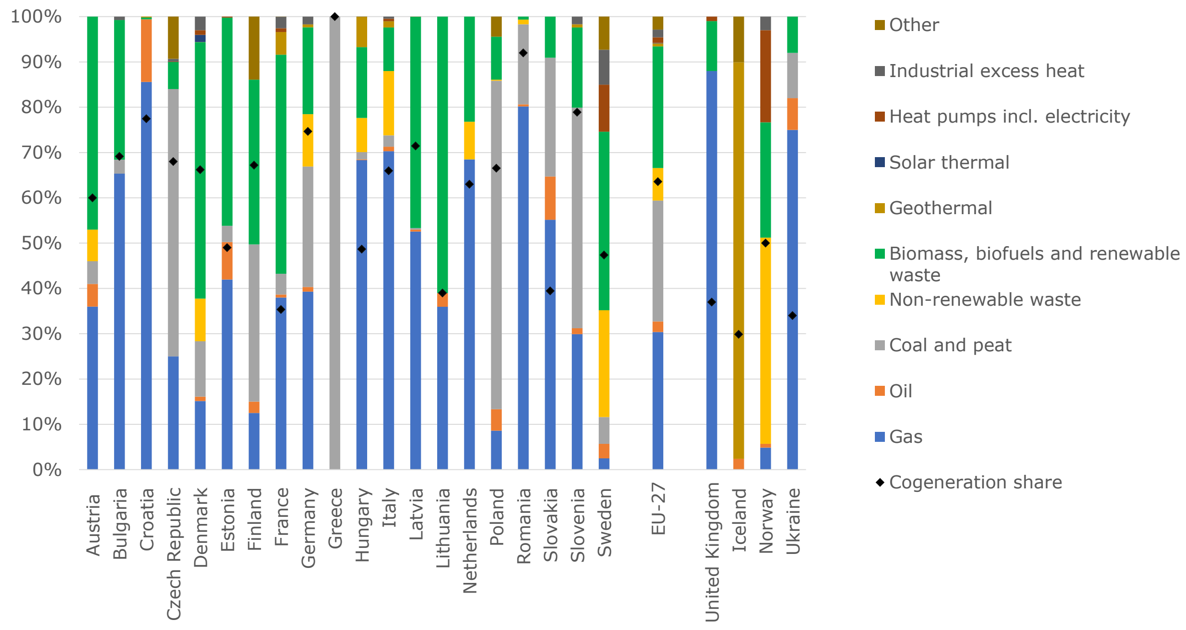


Figure 13: District heating fuel mix and cogeneration share in 2018 (Source: Country-specific sources as presented in the excel attachment)

Natural gas has the highest share in the EU-27 district heating fuel mix accounting for 30.4% (Figure 14), followed by biomass, biofuels, and renewable waste with a share of 26.9% and coal and peat with a share of 26.7%. The share of renewable wastes used as a DH fuel in the EU-27 is ca. 4.5%, with significant shares in Norway (13%), Germany (9%), France (9%) and Sweden (8%). On total, two-thirds of the district heat supply are generated with fossil fuels in the EU-27 member states. Renewable and non-renewable waste refers to heat generated by waste incineration plants where waste is used as a fuel. The waste heat from industrial processes in the graph is represented as industrial excess heat.

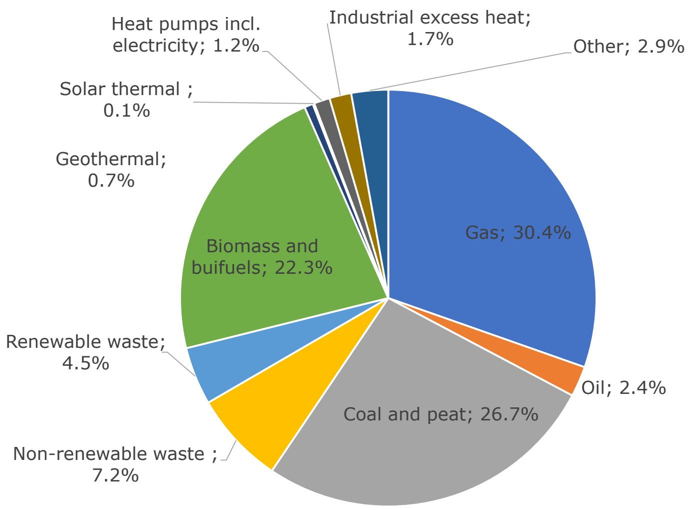


Figure 14: EU-27 District heating supply fuel mix in 2018

Gross nuclear heat production

By using the same dataset described in this chapter, the development of the gross nuclear heat production for selected countries is presented. The data includes the total amount of heat generated by nuclear reactors as heat content of the steam leaving the reactor. It can be observed that in Ukraine, Slovakia, Hungary, Czech Republic and Bulgaria, small share of the total heat supplied relies on nuclear energy.

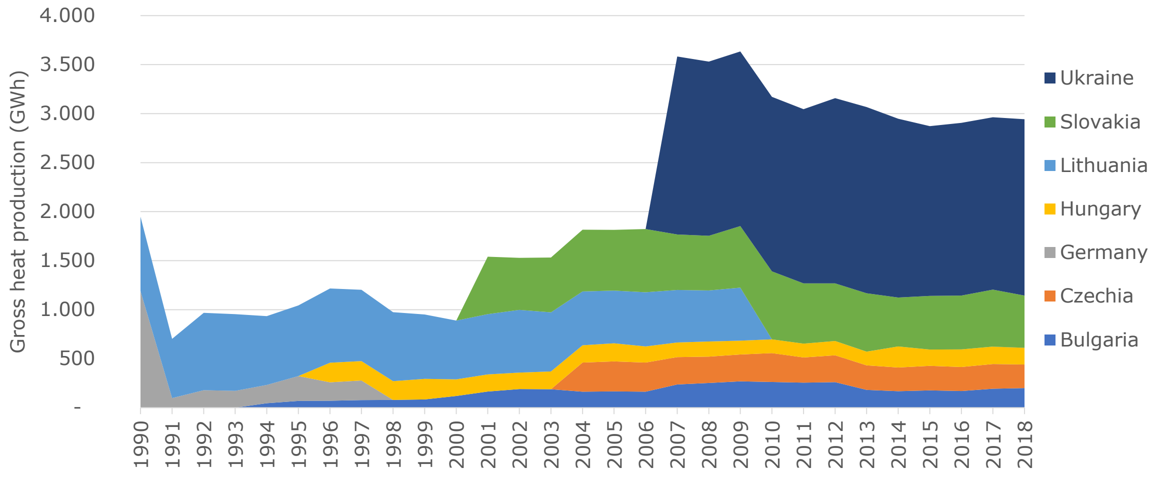


Figure 15: Gross nuclear heat production – main activity producers combined heat and power

A.2 DHC historical developments, size, and type of networks

This chapter aims in analysing the current structure of district heating and cooling networks in Europe regarding the characteristics of networks and installed system. The structure of the analysis is shown in Figure 16. The first section (A.2.1) analyses the heat supply technologies, fuel used and thermal condition of the supplied building stock in order to classify the existing district heating networks according to the generation-typology presented by Lund et al [13]. Section A.2.2 provides a classification according to the size of the networks. The objective of section A.2.3 is to provide an overview of and insights in the historic developments of DHC networks.

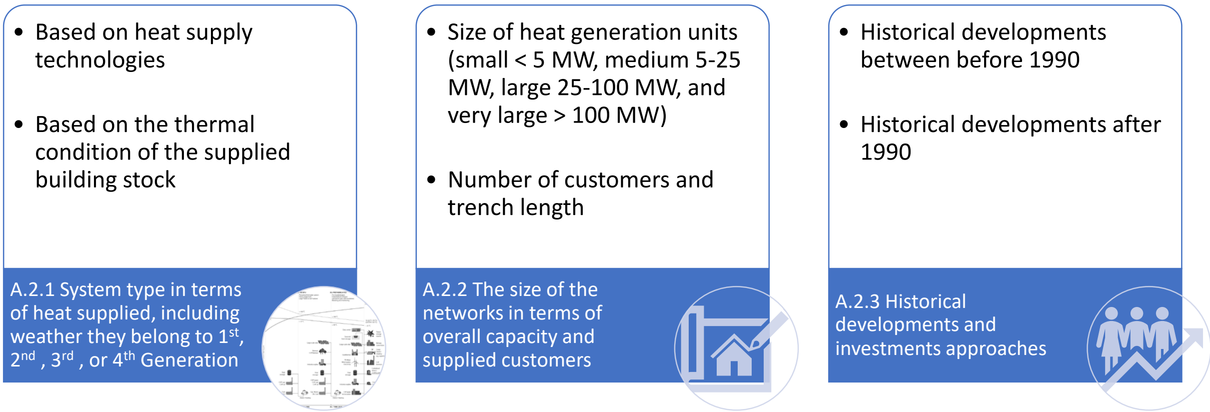


Figure 16: Structure of chapter A2

A.2.1 DHC system type in terms of heat temperature supplied, including whether they belong to first, second, third or fourth generation

DHC systems differ in terms of market penetration, use of local resources, overall trench length and supplied customers as well as country specific framework conditions such as climate or national and urban regulations. In recent years, the classification of district heating networks developed by Lund et al. has gained popularity and acceptance in both research and DHC industry (Figure 17). The networks are classified within the groups based on several factors such as heat supply temperatures, period of construction, type of pipes and housing substations, etc. with the focus on the supply temperature and share of renewable heat.

According to this classification, *First Generation DH networks,* built at the end of the 19th and the beginning of the 20th century, are mostly steam systems supplied by coal-fired boilers or waste incineration units. As hot water systems were found to have numerous advantages in comparison to steam systems, the *second-generation DH networks* built between 1930-1980 utilising hot water as heat transfer. The *Third Generation DH networks*, built mostly after 1980, focused on improving the energy efficiency of both, DH networks and heat generation units. They are characterized by pre-insulated pipes and compact prefabricated substations. As CHP became the predominant technology to generate heat, it became more critical to find the right supply and return temperatures[19]. The application of metering and monitoring equipment increased the efficiency of the

[19] By allowing proper steam expansion the supply and/or return temperatures (depending on the type of steam turbine used) of the district heating network can have a direct influence on the performance of the CHP plant, and thus affecting the electricity generation and its related costs. With proper monitoring, malfunctioning district heating customers substations with high return temperatures can be identified and repaired, leading to overall reduction in return temperature.

overall heat supply and distribution systems. The *Fourth Generation* (4GDH) defines the standard of newly built networks as well as for retrofitting of existing networks. The concept implies the integration of high share of innovative RES-H/C technologies such as large-scale solar thermal systems or heat pumps using renewable energy (geothermal and ambient energy) by further reducing supply temperatures, providing interaction between consumers and producers and integrating DH networks in the future smart energy systems.

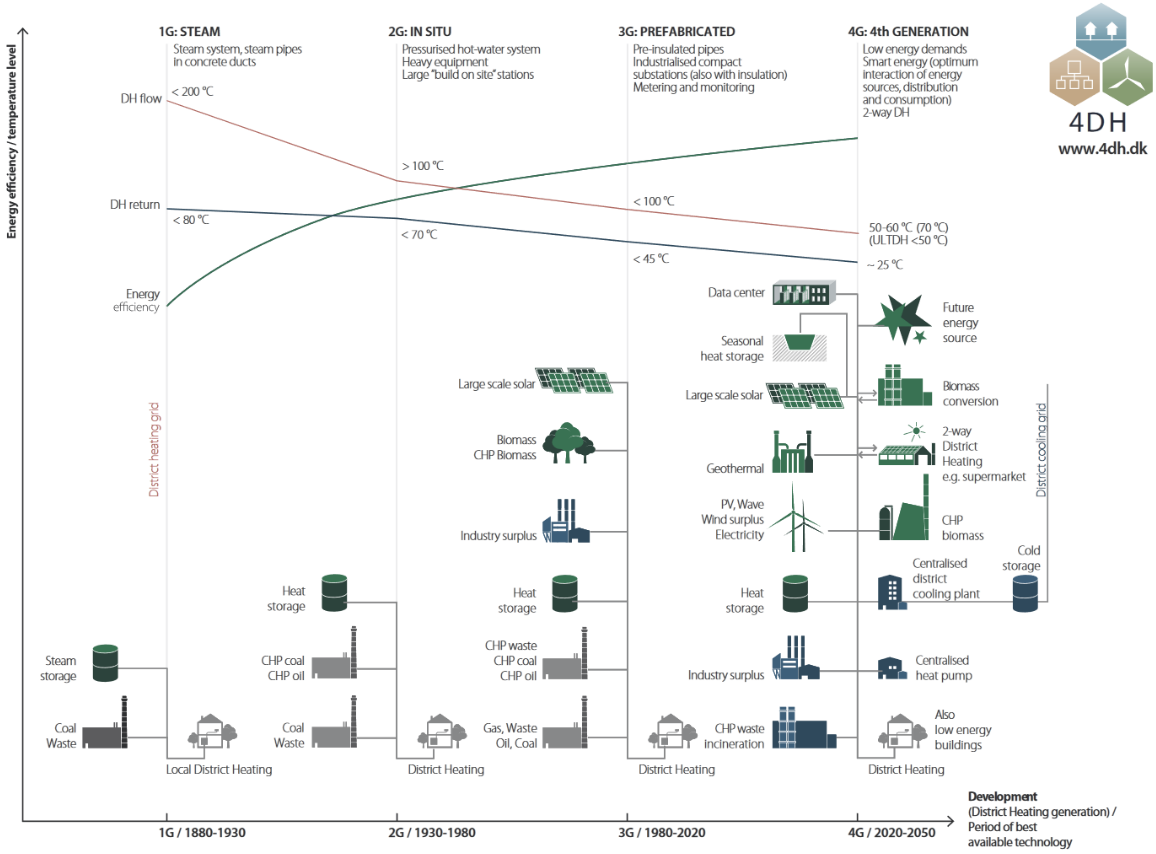


Figure 17: Classification of district heating systems [20] (Source:[14])

As presented in Figure 18 the goal of 4GDH systems is to define a technological concept appropriate for an integration with the whole energy system considering increasing flexibility demand of the electricity sector. 4GDH systems provide heat at low temperature levels facilitating the use of low-temperature heat sources (such as most renewables except for biomass) that are integrated with the operation of smart energy systems. However, there is not a uniform definition of 4GDH regarding the requirements on maximum supply temperature and share of low-temperature RES. Whereas Lund et al.[13], [14] define 4GDH with flow temperature up to 70°C, on the other hand, current national support schemes (e.g. Wärmenetzsysteme 4.0 in Germany [15] consider 4GDH with supply temperatures below 95°C, and at least 50% of heat supplied from renewable energy sources with maximum half of it from biomass).

[20] The concept of Fifth Generation DHC network or ultra-low temperature DHC as a separate concept of 4GDH was introduced in recent publications [213], [214]. As these systems are rather suitable for smaller application rather than city-wide networks, 5th generation DHC networks are not separately capture but summarized under the category of 4GDH.

As many of these indicators differ between networks, and in many cases even within one specific network consisting of several subnetworks, a country-specific classification based exclusively on supply temperatures is hard to define. Thus, the approach to classify district heating networks into suitable categories will rather focus on the amount of supplied heat and fuel use as well as on the type of buildings and their average specific heat demand connected to the network.

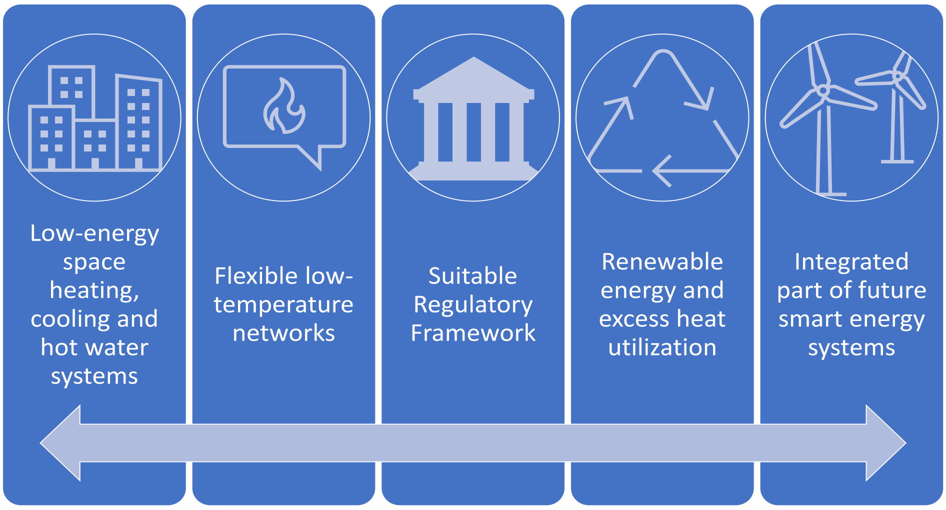


Figure 18: Concept of 4GDH including smart thermal grids (Source: Own representation based on Lund et. al [13])

A.2.1.1 Classification based on the heat supplied and fuel used

The decomposition of RES used for district heating reveals that bioenergy fuels (biomass, biofuels and renewable waste) are currently by far the main renewable sources (Figure 19). In the EU-27 they constitute almost 88% of the renewable heat produced, followed by industrial excess heat with 6%, heat pumps with 4%, geothermal with 2% and solar thermal with a negligible share of around 0,5%. In addition to Iceland where geothermal energy is the main source of heat, significant shares of geothermal heat can be found in Hungary, France, Italy and Croatia. Ambient heat through large-scale heat pumps have significant contribution to district heating supply only in Sweden with an overall installed capacity of large-scale heat pumps above 1000 MW. The country is still a unique example for a long-term application of large-scale heat pumps in almost continuous operation for more than 30 years. The share of solar thermal district heating is still negligible in all EU-27 member states except from Denmark where the technology is already established with almost 1.4 million installed square meter in 2018 [10]. However, large-scale solar thermal district heating projects gain attention as suitable district heating decarbonisation option and commercially developed projects have been implemented in other Member States such as Germany and Austria in recent years.

Apart from the supply temperatures, the use of renewable energy is a key characteristic of 4GDH systems. However, the data on heat supply cannot provide insights of the type of networks that use these renewable energy sources and their exact classification whether they belong to *Third* or *Fourth* generation. As depicted in Figure 19, the most utilized renewable energy sources are biomass and renewable municipal waste which shows that the development of 4GDH is at a very early stage. In addition to economic considerations, a barrier for implementing 4GDH networks with higher share of renewable technologies such as heat pumps and solar thermal is the poor energy performance of the existing building stock connected to district heating as well as the installed heat distribution systems in the buildings that require high supply temperatures from the network, whereas on the supply side, DH systems based on large heat pumps and solar thermal operate efficiently only with low distribution temperatures (see discussions in sections A.2.1.1 and B.4.1.3, and in the dedicated text box in section C.1.1.1.2).

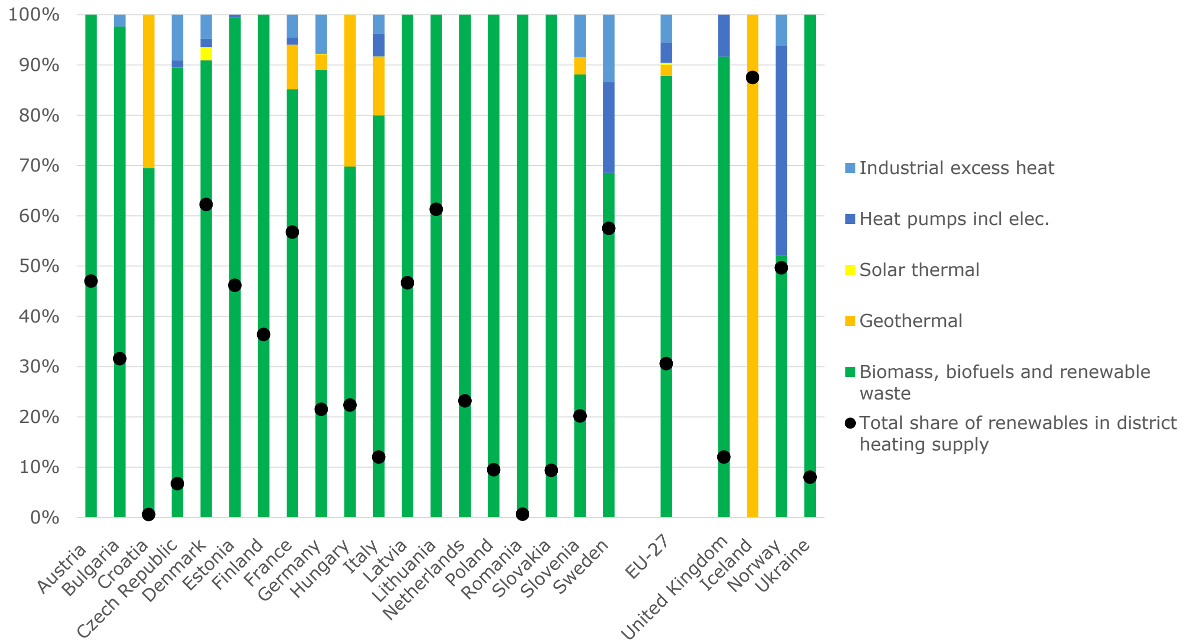


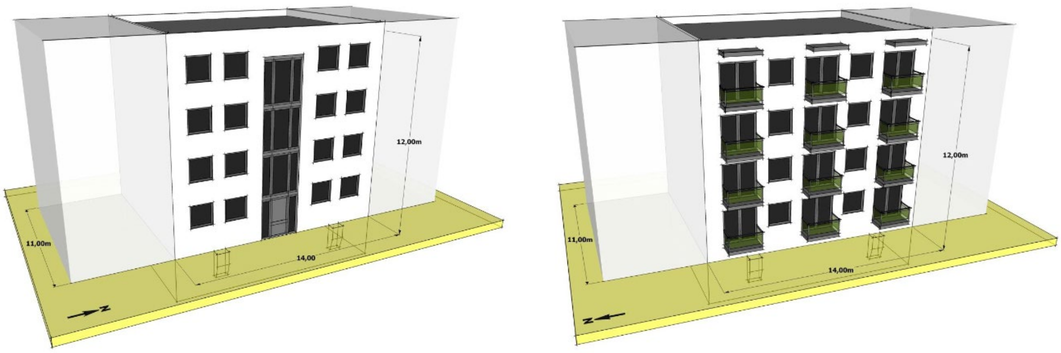
Figure 19: Total share of renewable heat in district heating supply mix and share of renewable fuels of the total renewable heat supply (Source: Country-specific sources as presented in the excel attachment)

A.2.1.2 Classification based on the supplied building stock

This subchapter provides an overview of the current building stock and a qualitative analysis of the type of existing buildings which could be supplied by low-temperature DH. As mentioned in the previous chapter, the poor energy performance of the existing building stock connected to the DH networks is a significant obstacle in reducing the DH supply temperatures, and therefore effectively increasing the share of RES technologies such as large-scale heat pumps, solar thermal fields, and shallow geothermal energy. The existing heat distribution systems inside poor energy performance buildings require at least supply temperature of 70°C at the radiators in the winter months, which means that the DH supply temperature is required to be in average above 90°C to cover not only the temperature losses in the DH network, but also the temperature drop which occurs in the housing substations. Reducing the radiators supply temperatures from 70°C to 55°C, would lead to an average reduction of the radiator heat capacity of ca. 37% [16], [17].

Based on the classification of different renovation depths by Esser et al. [18] , the existing poor energy performance buildings should undergo at least a "medium renovation" (energy savings between 30% and 60%) to be supplied by 4GDH networks. Depending on the type of the building, geographical location, and area of each building envelope elements, this would require at least a replacement of the windows and refurbishment of the roofs.

For a typical model building of a small multi-family house (Figure 20) located in the city of Frankfurt am Main in Germany, the specific heat demand and maximum heat capacity reductions under different renovation packages are calculated.



North – West side   South – East side

Figure 20: Typical model building of a small multi-family house (Source: [19])

From the results presented in Table 6 it is observed that by replacing the old windows with new double-glazed ones and applying thermal insulation based on the current standards on the roof, the maximum heat capacity (expressed in MW) required at outside temperatures of – 10°C is reduced by 34% with a specific heat demand reduction (expressed in MWh) of 41%. By adding thermal insulation on the basement and the exterior walls, the heat capacity is reduced by 40% and 67% respectively. It can be concluded that by replacing the windows and roof, the supply temperature at the radiators can potentially be reduced from 70°C to 55°C, assuming a proper hydraulically balanced system. For further supply temperature reductions, the refurbishment of the basement and exterior walls is required.

Table 6: Specific heat demand and maximum heat capacity for a small multi-family house under different U-values (W/m²K) renovation packages based on DIN 18599 monthly balance procedure

Small Multi-family house built before 1948	Area (m²)	U-values before	U-value after (R+W)	U-value after (R+W+B)	U-value after (R+W+B+Wl)
Exterior walls	177.5	1.97	1.97	1.97	0.24
Windows	120	2.83	1.2	1.2	1.2
Roof	154	1.49	0.24	0.24	0.24
Basement	154	0.95	0.95	0.24	0.24
Floor area	365				
Specific heat demand (kWh/m²)		219.4	130.1	112.2	51.0
Maximum heat capacity *(kW)		34.5	22.8	20.7	11.5
Specific heat demand reduction			41%	49%	77%
Heat capacity reduction			34%	40%	67%

*At -10 °C outside temperature; R-roof; W – windows; B-Basement; Wl -Exterior Walls

Although it is observed that it could be possible to reduce the supply temperature by ca. 15 °C after replacing the windows and insulating the roofs, it might be required to renovate the exterior walls as well depending on the building geometry and the ratio between exterior walls and floor area. This would be the case for some large multi-family houses, such as the one presented in Figure 21.

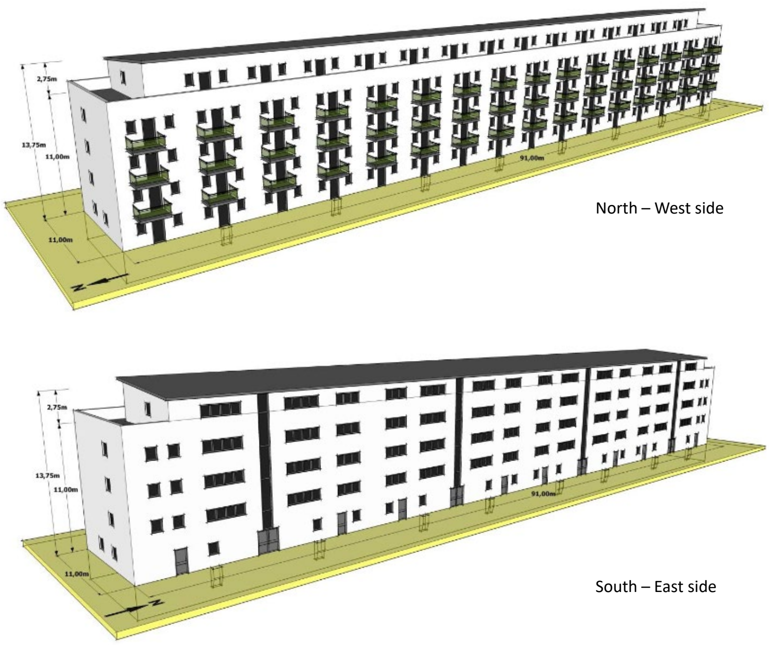


Figure 21: Typical model building of a large multi-family house (Source: [19])

From the results presented in Table 7, it is observed that for the large multi-family house, replacing the windows and insulating the roofs is not sufficient to reduce the supply temperature to 55 °C. For this example, without applying thermal insulation on the exterior walls, such a substantial supply temperature reduction is technically not feasible.

Table 7: Specific heat demand and maximum heat capacity for a large multi-family house under different U-values (W/m²K) renovation packages based on DIN 18599 monthly balance procedure

Large Multi-family house built before 1948	Area (m²)	U-values before	U-value after (R+W)	U-value after (R+W+B)	U-value after (R+W+B+WI)
Exterior walls	2756	1.55	1.55	1.55	0.24
Windows	522	2.9	1.2	1.2	1.2
Roof	1001	0.98	0.24	0.24	0.24
Basement	1001	0.83	0.83	0.24	0.24
Floor area	2850				
Specific heat demand (kWh/m²)		190.0	144.8	127.9	40.4
Maximum heat capacity *(kW)		248.5	199.7	188.2	79.9
Specific heat demand reduction			24%	33%	79%
Heat capacity reduction			20%	24%	68%

*At -10 °C outside temperature; R-roof; W – windows; B-Basement; WI -Exterior Walls

For the transformation to low-temperatures heat supply or 4 GDH, the current speed of energy performance improvement in the building is not sufficient [20]. The suitability of existing buildings for a 4GDH supply depends on several different factors such as building architecture, climate characteristics, hydraulic balancing of the heat distribution system, etc. Even if existing buildings perform major renovation to reduce energy losses and low-temperature district heating is theoretically feasible, additional adjustments at the housing substations and hydraulic adjustments of the internal heat distribution system might be necessary. Reducing the supply temperature, and hence the maximum radiators heat capacity, should be in theory assessed on a building specific level. Such an analysis could be very time consuming and without a proper local expertise, very hard to implement.

Although the goal is to increase the deep retrofit of the existing building stock, in the reality the stepwise renovations of individual building parts are prevailing [20]. By focusing on a targeted stepwise renovation combined with deep renovations where necessary, the goal of reducing the existing DH supply temperatures could be reached much faster. To do so, an active collaboration between municipalities and DH utilities via e.g., municipal heat planning process, is necessary (on top of appropriate regulation at national level).

A superficial analysis of the current building stock specific heat consumption on an aggregated residential and non-residential level and its suitability for 4GHD supply is presented in Figure 22. A threshold for the specific space heating consumption of 50 -150 kWh/m²*a is defined. Depending on the country's climate and the observed average heating degree days [21] for the period between 1990-2020, a country specific threshold for 4GDH is calculated. Nevertheless, more detailed analysis is required to include local particularities such as local climate adjustments within the country, energy poverty, etc. to identify the share of buildings suitable for 4GDH.

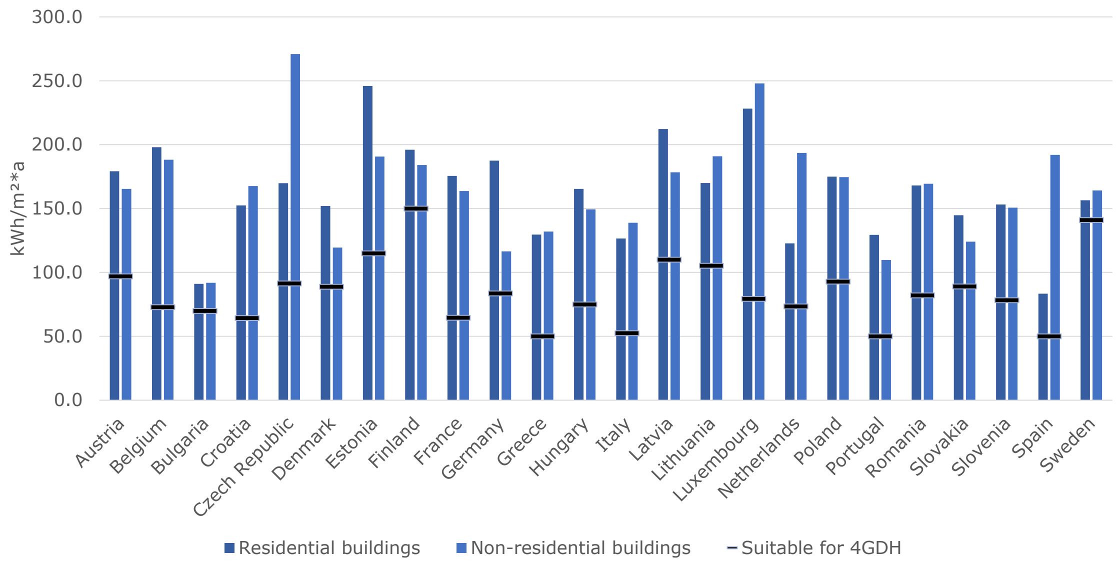


Figure 22: Weighted annual average of the specific heat consumption (kWh/m²*a) in residential and non-residential buildings (Source: Own calculation based on [21])

[21] Eurostat heating and cooling degree days – statistics: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Heating_and_cooling_degree_days_-_statistics

Developing the DH-building nexus in existing and new districts: insights from Greater Copenhagen and Greater Bordeaux (case studies in Annex 6)

In Denmark, while heat emitters in the 1970-80s operated at optimal regimes for oil boilers (90/70°C), **the deployment of DH pushed the emitters' temperatures down**, for the sake of energy efficiency. In the 1990s, the Danish building code integrated for the first time a requirement for heat emitters to operate on 70/40°C regime, strengthened at a second stage to **60/40°C**. As a result, today buildings in Copenhagen have an average temperature regime of 75/50°C, enabling the development of 4GDH networks. **Thermal refurbishment programmes typically address also secondary systems and heat emitters**, seeking at lowering return temperatures. Besides, incentive DH tariffs empower consumers all across the country to contribute to the reduction of their return temperatures, as illustrated in the case studies of Greater Copenhagen and Odense in Annex 7.

Greater Bordeaux has ensured a **technical match between local low-temperature energy sources and new buildings' temperature regimes** for its eco-districts "Bassin à flot" and "Cité du Vin". Supplying districts made of new buildings with low-temperature regimes for heating allowed the DH operator to integrate low-temperature clean and local energy sources (**excess heat from the WWTP and geothermal energy**) coupled with heat pumps to provide both heating and cooling with high efficiency. In addition to the local biomass fuel, this integration allows the DH system to reach a **70% share of renewable and waste energy sources** in its production mix.

A.2.2 Size of district heating systems in terms of overall capacity and number of supplied customers

In the following chapter A.2.2, district heating systems are classified according to the size. The size is differentiated based on the installed heat generation capacities and the network size in terms of supplied customers and trench length.

A.2.2.1 Size of installed heat generation capacities

The definition of the installed technologies based on their installed capacities follows the same approach and relies on the same sources as the one presented in chapter A.1.2. The technologies are classified in four capacity clusters:

- small (1-5 MW_{th}),
- medium (5-25 MW_{th}),
- large (25-100 MW_{th}),
- and very large (> 100 MW_{th}).

The classification is based on the base load of the DH network and therefore considers CHP plants (including industrial CHP), geothermal plants, large-scale heat pumps, and large solar thermal units. Since heat-only boilers are mainly installed as peak-load and backup capacity for the networks, the installed capacity is not included. As observed from Figure 23, most of the networks are being supplied by units with very large installed capacities, mostly due to the fact that CHP units are the predominant technology currently connected to existing DH networks.

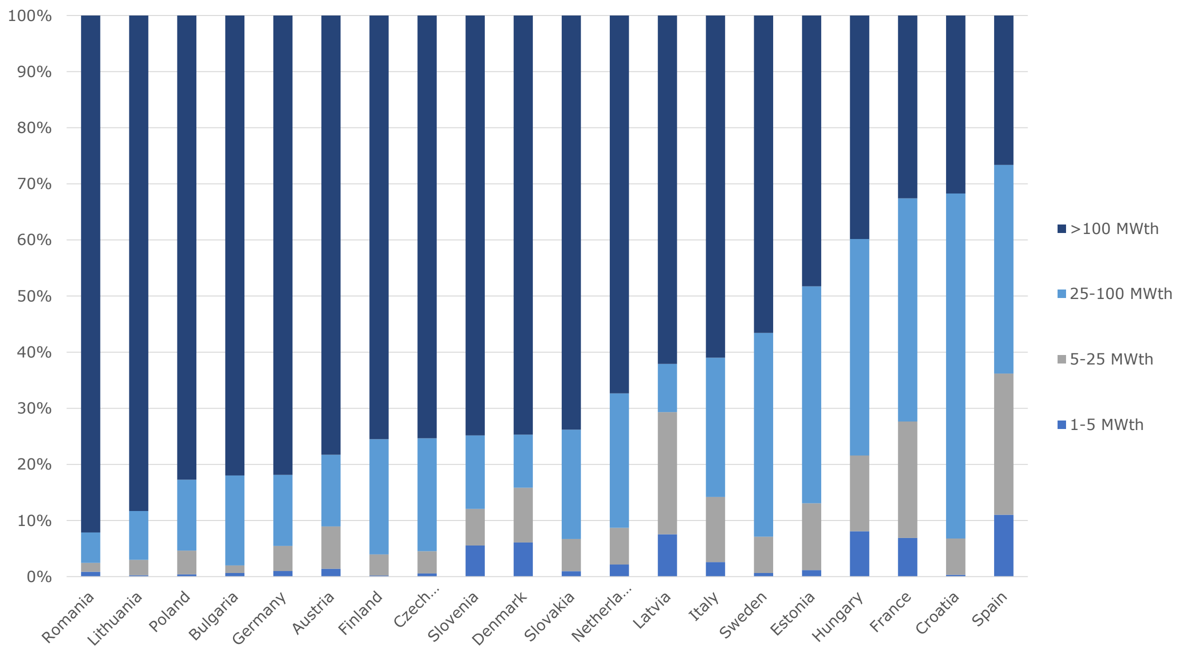


Figure 23: Share of installed technologies based on their installed capacities in select member states (Sources presented in Table 3, Annex 2 and Annex 3 section. The results are shown in Table 4.)

In Figure 24, the age structure of the current CHP unit stock is presented. Around 43% of the current CHP stock is almost 30 or more years old and built before 1992. Additional 23% of the analysed CHP stock is built between 1992-2002. As the share of RES electricity in Europe increases additional burden on the economic feasibility of the older CHP stock with very large heat capacities is to be expected.

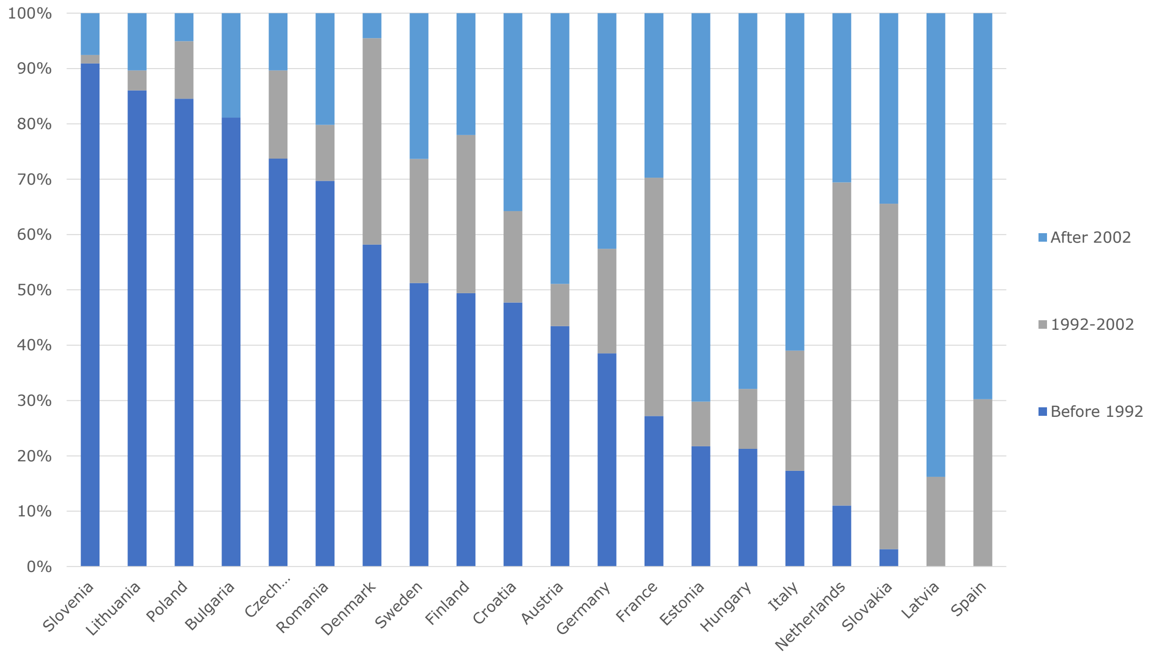


Figure 24: Age structure of CHP units in selected member states (Sources presented in Table 3, Annex 2 and Annex 3 section The results are shown in Table 4.)

A.2.2.2 DH networks size (trench length and number of supplied citizens)

Figure 25 summaries the total trench length and supplied citizens per country. The largest DH market in terms of trench length is Denmark with more than 30.000 km trench length, followed by Germany with 28.629, Sweden with 24.000 and Poland with 21.085 km. In terms of supplied citizens, Iceland has the highest share with 90% of the citizens supplied and served by DH network, followed by Denmark with 65%, Ukraine with 58% and Estonia with 51%. The highest district heating length density has Iceland (6,16 km/1.000 residents) followed by Denmark (5,3 km/1.000 residents), Finland (2,74 km/1.000 residents) and Sweden with 2,35 km/1.000 residents. The EU-27 average in 2018 is 0,38 km/ 1.000 residents.

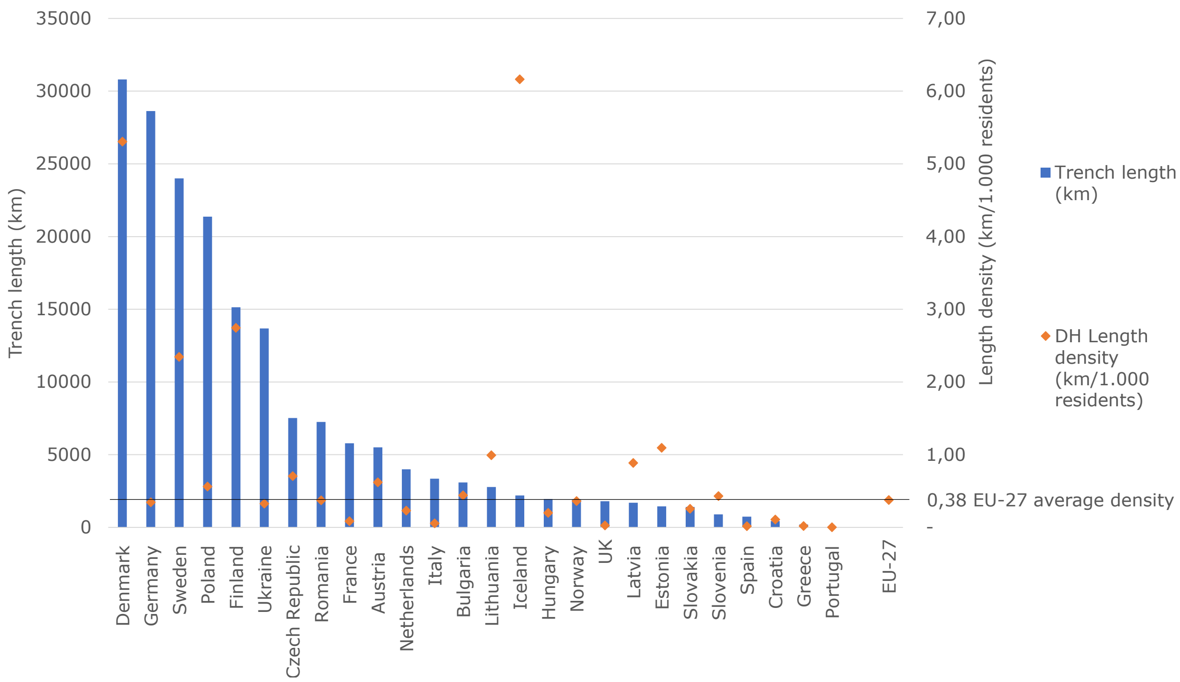


Figure 25: Trench length and district heating density in 2018 (Source: Country-specific sources as presented in the excel attachment)

In addition to the district heating length density, the supplied citizens per trench length are shown in Figure 26. The highest number of served citizens per km of trench length is in Ukraine with almost 1.800 citizens served by one km of followed by Slovakia with 1.320, Italy with 1.079, Croatia with 1.001, and France with 925 citizens. On the other end, in Norway, Denmark and Finland, the lowest specific values are observed with 110, 123, and 186, respectively.

The large differences between countries with similar share of supplied citizens (such as Slovakia with 34% and Finland with 38%) is most probably due to different building typologies (e.g. single houses versus large flats) connected to the network and the availability of DH as a possible heat supply option. From the results presented in Figure 25 and Figure 26 it can be observed that in countries with very high specific numbers such as Ukraine, Slovakia, France, Italy, etc. DH is placed in regions with very high heat and population densities, whereas on the other hand in Denmark, Finland, etc. DH is available as a heat supply option also in regions with much lower heat and population densities. Furthermore, there are large differences between countries which need to be considered such as the average size of the dwellings[22] and the number of occupants per dwelling[23], which has a direct impact on the served citizens per kilometre DH length indicator.

[22] Romania has an average dwelling size of around 42 m² and Norway around 120 m² (Source: People in the EU-statistics on housing conditions)
[23] The proportion of dwellings occupied by 3 or more residents is the highest in Slovakia with a share of almost 60%, where in Denmark and Norway the share is 30% (People in the EU-statistics on housing conditions)

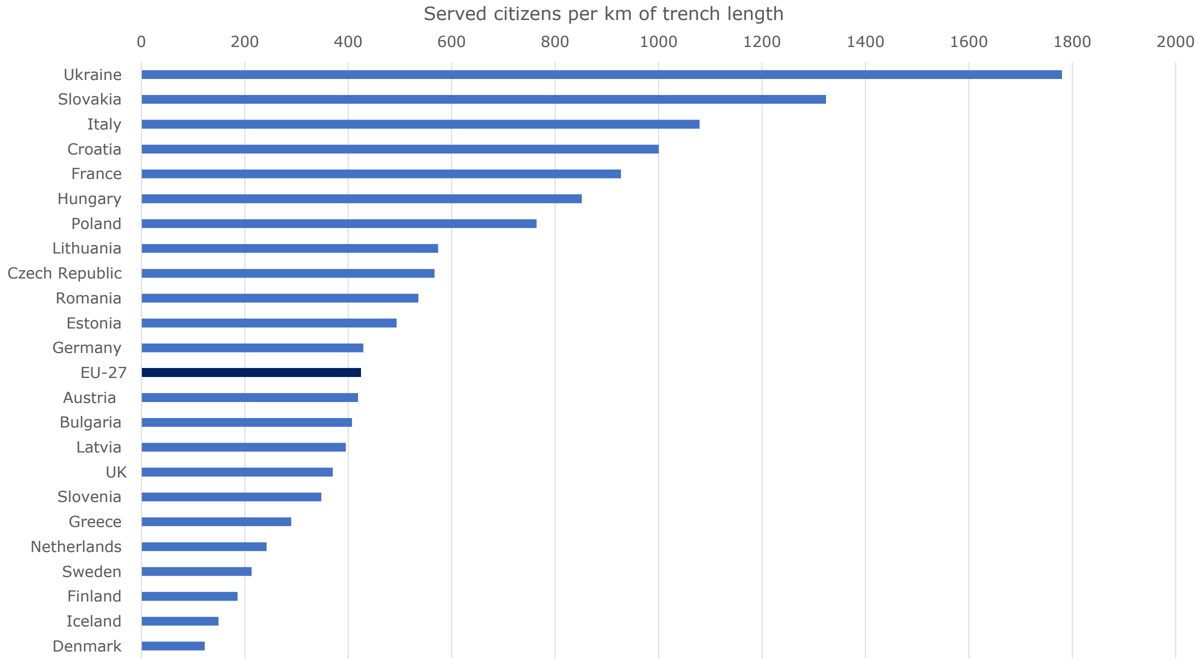


Figure 26: Served citizens per trench length in 2018 (Source: Country-specific sources as presented in the excel attachment)

A.2.3 Historical development and investment approaches followed

The following chapter gives an overview of the historical development of DHC systems. Due to limited availability of data, the analysis combines quantitative and qualitative approaches: a qualitative analysis based on literature and a survey among DHC country experts for the period before 1990, and a quantitative approach based on statistical data for the period after 1990. The reason behind this distinction is mostly due to the availability of unified and comparable statistical data for the EU countries after 1990 that is available on EUROSTAT, and the political changes that have occurred in Eastern Europe and USSR in the late 1980s and early 1990s.

A.2.3.1 Qualitative analysis for the period before 1990

The qualitative analysis of the historical developments for the period before 1990 relies upon a comprehensive literature research and the survey addressed to the main DHC experts in the 31 countries within the scope of this study. The contacted stakeholders have been identified as key actors in the DHC field in their country, and come from national regulatory bodies (e.g. Ministries, Energy Agencies, City Authorities), DHC national associations, DHC operators as well as research institutions or consulting.

Historically, first mentioning of a hot water distribution network are dated back to the 14th century in Chaudes-Aigues in France as the earliest example for district heating systems. According to historians, 30 houses were supplied by wooden pipe with hot water from the local geothermal source [22]. Although several ideas and concepts were proposed in the Netherlands in the 17th and in Russia in the 19th century, the first commercial DH network has been implemented in the USA in 1877. In the following ten years a dynamic development of district heating networks followed in the USA resulting in over 20 DH mostly steam based networks and a first DC network by 1890. The first DH network in Europe can be traced back to Hamburg, Germany in 1893, followed by Budapest in Hungary in 1899 and the DH network in the Copenhagen area of Fredriksberg in 1903, where the first waste incinerator supplied heat to a DH network.

With the beginning of 20th century, several projects in Europe have been developed in Russia, Poland, the UK, the Netherlands, Czechoslovakia, France, Iceland, and Switzerland. However, a dynamic development of DH systems started in Europe only after World War II. As many cities had to be reconstructed after the war, many major European cities developed city-wide DH systems (e.g., Berlin, Warsaw, Budapest, Bucharest, Belgrade, Sofia). The growth and deployment pace in the Eastern European cities and the USSR were much faster in comparison to Western Europe. In Western Europe and the Scandinavian countries, it took more time for the development and deployment of DH networks, mostly due to the research efforts spent in optimizing supply and return temperatures and improving the efficiency of CHP units. As a result, the Western European countries benefited from an improvement of the general energy-efficiency of DH systems and a more reliable piping technology such as the pre-insulated piping system that was invented and applied in the 1960s.

Another major event that led to a rapid growth and deployment of DH networks throughout Europe, especially in Denmark and Sweden, was the oil crisis in the 1970s. As the countries had to shift major parts of their consumption from oil to coal, some combined the fuel shift with a dedicated development of DH networks and a shift from market-driven model to a policy-driven system where planning and regulation were the preferred tools to guarantee security of supply and improve energy efficiency [23]. The second oil crisis in 1979 caused another spike in oil price and increased the price volatility of the energy market, which confirmed the political decision of many countries and regions to diversify the energy supply and invest in energy efficiency measures and efficient electricity and heat supply with CHP systems for which the development of district heating was an essential infrastructure.

At the end of the 1980s and the beginning of 1990s, the political changes that took place in Eastern Europe and the USSR, had a negative influence on district heating consumption in most of the countries. Due to the shift from planned to market-based economy and the privatization of state-own district heating networks, the prices of delivered district heat increased significantly, leading to many disconnections that resulted in decreased heat densities and thus higher distribution costs for district heating. As most of the networks were already more than 30 years in operation and required large investments in energy-efficiency improvements, the decreased heat densities aggravated the low efficiencies of the networks, which lead to a complete stagnation and in many cases closure of district heating networks and utility operators. This stagnation and reduction of district heating is observable and presented in the next subchapter dealing with the quantitative analysis after 1990.

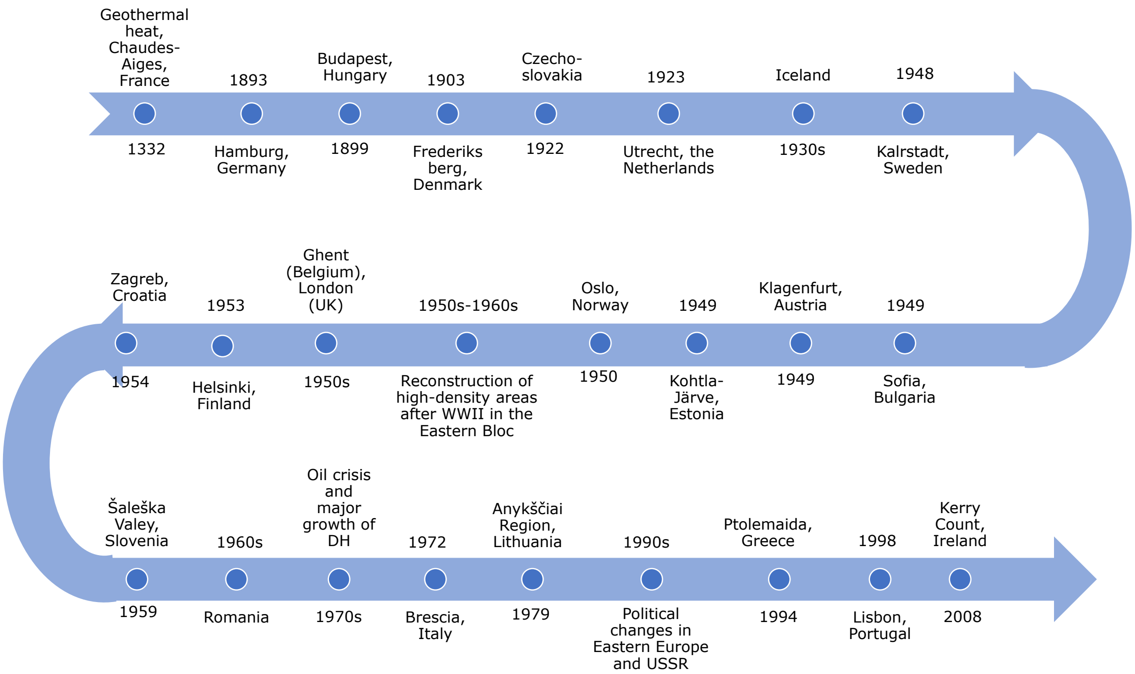


Figure 27: Historical development and landmarks of DH networks (Source: own representation based on [22], [24] and stakeholder survey)

A.2.3.2 Quantitative analysis for the period after 1990

For the historical developments of district heating production after 1990, the same dataset presented in section A.1.3 is used to identify the development of different types of heat production and fuel usage per country. The gross heat production is climate adjusted using the heating degree days (HDD) dataset from Eurostat [25] to estimate heat production in a standard year. To climate adjustment is necessary to determine the development of the DH networks based on the heat production statistics. The dataset is adjusted by using average HDD[24] per country for the period between 1975 and 2018. For each year, the recorded HDD is divided by the long-term average to create an HDD adjustment factor. The climate-adjusted heat production is obtained by dividing the registered heat production with the HDD adjustment factor for each year between 1990 and 2018. Even if the climate adjustment method based on HDD is commonly used, it cannot fully adjust for differences due to climate influences[25].

In Figure 28, the gross district heat production per type of generation for the main activity producers (as defined in section A.1.3) in the EU-27 +UK is presented. The total heat production for the period between 1990-2018 has increased by almost 15%. This increase relies mostly on the increased application of renewable cogeneration and heat only units.

[24] The HDD is a weather-based index designed to describe the space heating energy requirements of the buildings. In the calculation of the HDD, the base temperature is set to a constant value of 15°C. If the daily mean temperature is below 15°C for that day, the HDD is equal to the difference between the base temperature (15°C) and this mean temperature; if it is above, the HDD is 0.
[25] As country average, the HDD method flattens the differences of several climate zones within a country. Furthermore, not all the heat consumption and production are weather-dependent, e.g. for industrial process or domestic hot water. As this method assumes linear dependence between HDD and production, neither user behaviour habits nor thermal comfort are considered. Especially in mild winter months with higher outside temperatures, the lower HDD not necessarily lead to lower consumption. Additionally, the relation between HDD and heat consumption is not only influenced by the occupants of the buildings but as well as by the building envelope condition and thermal characteristics

The relative share of cogeneration-fossil and heat only-fossil for the same period has experienced a reduction of 13% and 16% respectively.

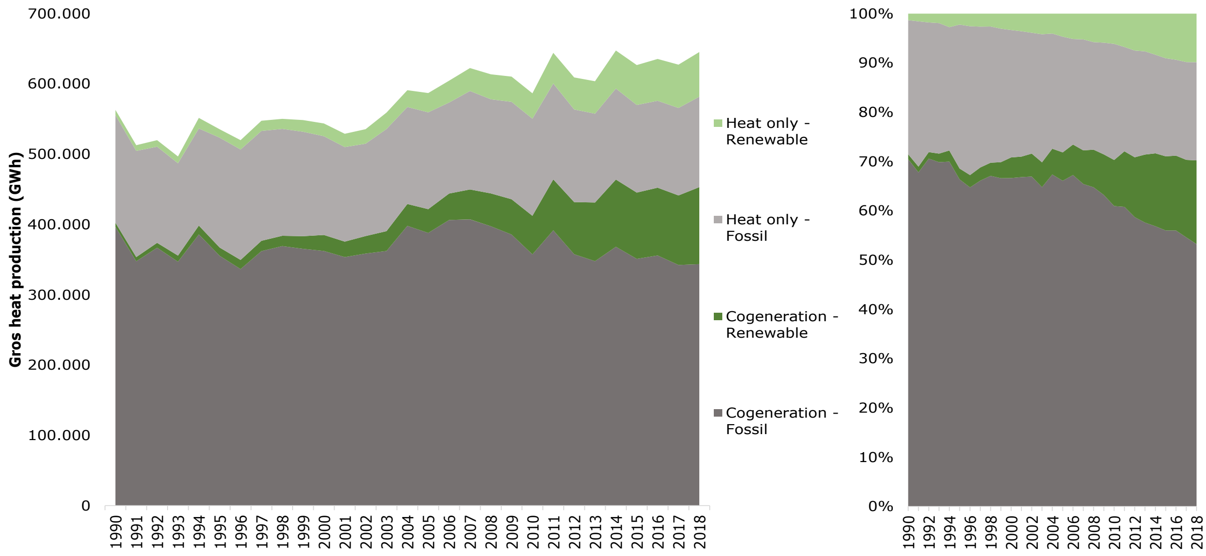


Figure 28: EU-27+UK Gross district heat production per type of generation (Main activity producers)

In 1990, 73% of total heat in DH networks was produced by oil and coal (Figure 29). In the period from 1990 to 2018, this share has been reduced to 29%. The coal and oil production have been mostly replaced by biofuels, renewable waste, and natural gas.

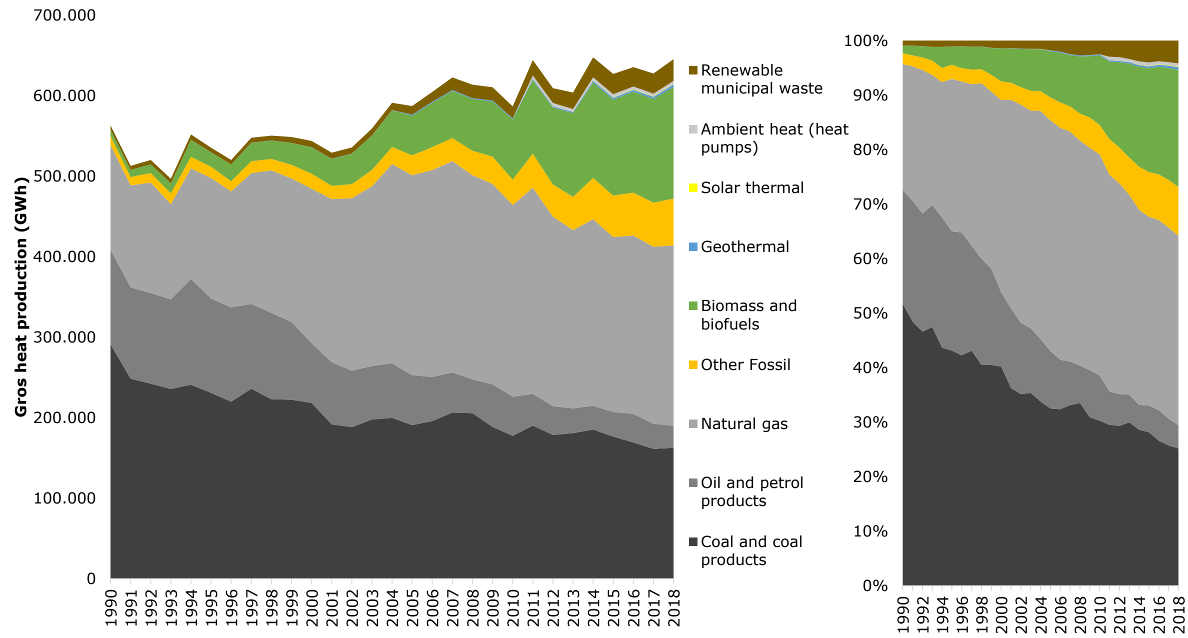


Figure 29: EU-27+UK Gross district heat production per fuel used (Main activity producers)

A.3 DHC regulatory framework, market actors and customer satisfaction

The structure of the chapter A3 is presented in Figure 30. The first section, A.3.1, describes the structure of the district energy sector and the most important suppliers. Section A.3.2 gives an overview of the overall regulatory framework of DHC and relevant authorities. This overview is supplemented by a more in-depth analysis in part B of the report. The last section A.3.3 provides insights into consumer perception and satisfaction of DHC as well as consumer protection requirements and measures.

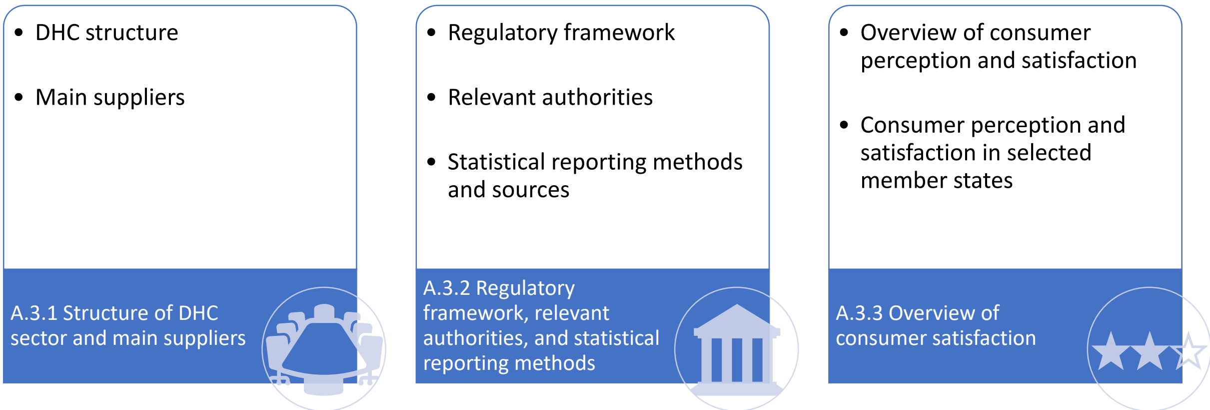


Figure 30: Overview of chapter A3 and its structure

The approach retained to collect the required information for both chapters A.3.1 and A.3.2 consists of a literature review completed by a country expert survey as detailed earlier in Block A introduction. The methodology for chapter A.3.3 follows the same approach, but is supplemented with a small survey of experts from three selected countries.

A.3.1 Structure of the district energy sector and of the important suppliers

Following the above-mentioned approach, this chapter presents the size of the cities served by DHC, the ownership of the DHC systems and the main suppliers in the different Member States as well as in the UK, Norway, Ukraine and Iceland. The focus of this section is a cross-analysis covering the whole geographical scope of the study, while country-by-country details are provided in the country factsheets in Annex 1.

The used sources for the following analysis (including Table 9, and Figure 31 to Figure 36) are listed in those factsheets and include in particular:

- National reports (Energy reports, report from Ministries, …)
- Websites, reports and surveys of national DHC associations
- Websites of suppliers
- Databases: Euroheat & Power (Country by Country Report 2019), International Energy Agency (Energy Policy Review), Eurostat, national database (open data)
- Studies and scientific papers

In order to structure, analyse and present the collected information from all countries, a number of categories were created, presented in the table below.

Table 8: Categories for the structure of the district energy sector and the main suppliers

Aspect	Categories
Size of cities served by DHC and geographical concentration	• "Distributed": DHC networks are distributed across the country, from small cities to large metropolis • "Scarce": DHC networks are present only in a few cities
Ownership of the DHC networks (in terms of number of networks)	• "Public": Mainly public ownership and operation • "Private": Mainly private ownership and operation • "PPP": Mainly PPP (Public-Private Partnership) • "Mix": Mix between public and private ownership, PPP and customers cooperative
Market opening to international suppliers	• "International": International suppliers are present in the market • "Local": Market composed only of local suppliers
Market composition	• "Big suppliers": A few big suppliers control the majority of the market (i.e. less than 10 suppliers control more than 70% of the market in terms of energy sales) • "Mix": Market composed by a mix of big and small suppliers

Based on the available information, the countries were classified accordingly and a cross-analysis has been conducted for each defined category. The following table presents this classification.

When a country does not present any DH or DC systems, it is excluded from the analysis and marked with "N.a." for "Not applicable" in the table below. For instance, Malta and Cyprus do not present any DHC networks so these countries are excluded from the following analysis.

When no data was collected from the survey nor found in the literature for a country for a specific aspect, the country is excluded from the corresponding analysis and marked with "-" in the following table.

The countries excluded from the analyses are also indicated in each of the following graphs.

Table 9: Structure of the district energy sector per country

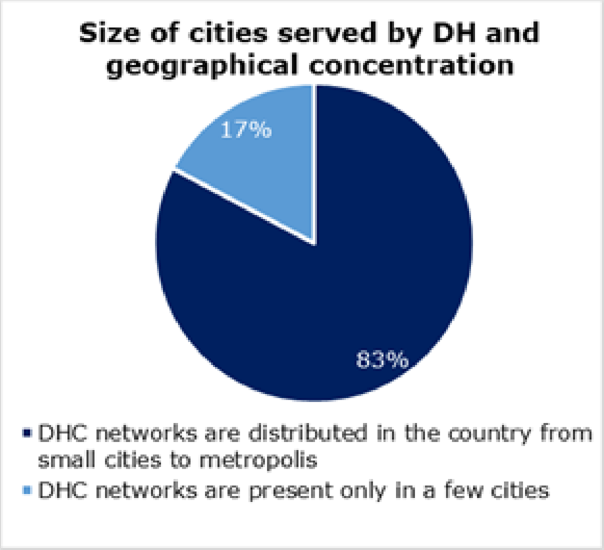
Country	Size of cities served by DHC and geographical concentration		Ownership of the DHC networks		Market opening to international suppliers	Market composition
	DH	DC	DH	DC		
Austria	Distributed	Scarce	Mix	Public	Local	Mix
Belgium*	Distributed	-	Private	-	International	Mix
Bulgaria	Distributed	-	Private	-	Local	-
Croatia	Scarce	-	Public	-	Local	Big suppliers
Cyprus	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.
Czech Republic	Distributed	-	Mix	-	International	Big suppliers

Country	Size of cities served by DHC and geographical concentration		Ownership of the DHC networks		Market opening to international suppliers	Market composition
	DH	DC	DH	DC		
Denmark	Distributed	Scarce	Mix	Public	Local	Big suppliers
Estonia	Distributed	Scarce	Private	Private	International	Big suppliers
Finland	Distributed	Scarce	Public	Public	International	Mix
France	Distributed	Distributed	Mix	Mix	International	Big suppliers
Germany	Distributed	Distributed	PPP	PPP	International	Mix
Greece	Scarce	N.a.	Private	N.a.	Local	Big suppliers
Hungary	Distributed	-	Public	-	Local	Mix
Ireland	Scarce	N.a.	Public	N.a.	International	Big suppliers
Italy	Distributed	Distributed	Mix	Mix	Local	Big suppliers
Latvia	Distributed	N.a.	Public	N.a.	Local	Mix
Lithuania	Distributed	N.a.	Public	N.a.	International	Big suppliers
Luxembourg	Scarce	Scarce	PPP	PPP	International	Big suppliers
Malta	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.
Netherlands	Distributed	Scarce	Mix	Private	Local	Mix
Poland	Distributed	-	Mix	-	International	Mix
Portugal	Scarce	Scarce	PPP	PPP	International	Big suppliers
Romania	Distributed	N.a.	Public	N.a.	International	Big suppliers
Slovakia	Distributed	N.a.	Mix	N.a.	International	Mix
Slovenia	Distributed	Scarce	Public	Mix	Local	Big suppliers
Spain	Distributed	Scarce	Mix	Mix	International	Big suppliers
Sweden	Distributed	Distributed	Public	Public	International	Mix
UK	Distributed	Distributed	PPP	PPP	International	Big suppliers
Iceland	Distributed	N.a.	Public	N.a.	Local	Big suppliers
Norway	Distributed	Scarce	Public	Private	International	Big suppliers
Ukraine	Distributed	N.a.	Public	N.a.	Local	Mix

- This means that the information was not found
N.a.: Not applicable (the corresponding country does not have DH systems or/and DC systems)
**For Belgium, only data for Flanders were found*

A.3.1.1 Size of cities served by DHC and geographical concentration

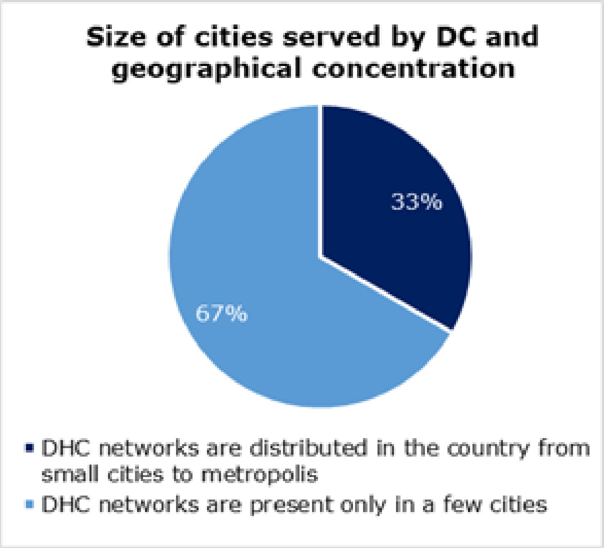
In the majority of the Member States as well as in the UK, Norway, Ukraine and Iceland, **DH systems are distributed all across the country**, from small cities to metropolis. The only exceptions are Croatia, Greece, Ireland, Luxembourg and Portugal where DH systems are only located in a few cities.



2 countries excluded from the analysis because they present no DH networks (Cyprus, Malta)

Figure 31: Geographical concentration of DH networks

On the contrary, **DC systems are in the majority of Members States only located in a few cities** except for France, Germany, Italy, Sweden and the UK where DC is more developed than in the other countries.



15 countries included in the analysis (Austria, Denmark, Estonia, Finland, France, Germany, Italy, Luxembourg, Netherland, Portugal, Slovenia, Spain, Sweden, UK, Norway) representing more than 90% of the total DC sales

Figure 32: Geographical concentration of DC networks

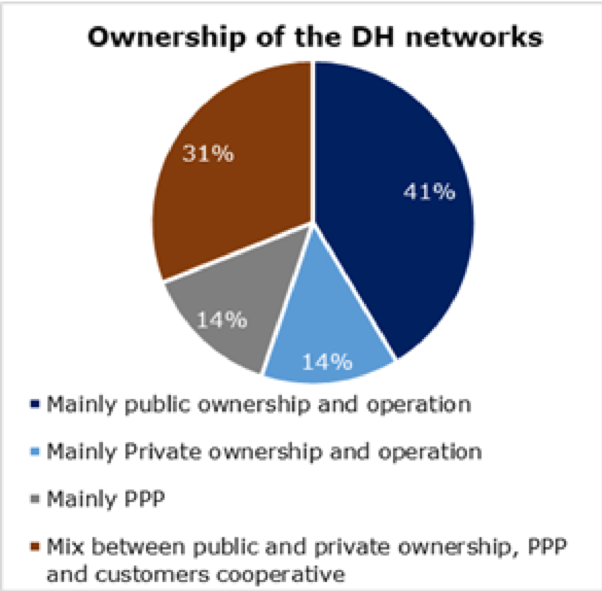
A.3.1.2 Ownership of the DHC network

The ownership structure differs significantly in the analysed countries. In almost half of the analysed countries, the **DH** networks are **owned and operated by public entities**. Municipal ownership or private companies where municipalities hold major shares is widespread. Besides municipalities, also other public or state bodies own district heating companies in some countries (e.g., Spain and Sweden). Public ownership can be found mostly in countries with stronger regulation (including price regulation) (discussed in A.3.2).

With 31%, **mixed** ownership (mix between public and private ownership, PPP and customers cooperatives) plays an important role in the European DH market. Thus, in these countries there is not one dominating ownership model. For example, customer cooperatives are a common ownership form in Denmark. However, other public and private companies and institutions are also active in the market.

A combination of private and municipal ownership (**PPP**) is also a common model that can be found e.g. in Germany. So called "Stadtwerke" (municipal utilities) are companies under private law (e.g. AG, GmbH) but completely or to large extent owned by municipalities. In the UK, social housing companies are involved at least in communal heat networks.

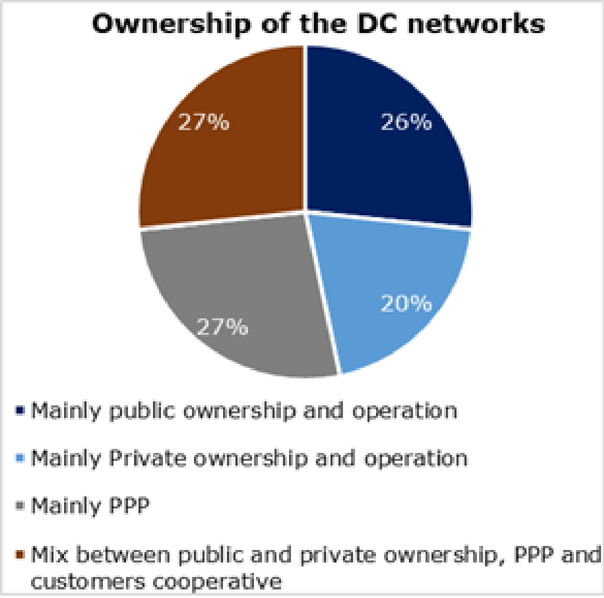
In only about 14% of the countries, the DH sector is dominated by **private** companies. These are usually the countries in which the DH sector is less regulated (and prices are liberalized, for example in Belgium).



2 countries excluded from the analysis because they present no DH networks (Cyprus, Malta)

Figure 33: Ownership of the DH networks

For **DC** systems, public ownership is not a predominant trend. Private ownership is more frequent when compared to DH systems.



15 countries included in the analysis (Austria, Denmark, Estonia, Finland, France, Germany, Italy, Luxembourg, Netherland, Portugal, Slovenia, Spain, Sweden, UK, Norway) representing more than 90% of the total DC sales in the analysed region

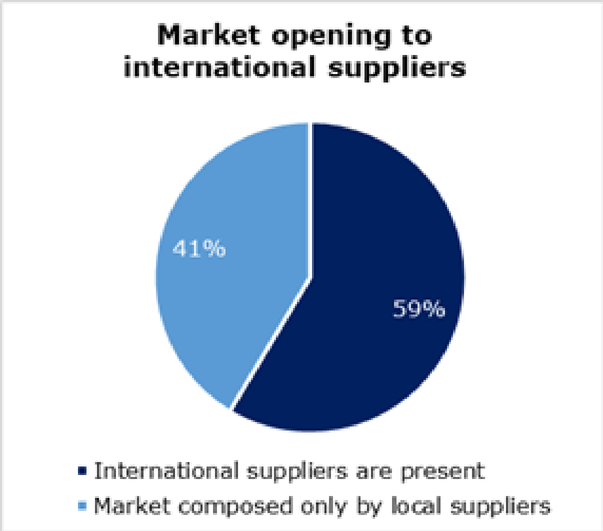
Figure 34: Ownership of the DC networks

A.3.1.3 Main suppliers and level of competition

Numerous DH suppliers exist in the analysed countries. The majority of them are local suppliers specific to each country, but some international players are present in several countries. There are very few specialised DC suppliers; big DH suppliers often position themselves in the DC sector when there are opportunities.

The DHC market of more than half of the analysed countries is dominated by Veolia[26], EDF[27], Fortum[28], Engie[29], Eon[30], Innogy[31], Vattenfall[32], CEZ[33].

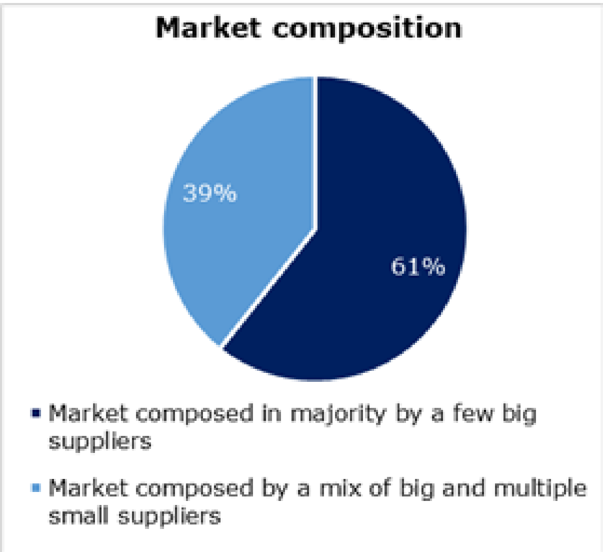
[26] https://www.veolia.com/en
[27] https://www.dalkia.fr/en
[28] https://www.fortum.com
[29] https://www.engie.com/en
[30] https://www.eon.com/en.html
[31] https://iam.innogy.com/en/about-innogy
[32] https://group.vattenfall.com/
[33] https://www.cez.cz/en/cez-group/about-cez



2 countries excluded from the analysis because they present no DHC networks (Cyprus, Malta)

Figure 35: Market opening to international suppliers

The DHC market of more than half of the analysed countries, is composed in mainly of a few big suppliers (local or international), i.e. a few suppliers control a clear majority (at least 70%) of the market. For the rest of the countries, small suppliers represent a significant part of the market.



3 countries excluded from the analysis because they present no DH networks (Cyprus, Malta) or because no data was found (Bulgaria)

Figure 36: Market composition

A.3.2 Overall regulatory framework, competent authorities and regulatory supervision

In the following chapter, an overview of the overall regulatory framework for DHC systems, the relevant authorities and the supervision of DHC systems in the different Member States as well as the UK, Norway, Ukraine and Iceland are presented in a cross-analysis. Details are provided for each country in the country factsheets in Annex 1. The aim of this chapter A.3.2 is to give a short overview, whereas block B of the report provides a detailed description of the components of the regulation as well as an in-depth analysis of the regulatory framework.

A.3.2.1 Overall policy framework

This section gives an overview of the overall policy framework of DHC systems in all countries considered in this study. The scope of the regulatory framework as well as the intensity of regulation of DHC varies considerably by country. Some countries apply very distinct regulations in **dedicated district heating laws** (e.g. regarding consumer prices), while others only rely on **laws that regulate energy and competition issues** in general ([26]). Similarly, the support frameworks also differ extensively and range from almost no support to comprehensive funding programs for infrastructure development and integration of renewables. Based on the existing regulations and the requirements set out in the EED (Art. 9, 10, 11) and RED II (Art. 20, 23, 24), the following aspects have been identified as key issues of a regulatory framework of DHC:

- Regulation of ownership and operatorship of DHC systems
- Regulation of prices for consumers
- Regulation of metering
- Regulation regarding grid access and usage (supply and demand side)
- Support frameworks for renewables, combined heat and power (CHP), grid infrastructure and other elements of the DHC system

As stated at the beginning, the applied methodology in this chapter A.3.2 consists of two steps. In the first step, a literature analysis for each country was carried out. In the second step, a survey was conducted to fill in the missing information. The output of this comprehensive data collection is the basis of the outline of the regulatory framework regarding the aspects listed above as well as additional aspects that were identified as relevant during the literature review (see country factsheets in Annex 1). The used sources of the literature review are cited in the factsheets and include in particular:

- Databases e.g. Euroheat & Power: Country by Country Report 2019[34], RES legal[35], IEA policy database[36]
- EU documents e.g. National Progress reports from MS[37], National Climate and Energy Plans (NECP)[38]
- Studies and scientific papers (see sources in factsheets in Annex 1)
- National laws and regulations (see sources in factsheets in Annex 1)
- Websites of national DHC associations (see sources in factsheets in Annex 1)

[34] https://www.euroheat.org/cbc/2019/
[35] http://www.res-legal.eu/
[36] https://www.iea.org/policies
[37] https://ec.europa.eu/energy/topics/renewable-energy/progress-reports_en?redir=1
[38] https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en

In order to structure the collected information and provide an overview, the countries were compared along the key issues of the overall regulatory framework listed above. For each issue different categories were defined. These categories are depicted in Table 10. The value 1 represents no specific regulation or support, while the value 2 and 3 display a different level, representing a stronger intervention by the regulator or the availability of explicit support schemes. For example, with regard to the regulation of owner- and operatorship, a distinction can be made between no specific regulation (1), requirement for registration (2) and obligation to obtain a licence or a permit (3).

Table 10: Categories for regulation and support of DHC

Aspect of regulatory framework	Categories for intensity of regulation or support
Ownership and operatorship	1. No specific regulation 2. Register or monitoring 3. Licences, concession, authorization, permit or public approval
Prices	1. No specific regulation or supervision (e.g. only cartel law) 2. Price is defined by DHC operator with a price calculation rule (e.g. price limits or calculation schemes) 3. Price is defined/set by regulator or defined by operator with ex-ante price control/approval of price
Metering	1. No regulation, e.g. only recommendations 2. Specific regulations for heat metering (e.g. obligations and/or quality requirements) 3. Specific regulations for smart heat metering and remote control (e.g. obligations for smart meters for new installed meters)
Grid access and usage (supply perspective, third party access (TPA))	1. No regulation, negotiated TPA with private contracts 2. Regulation of TPA with connection obligations limited to renewable or waste heat 3. Regulation of TPA with connection obligations for all heat producers
Grid access and usage (demand perspective)	1. No regulation, voluntary connection of consumers 2. Regulation of grid access with voluntary connection (e.g. obligations to negotiate grid access) 3. Regulation of grid access with mandatory connection under certain conditions (i.e. zoning)
Support of renewables	1. No specific support program 2. Specific support program
Support of CHP	1. No specific support program 2. Specific support program
Support of grid Infrastructure	1. No specific support program 2. Specific support program

Based on the available information, the countries were compared along the aspects listed above. Table 11 presents this comparison. The sum on regulation and support is used as a provisional proxy for the level regarding the regulation as well as for the level of support.

Table 11: Overview of the level of regulation and support in the Member States, the UK, Iceland, Norway and Ukraine (Source: Own compilation from various sources and own survey with national DHC stakeholders; see sources in factsheets in Annex 1)

Country	Regulation					Support			Level of regu-lation	Level of support
	Owner- and operatorship	Prices	Metering	Grid access (supply)	Grid access (demand)	Support of renewables	Support of CHP	Support of grid infrastructure		
Austria	2	2	2	1	1	2	2	2	8	6
Belgium[1]	2	1	3	1	1	2	2	1	8	5
Bulgaria	3	3	2	3	2	2	1	2	13	5
Croatia	3	3	2	1	(1)	1	2	1	10	4
Cyprus	1	1	1	1	1	1	2	1	5	4
Czech Republic	3	2	2	2	2	2	2	2	11	6
Denmark[2]	3	2	2	1	3	2	1	1	11	4
Estonia	3	3	3	3	3	2	2	2	15	6
Finland	1	2	2	1	1	2	2	1	7	5
France[3]	3	3	2	1	3	2	2	2	12	6
Germany	2	2	2	1	3	2	2	2	10	6
Greece	3	1	1	1	(1)	1	2	1	7	4
Hungary	3	3	2	1	2	2	2	2	11	6
Ireland	1	1	2	1	1	2	2	2	6	6
Italy	2	1	1	1	(2)	2	2	1	7	5
Latvia	2	3	(2)	3	(1)	1	2	1	11	4
Lithuania	3	3	3	3	3	2	2	2	15	6
Luxembourg	(1)	(1)	(1)	(1)	(1)	2	2	2	5	6
Malta	1	1	1	1	1	1	1	1	5	3
Netherlands	3	2	2	3	1	2	2	2	11	6
Poland	3	3	2	3	(2)	2	2	2	13	6
Portugal	1	1	(1)	1	1	1	2	1	5	4
Romania	(3)	(3)	2	(3)	(1)	1	(1)	1	12	3
Slovakia	3	2	2	2	3	2	2	2	12	6
Slovenia	3	3	2	1	2	2	2	1	11	5
Spain[4]	3	1	1	1	1	2	2	2	7	6
Sweden	1	2	2	3	2	2	2	2	10	6
UK	1	1	2	1	1	2	2	2	6	6
Iceland	3	3	1	1	3	2	1	2	11	5
Norway[5]	3	2	1	3	3	2	2	2	12	6
Ukraine	3	3	2	(1)	1	(1)	2	2	10	5

() This means that the information is not available or not clearly depicted in the literature and/or in the survey and therefore represents a personal assessment.
1 In Belgium, the regulation of DHC is a regional competence. The table shows the regulatory framework for the region of Flanders as there is no legal framework in place in Brussels or Wallonia (according to DHC stakeholder)
2 In Denmark, municipalities could impose a compulsory grid access for consumers until 2019. This option has been removed from the Heat Supply Act, but existing obligations, covering around half of all DH customers, remain in force.
3 In France, heat production plants with a capacity over 30 kW located within priority development areas are obliged to be connected to the heating network. However, as this regulation refers only to priority development areas, which usually do not include potential third party supplier, TPA is in practice not regulated.
4 In Spain, the prices for DHC are locally regulated if the network is developed under a concession regime. In the case of private networks, prices are not regulated.
5 In Norway, only DHC networks with a capacity of more than 10 MW are required to hold a concession and only networks with a concession can imply mandatory grid access for consumers.

The results of the comparison regarding the regulation of ownership and operatorship of DHC systems, prices and metering are visualised in Figure 37. In the majority of the countries, 56% in total, DHC systems need a licences or authorisation (e.g. in Bulgaria, Croatia, Denmark or Estonia). In 19% of the countries, DHC operators have to register or are monitored (e.g. in Belgium or Germany) and in 25% there is no specific regulation regarding **ownership and** operatorship (e.g. in Finland, Ireland or Sweden).

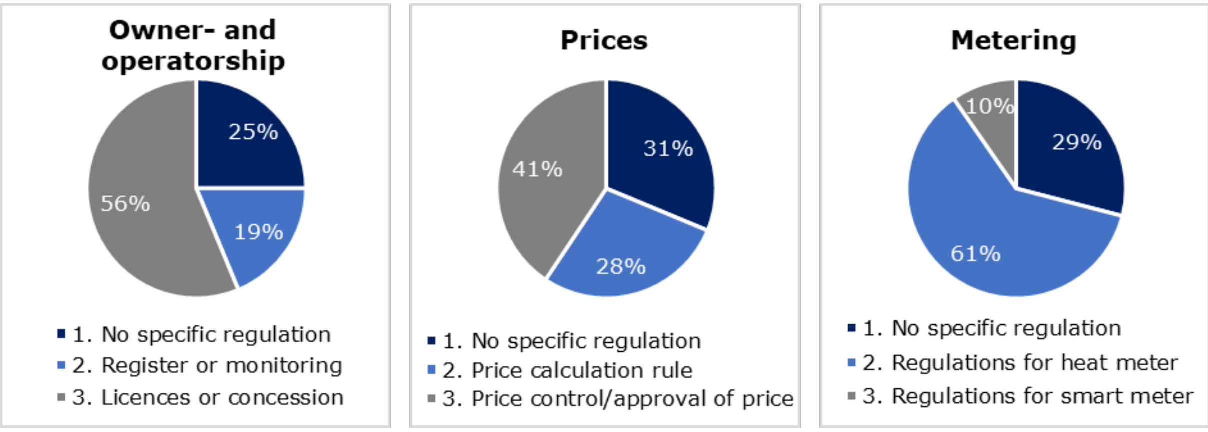


Figure 37: Regulation of ownership and operatorship, of prices and of metering (Source: Own compilation and assessment based on various sources and own survey with national DHC stakeholders; see sources in factsheets in Annex 1)

Regarding the regulation of **prices for consumers**, 31% of the countries do not have specific DHC price regulations (e.g. Belgium, Greece or Ireland). Almost the same amount of the countries, 28% in total, have specific price rules, such as a maximum value or the rule that prices must be set in a proportionate and cost-based manner (e.g. in Austria or Sweden). In many countries (41%), prices must be authorized before used or prices are administratively set by the regulatory authority (e.g. in Estonia or Latvia). Chapter B.2.1 deals with price regulation in more detail and addresses the regulatory requirements as well as price models and price components.

In 29% of the countries, there is no specific regulation concerning the **metering** of heat consumption (e.g. in Greece or Norway). However, in the majority of countries, 61% in total, specific regulations regarding metering, e.g. obligation to measure heat consumption, are established (e.g. in Austria, Bulgaria, Croatia, Germany or Hungary). In addition, some countries have introduced regulations on heat cost allocation ([27]).Three countries (Belgium, Estonia and Lithuania) already established regulations regarding the installation of smart meters (e.g. made smart heat meters mandatory for new installed meters). More details on measuring and accounting are given in chapter B.1.

With regard to grid access and usage, a distinction must be made between the supply and demand sides. Regulation of grid access of the supply side deals with the access and usage of third party generation plants to DHC grids. On the supply side, grid access and usage are often referred to as third party access (TPA). Chapter B.3 deals in more detail with TPA and covers different concepts of TPA as well as the current situation in Europe. Grid access on the demand side refers to the grid connection and usage of customers. The results of the comparison regarding grid access and usage are shown in Figure 38.

In 65% of the countries, there is no regulation of **grid access for suppliers** and thus no regulated TPA (e.g. in Austria, Belgium or Denmark). In 6% of the countries, a specific statutory framework contains an obligation for the operator to connect renewable and waste heat producers, if certain conditions are met (e.g. in Czech Republic and Slovakia).

In 29% of the countries, the regulation of TPA includes an obligation to connect all heat generators, if certain conditions are met (e.g. in Latvia, Lithuania or Poland).

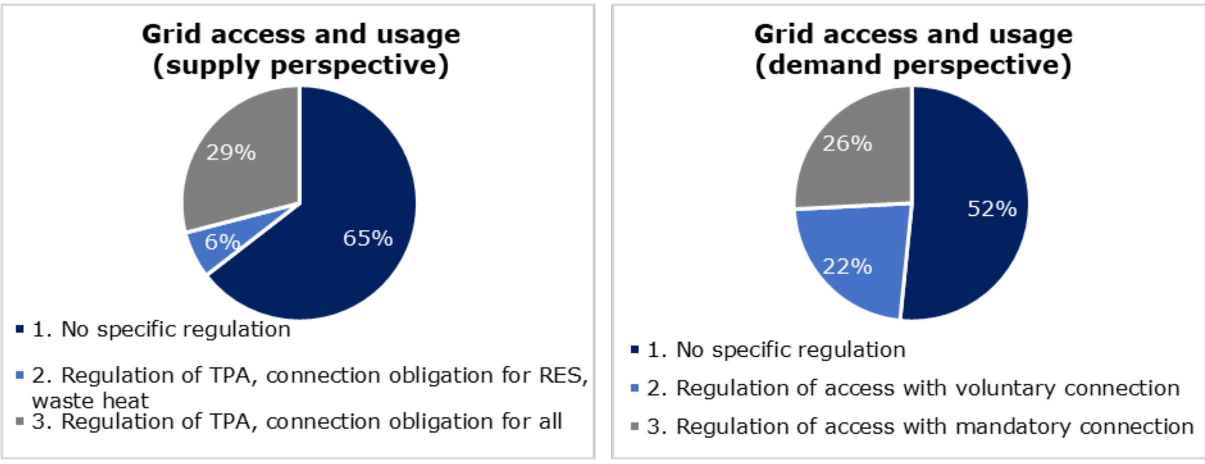


Figure 38: Regulation of grid access and usage (Source: Own compilation and assessment based on various sources and own survey with national DHC stakeholders; see sources in Annex 1)

On the demand side, there is no specific regulation of **consumer grid access** in the majority (52%) of countries. In 23% of the countries there is a regulation regarding consumer connection (e.g. regulation of contracts), but still voluntary connection to the grid (e.g. in Czech Republic, Hungary, Italy or Sweden). In 26% of the countries, consumers are obliged to connect to the DHC system under certain conditions (e.g. in Estonia or France). The obligation to connect refers in most countries only to new buildings in individual regions, e.g. when municipalities impose a form of district heating zoning with mandatory connection for new buildings. In France, for example, a mandatory connection can only be implemented when a study shows that DHC is the most cost-effective heating solution.

Concerning the **support framework**, a distinction is to be made between support of renewable heat systems, CHP and grid infrastructure. In addition, in many countries there is support for other elements of DHC (e.g. training and education programmes for installers or obligations for households to use renewable heat, which also include DHC with renewable heat, etc.). These additional elements are listed in the factsheets in Annex 1, but are not included in the analysis, as they are not specific for DHC, while they usually apply to other parts of the heat sector. For the support of renewables and CHP, a division is only made between no specific support (1) and the availability of specific support program (2). The results regarding the support framework are presented in Figure 39.

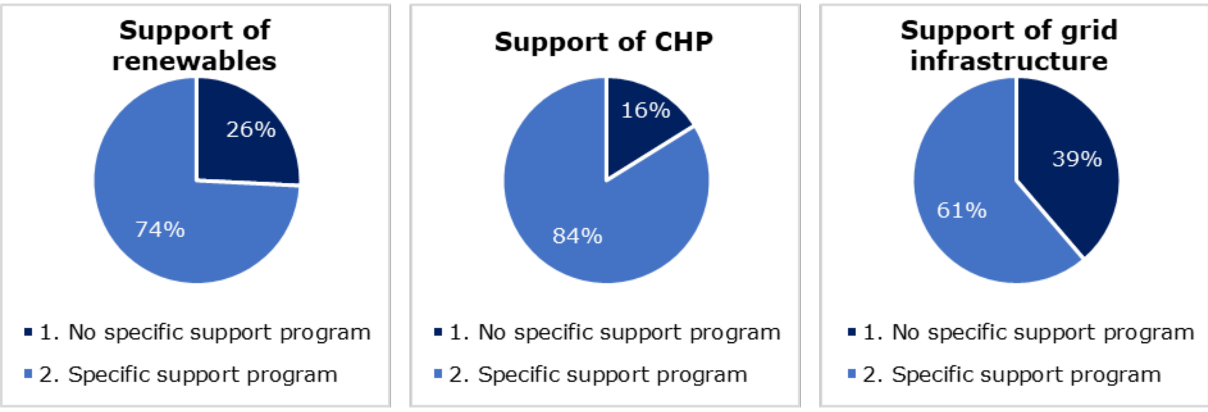


Figure 39: Support framework of renewables, CHP and grid infrastructure (Source: Own compilation and assessment based on various sources and own survey with national DHC stakeholders; see sources in factsheets in Annex 1)

In the vast majority of countries, there are support programmes for renewable heat (74%) and also for CHP (84%). Only a small number of countries seem to have no support programmes for renewable heat (e.g. Croatia, Portugal or Ukraine). In the case of support of grid infrastructure, 61% have a specific support programme. In 39% of the countries, however, there is no such support (e.g. in Belgium or Croatia). Chapter B.2.2 contains a more detailed analysis of the support schemes.

In order to provide a concluding overview of the regulatory framework, scores (i.e. the sum on regulation and support as a provisional proxy) were calculated, based on the levels of the different categories (see Table 11). With regard to regulation, a maximum score of 15 can be achieved, which corresponds to a strong intervention of the regulator. The minimum score is five, which means that there is no specific regulation in any category. In the case of support, a maximum score of six can be reached, which means that there are specific support programmes for renewable heat, CHP and grid infrastructure. At the minimum score of three, there is no support program in any category. Figure 40 and Figure 41 visualise the scores achieved and thus provides an overview of the level of regulation and support in the countries. Most countries show a rather high score in regulation as well as in support. Only a few countries established few regulation and support, which is most likely due to the low importance of DHC in their local heating market (e.g. in Portugal, Malta or Cyprus).

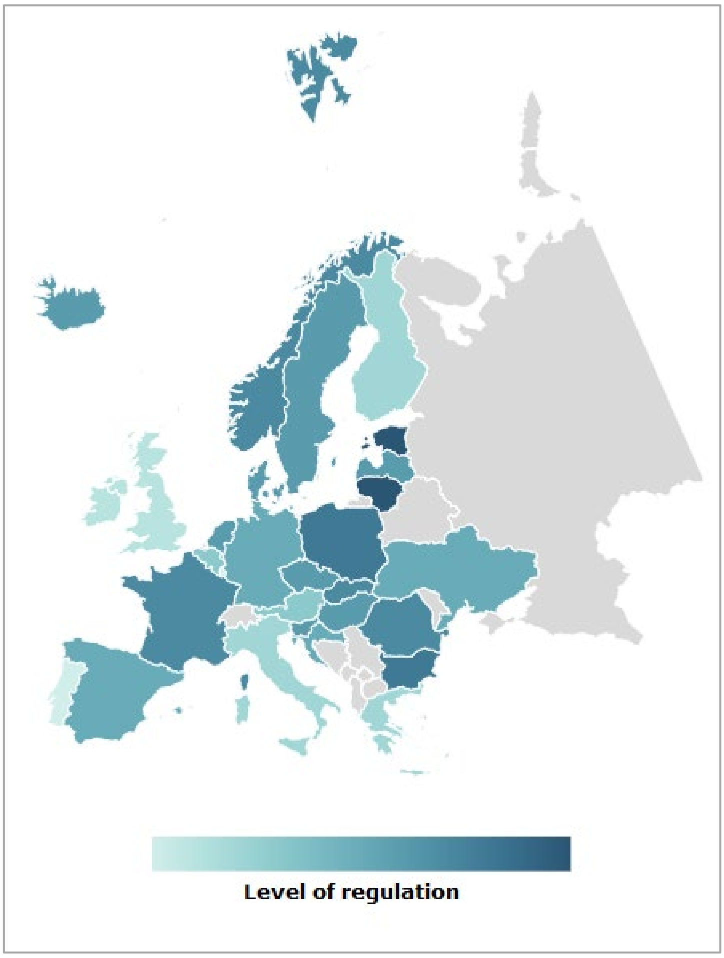


Figure 40: Map of the overall level of regulation in the Member States, UK, Iceland, Norway and Ukraine (Source: Own compilation and assessment based on various sources and own survey with national DHC stakeholders; see sources in factsheets in Annex 1)

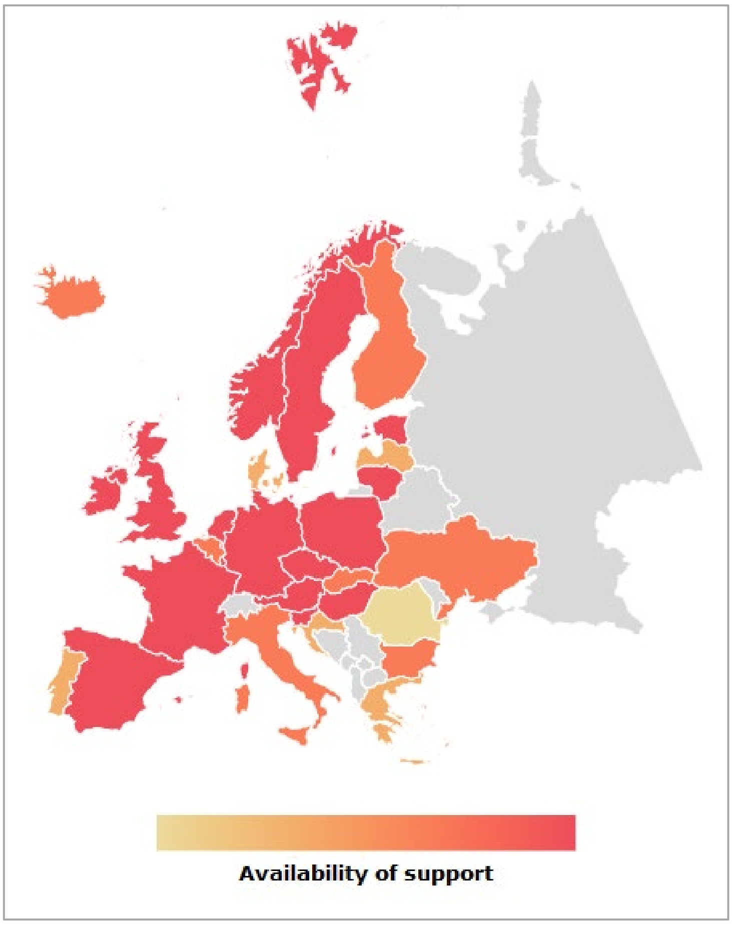


Figure 41: Map of the overall availability of support in the Member States, UK, Iceland, Norway and Ukraine (Source: Own compilation and assessment based on various sources and own survey with national DHC stakeholders; see sources in factsheets in Annex 1)

The level of regulation and support provides a first picture of the current regulatory framework in the countries (see Figure 40 and Figure 41). Nevertheless, this overview includes a lot of aggregations. This is mainly due to the fact that only the existence of regulation and support schemes is considered here, but not their effects. In this respect, one should also account for the rational or aim of regulations. In the case of price regulation and TPA, the natural monopoly of DHC grid operators is addressed, consumers are protected against excessive pricing and market access is granted for competitors. Metering regulation focuses on information and transparency and envisages on increasing energy efficiency while mandatory grid connection of consumers is driven by climate and economic issues. Thus, the existence of regulations supports the establishment of a transparent and functioning DHC system, but is not automatically reflecting favourable conditions for DHC. **Therefore, it should be emphasised that this overview cannot be used to draw conclusions about whether a country is providing favorable conditions for DHC**. This is illustrated in particular by the example of Denmark. Denmark has a lower score in regulation than for example Estonia. However, Denmark currently has very favourable conditions for renewables in DHC, in particular due to a high CO2 tax and a non-profit rule for DHC networks, which were not (fully) included in the aspects considered in the overview. Overall, the presence of regulation and support is a necessary, but not a sufficient condition for an efficient and strong DHC market. Block B of this report deals with regulatory aspects and support schemes in more detail and therefore allows for conclusions regarding the influence of regulation and support on DHC.

A.3.2.2 Overall relevant authorities and supervision

In this section, we indicate which authorities are responsible for the supervision of DHC in the different Member States, the UK, Iceland, Norway and Ukraine. Table 12 provides a list of the main regulatory authorities in the countries. In Annex 2, this list is supplemented with further authorities and relevant associations with links to the current websites.

Table 12: Regulatory authorities responsible for the supervision of DHC in the Member States, the UK, Iceland, Norway and Ukraine

Country	Regulatory authority responsible for DHC
Austria	E-Control
Belgium	Flemish Energy Agency
Bulgaria	Energy and Water Regulatory Commission (EWRC)
Croatia	Croatian Energy Regulatory Agency (HERA)
Cyprus	Ministry of Energy, Commerce and Industry (MCIT)
Czech Republic	Energy regulatory office (ERO)
Denmark	Danish Energy Agency
Estonia	Competition Authority
Finland	Ministry of Economic Affairs and Employment (MEAE)
France	Agency of the Environment and the Control of Energy (ADEME)
Germany	Federal Cartel Office (Bundeskartellamt)
Greece	Regulatory Authority for Energy (RAE)
Hungary	Hungarian Energy and Public Utility Regulatory Authority (HEA)
Ireland	Sustainable Energy Authority of Ireland (SEAI)
Italy	Regulatory Authority for Energy, Networks and Environment (ARERA) (ARERA)
Latvia	Public Utilities Commission (PUC)
Lithuania	National Commission for Energy Control and Prices (NCECP)
Luxembourg	Competition Council (Counseil de la concurrence)
Malta	Regulator for Energy & Water Services (REWS)
Netherlands	Authority for Consumers and Markets (ACM)
Poland	Energy Regulatory Office (ERO)
Portugal	Competition Authority (Autoridade da Concorrência, AdC)
Romania	Energy Regulatory Authority (Autoritatea Naţională de Reglementare, ANRE)
Slovakia	Regulatory Office for Network Industries
Slovenia	Energy Agency (Agencija zu energijo)
Spain	National Commission on Markets and Competition (CNMC)
Sweden	Swedish Energy Agency
UK	Department for Business, Energy & Industrial Strategy
Iceland	National Energy Authority (NEA)
Norway	Norwegian Water and Energy Directorate (NVE)
Ukraine	State Agency on Energy Efficiency and Energy Saving (SAEE)

Disclaimer: The list shows the main regulatory authorities on national level. In some countries, regional authorities are also relevant, but they are not listed here.

The tasks and competencies of the supervisory authorities vary depending on the level of regulation (see section A.3.2.1). In some countries for example, they are responsible for the licensing of DHC networks (e.g. in Bulgaria, Hungary, Lithuania or the Netherlands), the monitoring of DHC prices (e.g. in Bulgaria, Latvia or Lithuania), the regulation of grid access (e.g. in Croatia) or the allocation of support funds (e.g. in Finland). For some countries, their task is only the monitoring of cartel law (e.g. in Germany or Luxembourg).

Further information on the competencies of the authorities as well as additional authorities can be found in the country factsheets in Annex 1.

A.3.3 Consumer perception and satisfaction, consumer protection requirements and measures

In this section, an overview of consumer perception and satisfaction of DHC as well as on consumer protection requirements and measures is given (section A.3.3.1). Additionally, a more detailed analysis is provided for three selected countries, i.e. Estonia, Germany and Norway (section A.3.3.2).

A.3.3.1 Overview of consumer perception and satisfaction, consumer protection requirements and measures

Many studies stress that consumers' perception and satisfaction is a very important aspect of decision making and demand for energy services such as DHC. Unless there is an obligation to connect to an existing or new DHC network (e.g. under certain conditions in Denmark, France, Estonia, Germany or Lithuania), consumers need to be convinced of the advantages of connecting to such a grid. In practice, DHC systems often face the challenge that not enough citizens are motivated to connect to the DHC, for technical, economic, societal or other reasons. While some studies on acceptance issues in the area of heating and cooling exist, there is no extensive survey on the perception of DHC on the EU level so far.

In the following, an overview of consumers' perception and satisfaction as well as on consumer protection in the Member States, the UK, Iceland, Norway and Ukraine is provided. This overview is based on a web, document and literature search with a subsequent analysis for each country. Table 13 shows the summarised results of this literature analysis, whereas the country factsheets in Annex 1 contain brief descriptions of the available information on consumer perception as well as links to the literature.

To present the collected information on the consumer perception of DHC, categories were created for the type of source, as well as for positive and negative aspects mentioned in the literature (see Table 13).

With regard to the type of source, the following three categories (marked **P**, **C**, and **I**) are distinguished:

- **P** for provider or producer side, which represents a report or study of an energy company or provider association (e.g. DHC operator, DHC provider association)
- **C** for consumer side, which represents a report or study of a consumer association (e.g. consumer protection associations)
- **I** for independent, which represents a report or study of an independent agency, regulator or commission (e.g. energy agency, competition authority) as well as a report or study with independent market research (e.g. scientific publication)

Positive aspects mentioned in the literature can be divided into the following categories:

- **good overall image**, which means that DHC consumers are overall satisfied with their connection to the DHC system
- **high quality**, including aspects like high quality of heat, space heating with pleasant heat and hot water, simple and convenient handling

- **support of clients**, accounting for aspects like providing a dedicated centre/unit for the support for clients or good overall service
- **security of supply**, representing aspects like high security and no interruptions in the heat supply
- **transparency of prices**, comprising high transparency of prices and price structure
- **low costs**, representing aspects like low cost for heating and/or connection cost

Negative aspects mentioned in the literature can be divided into the following categories:

- **high prices**, addressing high prices/costs for heating and/or the connection to the DHC grid
- **billing issues**, reporting on low transparency of invoices and prices, inconsistent formats or complicated billing
- **metering issues**, representing aspects like no access to their meters or the measured consumption
- **monopoly issues**, encompassing issues with mandatory connection and problems with connection or disconnection as well as the monopoly-like structures that make changing suppliers impossible, no free choice of supplier
- **low quality**, standing for poorly performing technologies, no responsibility and compensation for damages as well as low heat quality

An overview of consumer protection in the countries considered is included in Table 13. This overview provides information on regulatory aspects, which are considered relevant with respect to consumer protection. These regulatory aspects include regulation regarding grid access of consumers, regulation of prices for consumers as well as regulation of metering. The information presented in Table 13 on these regulatory aspects is derived from/based on the overall regulatory framework in section A.3.2.1. Further information on consumer perception as well as on relevant authorities for supervision can be found in the country factsheets in Annex 1.

Table 13: Overview of consumer perception and protection of DHC (Source: Own compilation from various sources and own survey with DHC stakeholders; see sources in factsheets in Annex 1)

Country	Consumer perception			Consumer protection		
				Regulation regarding...		
	Type	Positive aspects	Negative aspects	Grid access	Prices	Meter-ing
Austria	P, C, I	good overall image [P]	high prices, monopoly issues, billing issues [C, I]	No	Yes	Yes
Belgium[1]	-			No	No	Yes
Bulgaria	-			Yes	Yes	Yes
Croatia	I		billing issues, high prices, low quality	(No)	Yes	Yes
Cyprus	-			No	No	No
Czech Republic	I		low quality, billing issues, metering issues	Yes	Yes	Yes

Country	Consumer perception			Consumer protection		
				Regulation regarding...		
	Type	Positive aspects	Negative aspects	Grid access	Prices	Meter-ing
Denmark[2]	I	good overall image, support of clients, transparency of prices		Yes	Yes	Yes
Estonia	P	good overall image		Yes	Yes	Yes
Finland	P, I	good overall image, support of clients, high quality [P, I]	high prices [P, I]	No	Yes	Yes
France	I	(high interest to connect)		Yes	Yes	Yes
Germany	P, I	Good overall image [I], high quality, security of supply [P]	monopoly issues [I]	Yes	Yes	Yes
Greece	-			(No)	No	No
Hungary	I		high prices, monopoly issues	Yes	Yes	Yes
Ireland	-			No	No	Yes
Italy	P, I	good overall image and high quality [P]	high prices [I]	(Yes)	No	Yes
Latvia	I		high prices, billing issues, metering issues	(No)	Yes	(Yes)
Lithuania	I		billing issues, metering issues	Yes	(Yes)	Yes
Luxembourg	-			(No)	(No)	(No)
Malta	-			No	No	No
Netherlands	I, C	high quality [C]	high prices, billing issues [I, C]	No	Yes	Yes
Poland[3]	I	good overall image, security of supply		(Yes)	Yes	Yes
Portugal	-			No	No	(No)
Romania	I		high prices, monopoly issues, low quality	(No)	(Yes)	Yes
Slovakia	I		billing issues, monopoly issues	Yes	Yes	Yes
Slovenia	P	high quality, low costs		Yes	Yes	Yes
Spain[4]	-			No	(No)	No
Sweden	I	good overall image	high prices, monopoly issues	Yes	Yes	Yes
UK	I	good overall image	low quality, high prices, monopoly issues, billing issues	No	No	Yes
Iceland	P	good overall image		Yes	Yes	No
Norway[5]	I	good overall image		Yes	Yes	No
Ukraine	I		billing issues, low quality	No	Yes	Yes

P = source is from type provider/producer (usually only information for a region or city); C = source is from type consumers; I = independent source; - no source could be found
() the information is not available or not clear in the literature and/or in the survey
1 In Belgium, the regulation of DHC is a regional competence. The table shows the regulatory framework for the region of Flanders as there is no legal framework in place in Brussels or Wallonia (Source: Answer in survey).
2 In Denmark, municipalities could impose a compulsory grid access for consumers until 2019. This option has been removed from the Heat Supply Act, but existing obligations, covering around half of all DH customers, remain in force.
3 In Poland the perception is elaborated by only one stakeholder opinion according to source.
4 In Spain, the prices for DHC are regulated if the network is developed under a concession regime. In the case of private networks, prices are not regulated.
5 In Norway, only networks with a concession can imply mandatory grid access for consumers.

Table 13 shows that information on the perception and satisfaction of DHC consumers is available for 22 countries, with most literature coming from independent sources. Thus, no information was found for a total of 9 countries. Thereby, countries with no information, but a relatively high final energy consumption of DHC in 2018 are Bulgaria and Spain (see section A.1). For France there is a study available focusing on the willingness to connect to DHC, but less on the satisfaction of already connected customers. Besides, most of the literature found focuses on the residential sector (e.g. households or homeowners) and only a few studies also look at other types of consumers [28]. In addition, there are some publications that do not distinguish at all between types of consumers (e.g. in annual reports of DHC providers or energy agencies).

Except for Finland, all sources of type P (i.e. reports of provider/producer) report only positive aspects of consumer perception. Independent sources and studies from sources of type C (i.e. reports from consumer side) are somewhat diversified and report both, positive and negative aspects. This illustrates how important it is to consider the origin or contracting body of the source.

In Sweden, Denmark, Finland, Norway and the UK the consumers' perception of DHC is overall very good, according to independent sources (see Table 13). Aspects that underline the positive image are **general customer satisfaction, transparency of prices, high quality of heat supply** without interruptions and **good customer service**. However, the case study of London, done in the framework of this study (Annex 6), shows that the consumers' perception in the Uk is sometimes suffering from the amalgam with "collective heating" (heating at multi-apartments building level).

Denmark and Sweden have specific regulations covering all three aspects, i.e. regulation of grid access, prices and metering. Denmark has a mandatory connection for consumers under certain conditions (see section A.3.2.1). This option has been removed from the Heat Supply Act in 2019, but existing obligations (i.e. areas with mandatory connection), covering around half of all DH customers, remain in force. On the contrary, in Sweden and Finland there is no specific regulation for DHC consumer's grid access and in the UK, only metering is regulated.

For some countries complaints or negative aspects about DHC are periodically recorded by regulators, agencies or associations (e.g. in Croatia, Italy, Latvia, Lithuania or Slovakia). The **most common complaint is about high prices, followed by billing issues**. Less frequently, **monopoly issues and low quality** are mentioned as negative aspects and metering issues are reported only three times. Countries where only negative aspects are mentioned are Croatia, Czech Republic, Hungary, Latvia, Lithuania, Romania and Slovakia. These negative aspects encompass for example high prices as well as billing and metering issues. Besides, there are complaints reported in Austria, Finland, Italy, the Netherlands and also in Sweden and the UK. The complaints in Sweden and the UK illustrate that negative aspects are also reported in countries with an overall good image.

In the majority of the countries, where negative aspects are reported, the regulatory framework includes comprehensive regulations regarding grid access, prices and metering. This shows that there is no clear relation between consumers' perception and protection. To further examine consumer perception and satisfaction and to understand it in relation to the consumer protection, three countries are analysed in detail (see section A.3.3.2)

A.3.3.2 Consumer perception and satisfaction, consumer protection requirements and measures in selected Member States

In this section a more detailed analysis, building on expert interviews, for three selected countries, i.e. Estonia, Germany and Norway, is provided. The selection of the three countries is based on the rationale that only limited information on DHC consumer perception were found in these three countries, the countries selected have reasonably large DHC markets, the regulatory approaches (regarding grid access, prices, metering) in the countries are somewhat different, interviewees were most likely available and the overall image of DHC was expected to differ between the countries.

For the analysis, a total of 10 expert interviews were conducted with regulatory authorities, climate and energy agencies as well as energy associations. Thereby, at least two interviews per country were carried out, in order to include different perspectives. The interviews each lasted 30 to 45 minutes, during which an open discussion took place along the following guiding themes:

1. **Perception of DHC**: How do you perceive DHC? What is good what is bad from your perspective? What characteristics are associated with DHC in your country?
2. **Complains of DHC consumers**: Do you receive complains about DHC? What do customers complain about?
3. **DHC consumer protection**: How do you perceive DHC consumer protection in your country?

Depending on the interviewee and the previous found information on consumer perception and protection in the country or region, the questions were adapted and expanded. In addition, if appropriate and useful, we asked about further relevant studies (i.e. in national language) that could be included in the analysis. In the following, the results of the interviews and therefore a detailed analysis regarding DHC consumer perception and protection for Estonia, Germany and Norway are presented.

Estonia

Estonia has a long history of DHC networks with the first heating network build in 1949 in Kohtla-Järve (see section A.1 and [2]). A large number of small systems (i.e. up to 10 buildings) were established during the Soviet era [2]. Hence, in several residential areas, DHC is the most common way of heating for the majority of inhabitants [2]. Thereby, more than half of the heat comes from renewable energy (mostly biomass) or recycled heat[39] (see section A.1 and [2]).

Regarding consumer protection regulations, **Estonia's national strategy is to fully regulate the DHC sector and its prices** [2]. Thus, there is already a lot of legislation in place. One of the main regulative instruments is the national District Heating Act[40]. According to this act, a district heating region is an area within the borders of a municipality in which consumer installations are provided with heat by way of district heating. In these district heating **areas all new buildings, with a few exceptions, are required to be connected to the network**. At the same time, a network operator is required to provide a network connection to an interested customer, unless this endangers the security of supply. Every municipality in Estonia has the right to establish a district heating area. For example, in Tallinn and Tartu such areas are established, but also several smaller municipalities defined district heating areas in their main residential areas [2].

Besides, all **district heating prices are regulated** in the District Heating Act. This includes the definition of a price rule for a maximum price. Specifically, § 8 states that the maximum price of heat must be set such that:

[39] Recycled heat includes surplus heat from electricity production (CHP), waste-to-energy cogeneration plants and industrial processes independently of the fuel used (renewables or fossil) for the primary process [2].
[40] District Heating Act, Estonian: Kaugkütteseadus, passed 11.02.2003, RT I 2003, 25, 154, Entry into force 01.07.2003, online: https://www.riigiteataja.ee/en/eli/520062017016/consolide

(1) the necessary operating expenses, including the expenses incurred in relation to the production, distribution and sale of heat, are covered;
(2) any investments necessary in order to perform the operational and development obligations can be made;
(3) environmental requirements are met;
(4) quality and safety requirements are met and
(5) justified profitability is ensured.

Moreover, the **maximum price must be approved** by the Estonian Competition Authority and must be made public. In addition to the price regulation, connection fees, connection contracts as well as metering are also regulated in District Heating Act. Overall, there is a strong regulation established, protecting DHC consumers.

At the same time, the **general image of DHC in Estonia is quite good**. From the consumer's perspective district heating is a convenient type of heating with high security of supply and environment-friendly heat. This is especially the case in larger cities or regions with high consumption density, where heat production and distribution of district heat is seen as efficient and climate friendly, with high heat volumes, based on renewable fuels, small heat losses as well as low heat prices. Nevertheless, there are also a few areas with low consumption density, where heat production and distribution of district heat are not seen efficient. District heating in these urban areas is associated with small sales volumes, based on fossil fuel, over dimensioned pipelines, large heat losses and also with high prices.

In line with the limited negative perceptions, the **number of consumer complaints to the Estonian Competition Authority is quite low**. In the last years, the Competition Authority was approached only a couple times and mainly with technical problems for which they are not in charge. For example, there were some complaints relate to the amount of energy used to heat old and not renovated buildings compared to the amount of energy used in a neighbouring fully renovated building. Hence, most of complaints lied in the responsibility of homeowners or apartment associations.

The good overall image of DHC in Estonia is also reflected in two available consumer satisfaction studies from district heating providers. In 2014, a survey was conducted in Tallinn on behalf of the local provider [29]. The survey was answered by 18.1% of the total consumers connected to the network. Thereby, an increase in customer satisfaction compared to previous similar surveys was recorded and consumers rated the quality of the heat service the highest [29]. Similarly, in Tartu the local district heating operator (Fortum) conducts a customer survey almost every year which shows that the level of satisfaction is very good and stable [30].

Germany

In Germany, the first networks were built around 1920, making Germany a pioneer in district heating (see section A.1). Nowadays, DHC has a market share of about 10%, with the largest share in the residential sector with almost 14% (see section A.1 and [2]). Thereby, fossil fuels still dominate DHC in Germany, although the share of renewable energy is on a continuous rise.

With regard to consumer protection regulations, DHC networks are not subject to the national energy law and there is no separate law for (district) heating as in the case of Estonia. Nevertheless, **DHC is controlled in the framework of the national**

competition act[41], regulating that monitoring of cartel behaviour is carried out by the federal cartel office and the individual state cartel offices in the 16 federal states. In this respect, the state cartel offices are primarily responsible for regional or local DHC, while the federal cartel office is responsible for state cross-border networks or if state offices transfer tasks to them. Such a transfer took place, for example, in 2012, when the federal cartel office conducted a comprehensive sector investigation and subsequently initiated several cartel proceedings due to cartel law concerns [31].

On the subject of mandatory grid connection of consumers, **a municipality has the right to determine by statute that within a certain area each property must be connected to the DHC grid**. The legal basis to introduce this obligation is the respective communal ordinances of the federal states. Precondition for compulsory connections and use of DHC are, for example, the reasons of "common good". Currently, all federal states provide the possibility to introduce mandatory connection and use of DHC [32]. However, in practice, municipalities introduce mandatory connection less and less frequently [32].

In order to **strengthen consumer protection**, conditions for district heating consumers (i.e. pricing) are regulated by the ordinance on general conditions for the supply of district heating[42]. As the name of this ordinance implies, this regulation sets a general framework for standard conditions for the supply of district heat to customers. Thereby, customers connected to district heating networks have the right to be supplied according to the general conditions laid out in the ordinance if standard business conditions are being used. The supply of industrial customers does not fall under the scope of the ordinance. The regulations of the ordinance cover the entire contractual relationship from contractual agreement, installation to termination of the service. Among other things, detailed regulations are made on heat delivery contracts, liability, technical connection conditions, billing and even the discontinuation of supply and termination without notice. Regarding prices, the ordinance regulates that the so-called **price change clauses can be used**, but must adequately take into account both the cost development in the production and provision of district heating and the respective conditions on the heating market. The aim of this regulation is to **ensure that prices are cost-oriented**. In most cases, DHC prices in Germany consist of a consumption-independent basic annual price and a consumption-dependent energy price. Within the framework of price change clauses, defined in the heat delivery contracts, the prices can be continuously adjusted with special price change factors, even in long-term contracts. As an example, the price change clauses of one of the largest DHC provider, Vattenfall in Berlin [33], states that the new price (P_{new}) is calculated by multiplying the price valid until then (P_{old}) with the ratio of the new price change factor (PF_{new}) to the price change factor from the previous period (PF_{old}), leading to the fowling formula:

$$P_{new} = P_{old} \cdot \frac{PF_{new}}{PF_{old}}$$

Thereby, the factors (PF) include different price elements connected to specific cost that change over time, e.g. investments, wages, prices for coal and oil or prices for CO2 certificates. The base price is adjusted annually and the consumption-dependent energy price is adjusted quarterly by this provider.

The calculation of the prices is often perceived as very complicated, which is also reflected in DHC consumer complaints. Consumers can turn to the cartel offices with problems. They report that they receive **several complaints about price increases and complicated price calculations**, especially at billing time. Besides the cartel offices, consumers can

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[41] Competition Act; German: Gesetz gegen Wettbewerbsbeschränkungen (GWB); published on 26 June 2013 and last amended 12 July 2018; online: https://www.gesetze-im-internet.de/englisch_gwb/index.html
[42] Ordinance on general conditions for the supply of district heating, German: Verordnung über Allgemeine Bedingungen für die Versorgung mit Fernwärme (AVBFernwärmeV); published on 20 June 1980 and last amended 25 July 2013; online: https://www.gesetze-im-internet.de/avbfernw_rmev/BJNR007420980.html

also contact consumer advice centres, which, however, cannot provide support for complaints in most cases. Often, **consumers do not seem to know who to turn to** and who can help them. Apart from prices, the dependency on one provider is (in some cases) observed negatively. This year (2021), complaints are expected to increase as the new national CO_2 price for heat and transport leads to an increase in DHC prices, which seems to confuse consumers, as many assume that their DHC network is efficient and environmentally friendly and are therefore surprised that CO_2 is priced.

Climate and environmental issues are becoming increasingly relevant in Germany. This increasing relevance is reflected in election results of green parties and movements like Fridays for Future, which are gaining a lot of popularity and attendance in Germany. Activists are therefore becoming louder, criticising local DHC networks that use coal-based CHP. At the same time, the potential for climate friendly heating trough DHC is recognised. In addition to environmental and pricing concerns, connected consumers mention high security of supply, very low expenditure and low space consumption in one's own cellar as positive aspects. Concluding, DHC is overall perceived rather positively by consumers, so that the general image can be estimated as medium to good.

The described perception is also reflected in some available publications. Zaunbrecher et al. (2016) investigate in their research local district heating network design preferences [34]. Results of their analysis show that the energy source was the most important attribute. But the preference for energy sources changed dramatically when introducing different prices for energy sources. More resent research form Krikser et al. (2020) show that district heating from renewables is the most preferred heating option for households in Germany followed by district heating from fossil fuels [35]. Furthermore, the paper provides profound insight into the willingness-to-pay for different heating options. And lastly, according to the BDEW (2019), the simple and convenient handling, the high safety standards and the long-term secure supply are highly positively perceived [36].

Norway

Compared to the other Nordic countries, the district heating market in Norway is quite small (see section A.1). Historically, the comparatively smaller market is related to fairly cheap direct and indirect electric heating, because of low electricity prices. With rising electricity prices towards the end of 1990, regulations for district heating and investment subsidies were introduced to encourage the development of networks. Through this new framework, DHC capacity have grown strongly since the early 2000s [37]. A main driver for the growth was thereby the new requirement to use heat from waste incineration. Nevertheless, today, electricity is still the dominant source of energy for heating in the residential and services sectors and DHC accounts for about 12% of the heat market [2]. Thereby, the service industry is the largest consumer [2]. One driver that is presently increasing the expansion of DHC, is the use of further excess heat potential, e.g. from data centres as well as a general stronger focus on district cooling.

The construction and operation of DHC networks is regulated by the Norwegian Energy Act[43] as well as by the Planning and Building Act[44]. Thereby, the Norwegian Water Resources and Energy Directorate (NVE) serves as the main regulator of the DHC sector, being responsible for supervision of the market. In accordance with the Energy Act, DHC

[43] Energy Act, Norwegian: Energiloven, passed 26.06.1990, online: https://www.regjeringen.no/globalassets/upload/oed/vedlegg/lover-og-reglement/act_no_50_of_29_june_1990.pdf
[44] Planning and building act, Norwegian: Plan- og bygningsloven, passed 14.06.1985https://www.regjeringen.no/globalassets/upload/kilde/krd/reg/2005/0001/ddd/pdfv/242652-the_planning_and_building_act.pdf

networks with a capacity of more than 10 MW are required to hold a concession, granted by the NVE. For networks with a concession, the **municipality can introduce mandatory connection** for new and refurbished buildings according to the Planning and Building Act. At the same time, there is no obligation for the connected customer to purchase energy from the DHC provider and, reverse, there is no obligation for the DHC operator to provide energy. Besides, building owners can apply for a full or partly exemption of the obligation to connect, if they can prove that their alternative heating choice is more environmentally friendly, which is in practise often very difficult to measure. There is also an option to apply for a concession for smaller DHC networks, if the developer or operator wants the municipal authority to impose compulsory connection, which is why also many smaller networks have a concession.

DHC network with a concession have to meet wider regulatory requirements, such as a strict price regulation: a DHC provider cannot charge more than the alternative retail cost of electric heating within the respective concession areas. Therefore, **prices of DHC are as high as the electricity price including all taxes and levies**. This means that DHC prices are rather market oriented and do not necessary reflect the actual cost. Besides, because of this regulation, DHC operators have to cope with high volatility of their price, as electricity prices can fluctuate quite strongly (monthly electricity price is mostly used for comparison). The calculation of the price is usually published by the DHC operator. An exemplary price calculation for household prices in 2021 is shown below [38]:

Nord Pool's monthly electricity price for Oslo in January 2021	50.049 øre/kWh
Grid fees for private customers	35.84 øre/kWh
Administrative surcharge	2.0 øre/kWh
Profile supplement	1.0 øre/kWh
Electricity certificate price	0.04 øre/kWh
Sum = District heating price (without VAT)	**88.93 øre/kWh**

The overall **image of DHC in Norway seems to be quite good**. Consumers connected to a network with mandatory connection can appeal to the NVE regarding prices and other conditions. The **few customer complaints** per year indicate a high satisfaction with prices and services. In the last year NVE got only about three to four complaints. The main complaint was thereby about prices, as some people misunderstand the regulation and only compare their heating price with the electricity spot price. Besides, in some areas, DHC networks have been in operation for decades and are therefore taken for granted [39]. Most people in Norway seem to be not interested in their heating source, they simply accept their current heating system.

Discussion

Table 14 summarizes the results and shows that the three countries follow different approaches for consumer protection. All three countries rely on specific regulations, especially with regard to prices. Thereby, **Estonia follows a strong regulated method**, specifying what cost can be included in the DHC price combined with an ex-ante price control. **Norway uses a more market-oriented approach** with a general price cap derived from the electricity price. The regulation in **Germany is also more market-oriented and offers the greatest level of freedom** for the provider. In addition to price regulation, different approaches regarding mandatory connection of consumers can be observed in the three countries. While connection obligations can exist in all three countries, in Norway the connection obligation does not include a use obligation.

At the same time, there are differences in the perception of DHC, even though in all three countries DHC seems to have a rather positive image. In Estonia and Norway there are very few customer complaints, while in Germany the price adjustment clauses are difficult to understand and offer grounds for criticism and questions at billing times. Against this background, more transparency or simplification regarding the price clauses in Germany could reduce the number of inquiries. The price caps in Norway are also rarely not understood, but are generally more comprehensible and thus more transparent. In summary, from the whole analysis, it can be concluded that **fair and transparent pricing through appropriate regulation as well as concrete contact points for consumers can make a positive contribution to the perception and thus support the further expansion of DHC**.

Table 14: Overview of perception and protection of consumers in Estonia, Germany and Norway (Source: Own compilation and assessment by various sources and interviews with national DHC stakeholders; see sources in factsheets in Annex 1)

Country	Estonia	Germany	Norway
Perception & satisfaction	• Good image and high satisfaction • Studies on satisfaction from provider underlining positive perception	• Image can be estimated as medium to good • Publications show a high preference for DHC, but also high price sensitivity	• Good overall image and high satisfaction
Authority & complaints	• Competition Authority deals with complaints • Only a couple complaints last year mainly about technical problems	• Competition Authority deals with complaints • Unclear for consumers who the responsible authority is • Several complaints last year about prices and complicated price calculations	• NVE deals with complaints • Only a few complaints per year about prices
Overall regulation & concessions	• DH market is fully regulated in DH Act • DH networks need a licence	• DH is controlled with Competition Act • Ordinance on general conditions to strengthen consumer protection	• DH is regulated by the Energy Act • Networks with a capacity of more than 10 MW need a concession
Regulation regarding pricing & billing	• Price calculation rule with maximum price • Approval of price by the Competition Authority	• Price change clauses, i.e. periodic adjustment with price change factors	• Price cap is alternative retail cost of electric heating • Applies only to networks with a concession
Regulation regarding grid connection of consumers	• Mandatory connection possible • Operator must provide a connection to customer within an DHC area (unless it endangers security of supply)	• Mandatory connection possible	• Mandatory connection possible • No use obligation, i.e. only connection obligation

B. Regulatory regimes applied to district heating and cooling

Block B will provide an overview of the regulatory regimes applied to district heating and cooling, in particular with regard to network/system access, measurement and pricing and contractual modalities for third party access. Additionally, the impact of the national building regulations and urban planning on the DHC systems will be investigated. The geographical coverage of this task is the EU and its Member States, the UK, Norway, Iceland and Ukraine. The analysis focuses on the regulatory regimes in the Member States and on those countries in which district heating and cooling plays a major role in the heating market.

The description of regulatory regimes is divided into four chapters.

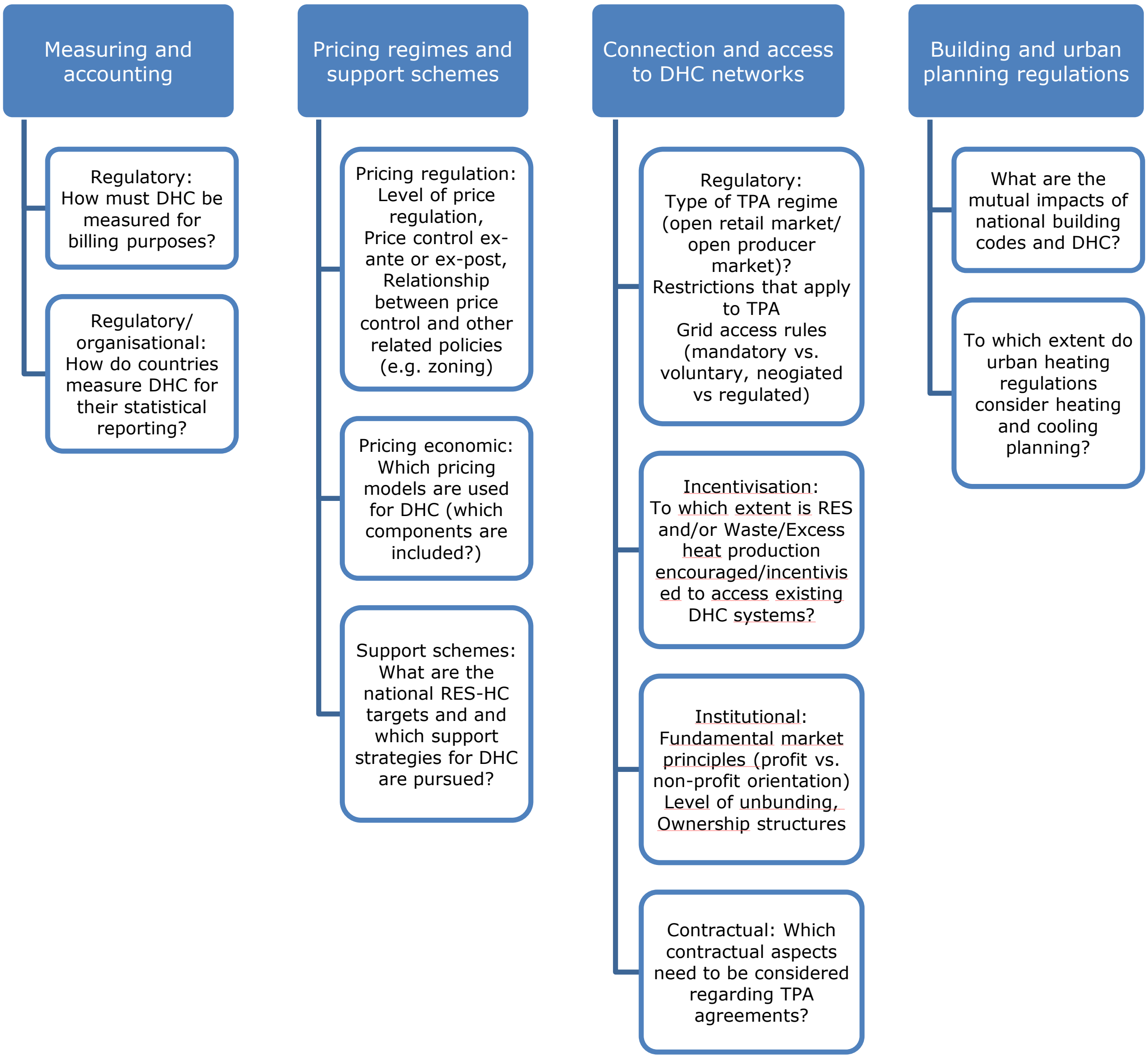


Figure 42: Block-B overview of chapters

A specific focus will be put on selected focus countries that reflect all the different DHC markets situations in the EU. The ten focus countries are:

- "Advanced" Nordic DHC countries: Finland, Denmark, Sweden
- Significant DHC markets: Germany, Poland
- Eastern European countries: Slovakia, Bulgaria
- Baltic country: Lithuania
- "Emerging" DHC markets: France and the Netherlands

The country selection was made in such a way that countries are analysed in which district heating has a different role in the heating market (established district heating markets vs. emerging markets). On the other hand, rather different regulatory regimes for district heating and cooling will be covered.

Like for block A, the analysis performed in block B is based on a comprehensive literature review that has been complemented by a survey addressed to the main DHC stakeholders in the 31 countries entering the scope of this study (see block A introduction for more details).

B.1 Measuring and accounting

B.1.1 Measuring DHC supply for billing purposes

B.1.1.1 European legislation

According to the Energy Efficiency Directive (2012/27/EU, EED)[45], amended by Directive 2018/2002[46], Member States shall ensure that final customers for district heating and district cooling are provided with competitively priced meters **that accurately reflect their actual energy consumption** (Art 9a amended EED). The meter shall be installed at the heating/cooling exchanger or point of delivery. The Directive emphasises the importance of real measurement of the quantity of heat consumed. Billing on the basis of pure estimates is not sufficient.

In multi-apartment and multi-purpose buildings with district heating and/or cooling supply, individual consumption meters shall also be installed to measure the consumption of heating, cooling, or hot water **for each building unit** (Art 9b amended EED). Where the installation of individual meters is not technically feasible or not cost-efficient, individual heat cost allocators shall be used for measuring heat consumption at each radiator, as long as such cost allocators turn out to be cost-efficient. Where even for the cost allocators cost efficiency is not given, alternative cost-efficient methods of individual heat consumption measurement may be considered. The general criteria, methodologies and/or procedures to determine technical non-feasibility and non-cost effectiveness shall be clearly set out and published by each Member State. In order to support Member States in implementing these requirements, in 2016 the EU Commission commissioned a guideline[40].

Ideally, meters should be installed on two levels, at the overall delivery point (heat/cold exchanger between district heating or cooling network and the building), and inside the building to distribute the total consumption of a building to the different users (individualized metering).

Furthermore, where meters or heat cost allocators are installed, Member States shall ensure that billing and consumption information is reliable, accurate **and based on actual consumption or heat cost allocator readings** (Art 10a amended EED).

Meters and heat cost allocators installed after 25 October 2020 shall be **remotely readable devices** (Art 9c amended EED). The conditions of technical feasibility and cost effectiveness shall continue to apply. Meters and heat cost allocators which are not remotely readable, but which have already been installed shall be rendered remotely readable or replaced with remotely readable devices by 1 January 2027, unless the Member State in question demonstrates that this upgrade is not cost-efficient.

The following chapter investigates how Member States measure district heating for billing purposes and focuses on the measurement of heat at the delivery point to the building (e.g. the heat exchanger between the network and the building). This analysis is based on a detailed literature review and is completed by the inputs collected through the survey carried out in the various countries of the study.

[45] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC
[46] Directive 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency

B.1.1.2 Status of implementation

According to an analysis carried out by the Concerted Action of the EED (CA-EED) on the status of how Member States have implemented the metering requirements of the EED, it is stated that "*the implementation of EED requirements as regards individualized metering and consumption-based, frequent billing for district heating, cooling and hot water is perceived as presenting a higher degree of difficulty due to the technical and physical necessity in many situations of installing several meters or heat cost allocators to obtain the consumption of a single end-user*" [41]. In 2016, in about half of the Member States, DHC meters that accurately reflect the final customer's actual energy consumption were offered to consumer groups [42]. According to the survey results, the situation did not change significantly until 2020 (see Figure 43 and table in Annex 4).

Figure 43 provides an overview of the regulatory requirements for metering for the purpose of billing district heating and cooling in the Member States as well as the UK, Iceland, Norway, and Ukraine. There are only a few countries where metering is not regulated**. In most countries, both, metering at the supplier-customer interface as well as individualized metering inside multi-use buildings is regulated**.

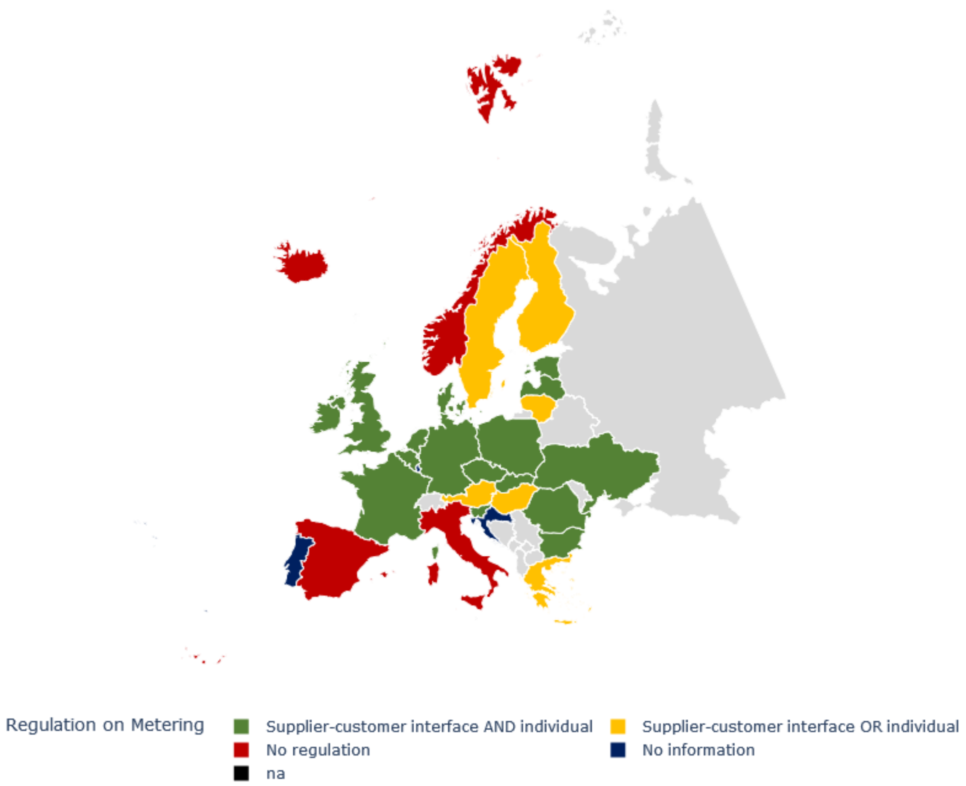


Figure 43: Map of the status of regulation on metering at the point of delivery and on individualized metering (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

B.1.1.2.1 **Metering of DHC at the supplier/consumer interface for billing purposes**

In the following the status concerning the regulation of metering of district heating and cooling for billing purposes (interface supplier/consumer) is described. It also comprises the description of the scope of the regulations. Information on the scope of the regulation is available for 18 countries. In Belgium, only the requirements and regulations defined for Flanders are considered. According to VREG, the Energy Regulator in Flanders, the legal framework on DHC is a regional competence and each region (Flanders, Wallonia and

Brussels) can set the framework independently. There is no federal legal framework apart from one law on social tariffs for district heating and currently there is no regional legal framework on DHC in place in Wallonia and Brussels.

Metering at the supplier-customer-interface is **lacking regulation in three Member States** (Greece, Italy and Spain) as well as in Norway and Iceland. In Spain, details on metering are clarified in public tenders or in private contracts in the case or private networks. In five additional countries information is not available. This might be due to the fact that there is no DHC or that DHC does only play a minor role and therefore no regulation is in place (e.g. Cyprus, Malta). In all other countries specific regulation is in place.

The **requirements of the EED** (see description above) **are the basis of national regulation and legislation** while some Member States go beyond these requirements. Several countries only refer to the requirements defined in the EED and state that these requirements are translated in national laws and regulations (e.g. in the Netherlands and Slovenia). **Additional requirements and parameters** typically defined in national regulations are

- point of metering;
- obligations for metering companies;
- accuracy of metering and probably technical specifications of meters installed;
- calculation of cost-effectiveness of the installation of meters;
- building classes, in which meters must be installed.

Additionally, in some countries it is already mandatory that **new meters are remotely readable** (e.g. Flanders/Belgium) and/or even **provide consumption information** for DHC-companies and final customers (e.g. UK) frequently. In Finland customers must be billed at least four times a year and many companies already bill once a month and provide monthly consumption information accordingly.

In the UK, a series of amendments to the Heat Network legislation came into force in November 2020 addressing metering and billing[47]. In the amendments building classes are defined, in which heat meters and/ or heat cost allocators must be installed or not: viable class (meters must be installed), exempt class (meters must not be installed) and an open class (meters must be installed if the result of a cost-effectiveness assessment is positive). Furthermore, a tool is provided to assess the cost-effectiveness of the installation of meters. If meters must be installed, it is the obligation of heat suppliers to install the devices. Meters must not only measure, but also save and display actual consumption in specified cases.

More detailed information on metering regulation at the supplier/consumer interface for billing purposes in the ten focus countries is provided in Table 15 based on the survey results.

In most cases, mainly technical requirements and specifications are defined in national legislation. Exceptions are Bulgaria, Finland and Sweden where also information responsibilities are defined in the sense that DHC companies must **provide consumption information to final customers several times a year** (up to monthly). In Denmark, flow rates and temperature differences between supply and return flow are measured. In

[47] https://www.legislation.gov.uk/uksi/2020/1221/contents/made

most Danish DHC systems it is quite common that contracts contain a **motivation component** to incentivize lowering the return temperature (rewards/penalties).

Table 15: Detailed overview of metering regulations at the supplier/consumer interface for billing purposes in the ten focus countries (Source: Own survey with national DHC stakeholders)

Country	Heat metering supplier/customer interface
Bulgaria	Heat metering at the supplier/customer interface for billing purposes is regulated. District heating companies have the obligation to meter the heat consumption on a monthly basis and provide this data to heat cost allocation companies. The latter perform the distribution according to the calculation methodology of the allocation method defined/chosen by the clients. All obligations of the parties are stipulated in the Energy Act and detailed in Ordinance No Е-РД-04-1 as of 12.03.2020.
Denmark	Heat metering at the supplier/customer interface for billing purposes is regulated. The applicable technical standard for thermal energy meters is actual the EN 1434. The meter is the boundary between supplier and customer. Therefore, substations are owned by the customers after the meter. The meter itself must be able to calculate (via metering) the customers heat consumption. The minimum heat meter data required for the billing is energy consumption and water volume. Substations should be able to regulate and control heat supply based on frequent measurements. The regulation provides several options and therefore freedom for charging customers. Most companies charge customers by energy (MWh). Some are still charging by cubic meter (m^3), which automatically incentives to utilize the heat from one cubic meter as much as possible. Furthermore, some companies have punishment tariffs if customers do not lower return temperatures enough. In contrast, also motivation tariffs exist: costumers who reduce their return water below a predetermined temperature have a lower price per kWh.
Finland	Heat metering at the supplier/customer interface for billing purposes is regulated as well as metering (technical regulation: accuracy, etc.) and billing obligations. However, the technical interface is not regulated. The relevant directives are the Measuring Instruments Directive (MID) and the Energy Efficiency Directive. Customers must be billed at least four times a year based on the actual, measured consumption. The normal billing interval of most companies is currently monthly (12 times a year).
France	Heat metering at the supplier/customer interface for billing purposes is regulated. Since 2015, in all DHC networks the thermal energy delivered to each building must be metered. The obligation is defined in law n°2010-788 of 12th July 2010 (LOI n° 2010-788 du 12 juillet 2010 portant engagement national pour l'environnement).
Germany	Heat metering at the supplier/customer interface for billing purposes is regulated. Requirements are defined in the AVBFernwärmeV (Ordinance on General Conditions for the Supply of District Heating) in article 18. In order to determine the consumption-dependent charge, the DH company must use measuring equipment which must comply with the calibration regulations. The quantity of heat supplied shall be determined by measurement (heat measurement). Instead of heat measurement, measurement of the water quantity is also sufficient

Country	Heat metering supplier/customer interface
	(substitute method) if the devices for measuring the water quantity were installed before September 3, 1989.
Lithuania	Heat metering at the supplier/customer interface for billing purposes is regulated. Heat meters at the inlet (supply) are mandatory. The requirements of metering devices, responsibilities and duties as well as measuring location are defined in the Heat law IX-1565 from 2003.
Poland	Heat metering at the supplier/customer interface for billing purposes is regulated. District heating companies sell heat based on measured data. Details are defined in the Polish Energy Law. Location of metering and settlement systems for a whole building are usually included in grid connection agreements.
Slovakia	Heat metering at the supplier/customer interface for billing purposes is regulated. In Act 657/24 Coll. on the heating sector it is defined that each consumer/ the consumption of each final customer must be metered. The Act also includes further specifications of heat metering in DHC-systems.
Sweden	Heat metering at the supplier/customer interface for billing purposes is regulated. Details are defined in the Swedish District Heating Act. District heating companies are obliged to measure the amount of heat energy supplied as well as its distribution over time. The companies also must provide information on consumption to the end users.
The Netherlands	Heat metering at the supplier/customer interface for billing purposes is regulated. The regulation for metering is in accordance with the requirements in the EED; no further details are defined.

B.1.1.2.2 **Individual consumption metering in multi-apartment and multi-purpose buildings with DHC supply**

In the following the status concerning the regulation of individual consumption metering in multi-apartment and multi-purpose buildings with DHC supply is described. Only in 17 out of the analysed 31 countries regulation on individualized metering is in place. For five countries (mainly countries in which DHC does not play an important role) no information is available.

In all countries with regulation in place individual metering is only required if it is technically feasible and cost-effective. In the UK, a tool to calculate the cost-effectiveness of metering is provided. In several countries, the requirement for individual metering is that the building has a horizontal distribution system (e.g. in Bulgaria). A prerequisite for individual metering is that the whole heating demand of one unit (dwelling/ apartment, office, …) can be measured with one meter, which is only possible in buildings with horizontal distribution. If heat, cold and hot water are distributed vertically the consumption and cost allocation is implemented differently. In the latter case, generally cost allocators at the radiators are used. The reason is that in buildings with vertical distribution each ascending pipe serves heat transfer systems (e.g. radiators) in different units on different floors and therefore several meters would be needed for one building unit.

Very detailed information on possibilities of cost allocation can be found in Austria. In the Austrian "Heizkostenabrechnungsgesetz" (Heating Cost Accounting Act) it is defined that between 55 % and 75 % of the total energy costs (for heating) must be allocated by individual meters and the rest is allocated on the basis of heated living space. The exact values must be negotiated between the energy supply company and the heat consumer in a written contract. If no agreement can be found, 65 % are allocated by measured consumption and 35 % based on heated living area. Similar explanations and definitions can be found in Germany in the "Heizkostenverordnung" (Heating Costs Ordinance).

The regulation and rules in Spain on the other hand are vague. Usually, the complete building is seen as the supply point and no measuring of individual consumption is foreseen. Distribution between different independent units inside the building can be carried out by accounting systems or by percentage distributions based on parameters like the conditioned floor space.

In most of the ten focus countries, individual consumption metering in multi-apartment and multi-purpose buildings with DHC supply is regulated. Exceptions are Finland, Lithuania and Sweden. In all other countries, the regulation mainly follows the requirements of the EED. The status is summarized in Table 16.

Table 16: Detailed overview of regulations on individual consumption metering in multi-apartment and multi-purpose buildings with DHC supply in the ten focus countries (Source: Own survey with national DHC stakeholders)

Country	Individual heat metering
Bulgaria	Metering of individual consumption is regulated. However, it is limited to multi-apartment and multi-purpose buildings in which horizontal heating installations exist. In multi-apartment buildings with vertical installations heat is only metered at the inlet while the consumption/ cost distribution for each apartment/unit is performed by heat cost allocators. Detailed descriptions of practical issues related to the distribution in buildings with vertical installations can be found in the ECJ joined Cases C-708/17, C-725/17, EVN Bulgaria Toplofikatsia.
Denmark	Metering of individual consumption is regulated. If technically feasible/ possible DHC companies deliver heat and cold to each apartment or building section separately. This is technically feasible and done in buildings with horizontal distribution systems. In these cases, heat and cold supply is measured at each supply point.
Finland	Metering of individual consumption is not regulated.
France	Metering of individual consumption is regulated. Since 25th October 2020, individual consumption metering for each building unit is mandatory if it is technically and economically feasible. Details can be found in the Evolution of Housing, Urban Planning and Digital Sectors Act (loi ELAN n°2018-1021) from 23rd November 2018 and its application decree n°2019-496 from 22nd May 2019. Technical details are defined in an application decree published on 6th September 2019.
Germany	Metering of individual consumption is regulated. It is specified in Article 5 of the HeizkostenV (decree on heat cost allocation). Heat meters or heat cost allocators shall be used to record the proportional heat consumption, and hot water meters or other suitable equipment shall be used to record the proportional hot water consumption. Unless calibration regulations apply, only such equipment may be used for recording consumption for which expert bodies have confirmed that it complies with the recognized rules of technology or that its suitability has been proven in some other way. The equipment must be suitable for the respective heating system and must be installed in such a way that its technically perfect function is guaranteed.
Lithuania	Metering of individual consumption is not regulated. However, there are rules defined for the allocation of the heat quantities consumed in a

Country	Individual heat metering
	building and therefore also for the heating costs. The Law on Heat as of 20 May 2003 refers to methods recommended by the National Commission for Energy Control and Prices, which also needs to approve other/ new methods for energy and cost allocation. The method to be applied must be selected by a majority of apartment owners of building and is also depending on the type of measurement devices used and heating/ hot water system installed.
Poland	Metering of individual consumption (in multi-user buildings) is regulated in Article 45a of the Energy Law: the owners or administrators of these buildings must equip the buildings with meters and establish a settlement system, which allows the cost allocation for each user.
Slovakia	Metering of individual consumption is regulated in the Heating Energy Act No. 657/2004 Coll[48]. It contains detailed information on obligations concerning the supply of domestic hot water (§ 17) temperature assurance, measuring heat quantities, volumes (also from cold water used for providing domestic hot water). Measuring heat for space heating is described in § 18. It includes rules on individual metering and alternative measures for cost allocation. Rules on individual metering do not apply for buildings with a total floor area of less than 500 m². So far, only annual reading and billing is mandatory.
Sweden	Metering of individual consumption is not regulated.
The Netherlands	Metering of individual consumption is regulated. Sub-metering is in line with the EED. If technically and economically feasible, individual consumption meters are installed to measure the consumption of heating, cooling, or hot water for each building unit. Otherwise, individual heat cost allocators are used for measuring heat consumption at each radiator. If even the cost allocators are not cost-efficient, alternative cost-efficient methods of individual heat consumption measurement can be considered.

B.1.1.2.3 **Predominant method for heat metering**

From a technical point of view today, there are a wide variety of different ways to meter district heating and cooling. Metering options include [43]:

- metering the water flow rate and the temperature differential between the inlet and the outlet (supply and return pipe) and then to calculate the extracted heat on the basis of these parameters (integration unit);
- metering the water flow rate and the temperature level of the inlet (encouraging consumers to maximise the extracted heat from a given water flow at a given temperature level);
- metering the water flow rate only (encouraging consumers to maximise the extracted heat from a given water flow).
- And there are also systems where district heating is charged on the basis of a set return temperature (discouraging consumers to take large volumes of water while returning it at a high temperature level)[49].

[48] https://www.zakonypreludi.sk/zz/2004-657

[49] More technical details on advantages of the minimization of the return temperature are provided in block C.

Technologies for automated meter readings from district heating systems are based on either radio communication, communication over the electricity network (Power Line Communication), or mobile communication through a point-to-point solution (P2P) [44].

In the following the **predominant method for heat metering** is compared. A detailed overview is provided in Figure 44 and in the tables in Annex 4. The most common metering method (19 out of 31 countries) is measuring the water flow rate and the temperature differential between the inlet and the outlet. This means that in the majority of countries heat consumption is measured with the most adequate metering method. Metering the water flow rate and the temperature level of the inlet (option b in Figure 44) is only applied in Greece. Metering the water flow rate only (option c in Figure 44) is the dominating method in only three countries (Italy, UK, Iceland). For eight countries information is missing. However, this mainly applies to countries in which DHC plays no or only a minor role in the heating sector (e.g. Cyprus, Portugal, Malta, Croatia).

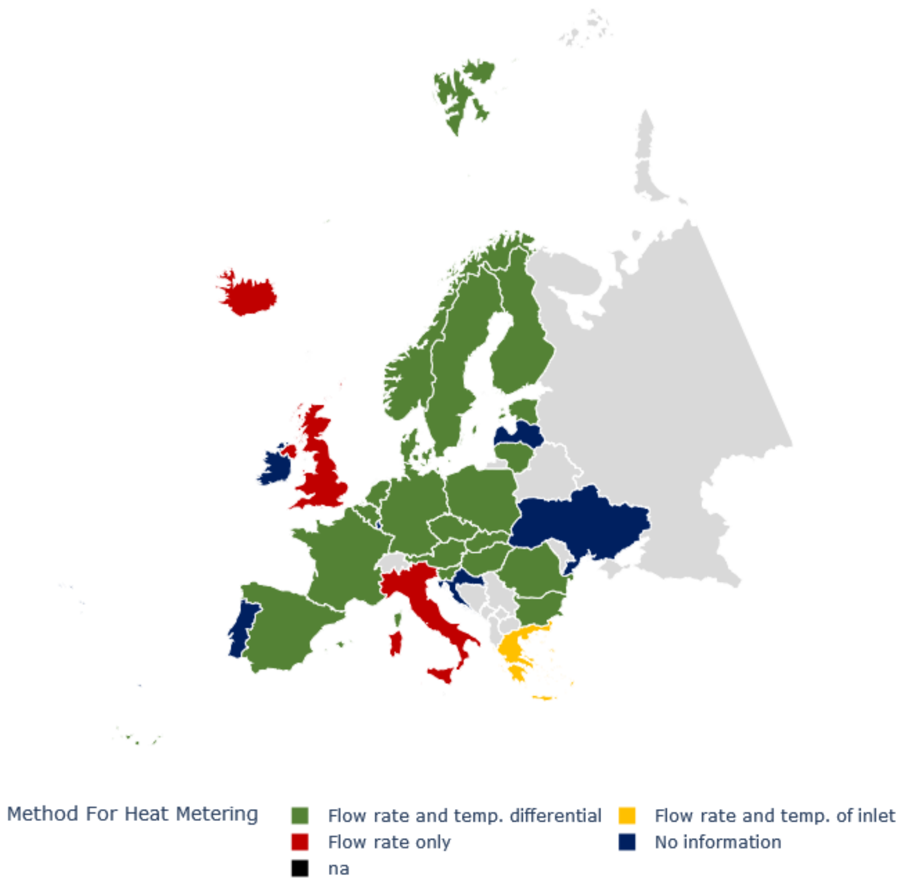


Figure 44: Map of the predominant method for heat metering (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

B.1.1.2.4 **Smart meters and remote metering/ reading**

Smart heat meters not only measure (and save) the consumed heat. They can be integrated in communication networks and can provide real time consumption information for final customers, but also to energy suppliers. They allow remote reading of meters for billing purposes. Thereby they can reduce the effort and expenditure for meter reading but can also help to detect faults faster.

In the following the status of smart heat meter application and regulation as well as remote metering and reading is described. In most countries **smart meters are not yet widespread** in district heating or cooling systems. However, there are **pilot projects in almost all countries** and some ambitious projects and roll outs of single DHC-companies. In Iceland for instance some DH-companies started to equip each supply point/ customer with smart meters.

Figure 45 provides an overview of (ambitious) **roll-outs of smart heat meters**. Even though smart metering is not regulated in most countries, in some countries there is an ambitious roll-out of that type of meters. These roll-outs are often driven by DHC companies, which see a great benefit and cost-saving potentials in smart metering due to improved system performance and cost savings in the reading routines.

Ambitious role outs of smart meters are only recorded in eight countries (Belgium, Denmark, Estonia, Finland, France, Lithuania, Poland, Iceland). In Iceland and Denmark, the role out is mainly driven by DHC-companies without any obligation to install smart meters. The installation is mainly driven by the fact that smart meters allow for a better understanding and optimisation of the systems, the possibility to control return flow temperatures and thereby increasing the efficiency. In addition, smart meters are a prerequisite to implement new tariffs. In most other countries, smart meters are mandatory only in new buildings or when heat meters must be replaced. For seven countries no detailed information is available. In the sixteen remaining countries, smart meters are not used at all or only in some pilot projects. In Slovakia, smart meters are not mandatory yet, but also used more widespread than just in pilot projects (approx. 5 % of the heat consumption in DH-systems is subject to smart meter reading).

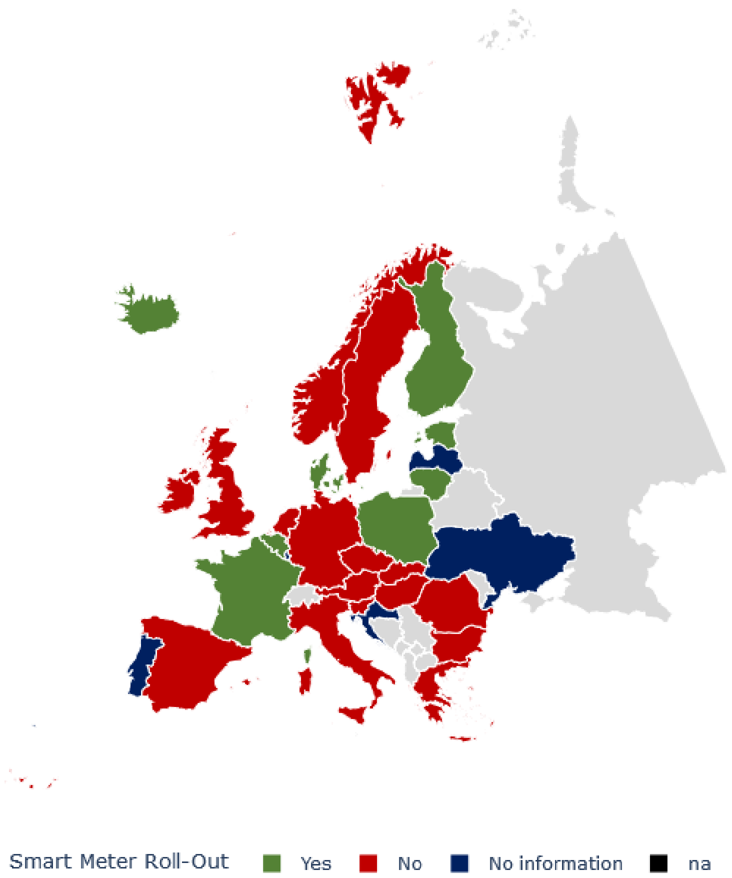


Figure 45: Map of (ambitious) roll-outs of smart and remote meters (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

Information on **regulation of remote metering/reading** is only available for three countries (Belgium (Flanders), Estonia and Lithuania; see Figure 46). In Estonia and Lithuania smart meters are mandatory. In 17 countries no regulation is in place. For eleven countries, no information is available.

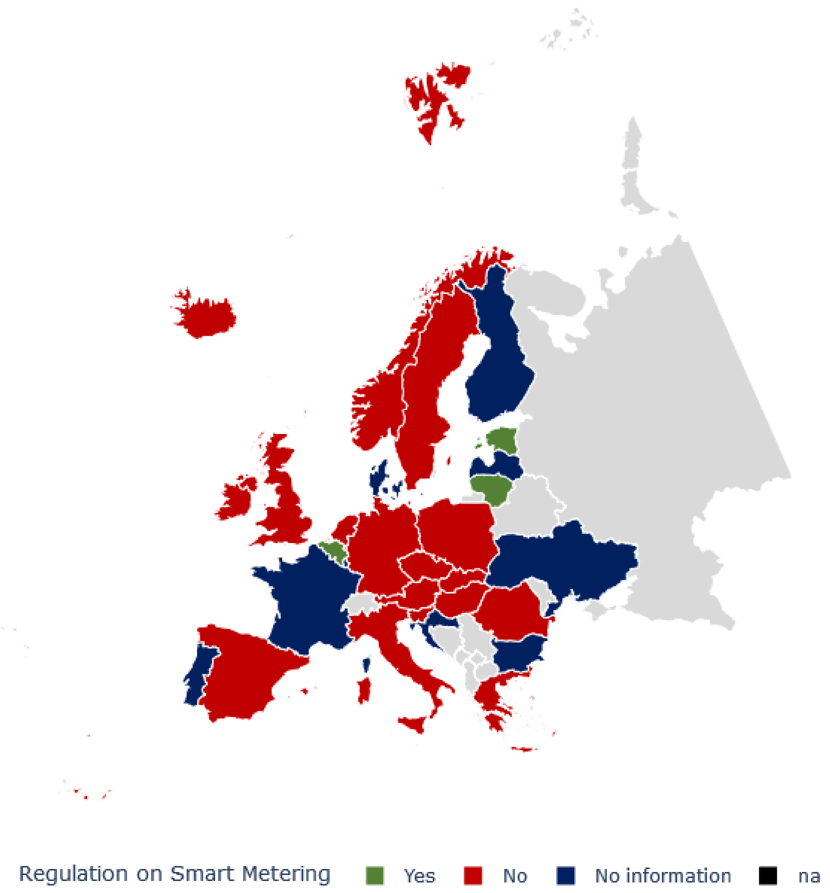


Figure 46: Map of the status of regulation of smart and remote meters (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

The status of smart heat meter role out and regulation on remote metering/ reading in the ten focus countries is summarized in Table 17. Smart metering is only mandatory in one of the focus countries (Lithuania). In Finland, 84 % of the installed meters can provide hourly metering data and can be considered as smart meters, even though smart metering is voluntary.. Another 15 % of the heat meters can provide monthly data.

Although Germany has a large DHC market, smart metering and remote reading are still not quite common. Also, in the other focus countries smart meters are mainly used in pilot projects and have a maximum market share of 1 % to 5 %.

Table 17: Detailed overview of regulations on and status of smart heat metering and remote reading in the ten focus countries (Source: Own survey with national DHC stakeholders)

Country	Smart Meters and remote metering/reading
Bulgaria	Smart heat meters: only used in pilot projects Remote metering/reading: No information available
Denmark	Smart heat meters: Smart meters are not mandatory. However, many companies already use them. The meters installed allow to use return temperatures for pricing and incentives and a few utilities apply hourly or seasonal prices.

Country	Smart Meters and remote metering/reading
	Remote metering/reading: Heat meters with remote reading are widespread.
Finland	Smart heat meters: Smart meters are widely used. The use is voluntary but nowadays approx. 84 % of heat sales are metered hourly and another 15 % of installed meters are remotely readable on a monthly basis. In addition, many DH companies offer online services to their customers and provide the consumption information from the meters. Remote metering/reading: most heat meters (99 %) installed are remotely readable (either hourly or monthly readings)
France	Smart heat meters: Smart heat meters are used in pilot projects. Remote metering/reading: Most heat meters are automatic and connected to digital tools of the DH-companies
Germany	Smart heat meters: Smart heat meters are used in pilot projects. Remote metering/reading: Remote metering/ reading is only applied in pilot projects.
Lithuania	Smart heat meters: Smart Meters are mandatory Remote metering/reading: No detailed information provided, but as smart meters are mandatory it can be assumed that most meters are remotely readable.
Poland	Smart heat meters: Smart heat meters have not been mandatory yet, but they are used generally Remote metering/reading: No detailed information provided, but as smart meters are mainly used it can be assumed that most meters are remotely readable.
Slovakia	Smart heat meters: smart meters are not mandatory. However, they are applied in more than just a few pilot projects (covering about 5 % of the delivered DH volume) Remote metering/reading: No detailed information provided
Sweden	Smart heat meters: Smart meters are currently used on a voluntary/ industry standard basis Remote metering/reading: No detailed information provided
The Netherlands	Smart heat meters: Smart meters are now used in about 1 % of the connected buildings. Remote metering/reading: No detailed information provided

B.1.2 Measuring DHC supply for statistical reporting purposes

Directive 2012/27/EU on energy efficiency, amended by Directive 2018/2002, requires Member States to submit annual statistics on district heating and cooling production and capacities, in relation to total heating and cooling production and capacities (Art. 24 (6) EED). To streamline this reporting requirement, Eurostat provides a template for district heating and cooling data reporting[50], including instructions on how data requirements are defined, and which methodology data compilation should be based on [45].

[50] https://ec.europa.eu/eurostat/documents/38154/42195/DH-DC-reporting-template.xlsx/f200efa0-d5cf-450c-bfed-461c109e46fe

The following chapter investigates the legal requirements Member States as well as the UK, Iceland, Norway, and Ukraine apply for providing statistical data. According to the survey results in 15 Member States as well as in the UK and Norway legal **obligations to collect the data in accordance with the EED** are in place (see Figure 47 and Annex 4). In Ireland, Italy, the Netherlands and Spain no legal obligation exists. In Spain, however, measure 1.6 "Framework for the development of thermal renewable energies" of the PNIEC[51] ensures data collection and reporting and thereby compliance with the reporting requirements of the EU. For eight Member States no information was provided in the survey. In most countries with a legal obligation to collect data in accordance with the EED also data on renewable sources is collected and an obligation to report the use of renewables in DHC is in place.

In addition, **15 countries have obligations in place to report renewable sources used for DHC by type**. However, the level of detail differs and usually considers local conditions. In countries, where biomass plays a major role in DHC generation, biomass is divided in sub-types. On the other hand, other renewable sources, which only play a minor role are often aggregated. In Lithuania, which has no obligation to collect DHC statistics as defined in the EED, national obligations to collect detailed statistics on renewables used in DHC generation exist. In two countries no obligation to report renewable sources by type exists and in 14 countries, no information is available at all.

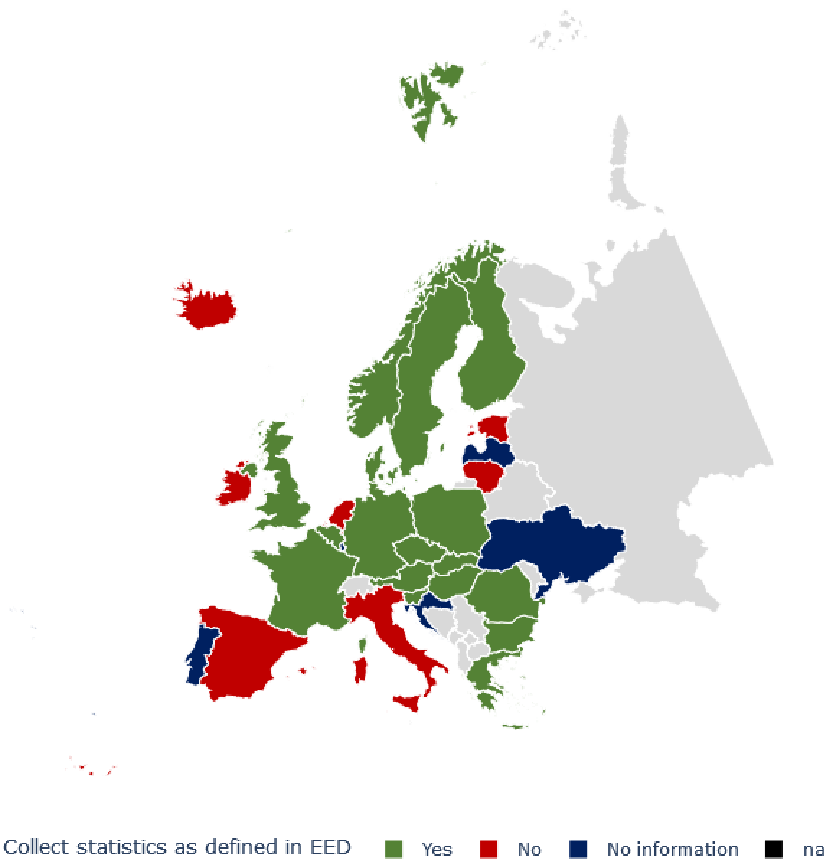


Figure 47: Map of the legal obligations to collect DHC statistics as defined in the EED (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

[51] Plan Nacional Integrado de Energía y Clima (National energy and climate plan)

The responsibility for data collection and reporting is distributed among very different actors in the analysed countries (see Annex 4). Often national ministries, in most cases the ministries responsible for the energy sector and/ or environment are responsible for data collection and reporting (e.g. in Austria, Bulgaria, France, Hungary and UK). In several countries also other bodies support the ministry in data collection and reporting (e.g. France). In Belgium (Flanders), Denmark, Slovakia and Sweden Energy Agencies collect and report DHC data. Furthermore, Energy Regulatory Offices (Czech Republic, Poland) as well as Statistical Offices (Finland, Germany) fulfil the reporting obligations defined in the EED.

In Annex 3, existing **statistical sources** for DHC in the Member States, the UK, Iceland, Norway, and Ukraine are listed. Additionally, further information on the statistical sources and their methods can be found in the country factsheets in Annex 1.

Methodologically, the statistical sources usually classify statistics by topics (e.g. environment or energy, society, economy, enterprises, regions). Heating and cooling are mostly classified under the topic "energy" or "environment". In addition, there are quality assurance procedures in all countries that comply with the standards of the European Statistical System[52] (ESS) and the European Statistics Code of Practice[53] (CoP). These reports include detailed information on methodology, timeliness, and comparability. The 16 principles of the CoP range from professional independence to accessibility and clarity of statistics. All statistical offices indicate that they apply the methods and principles of the ESS and the CoP. Moreover, the majority[54] highlight some principles, especially the principles focusing on the quality of the output, on their website.

Additional to the CoP, a few statistical offices[55] also point out that they implemented a quality management system, conduct internal audits (e.g. in Ireland and Italy) or having an additional institution monitor quality, as the Advisory Board of Official Statistics does in Finland. Besides these methodologies, mainly focusing on quality assurance, few information on statistical methods are available. Information on specific statistical approaches are only given for individual topics (e.g. methods for estimating the consumption of biomass wood pallets in Denmark[56]), but none of the national statistical offices state any specific methods referring to DHC statistics.

In many countries, the statistical office does not (yet) **publish statistics on DHC**. In most cases, only statistics on heat or energy in general are published (at the present time). However, in some countries, there are further associations that publish explicit data on DHC, e.g. AGFW in Germany or the Danish Energy Agency (see Annex 3). These associations provide information on their statistical methods, which are generally in line with the methods of the national statistical offices, but they also do not have specific information for DHC statistics.

DHC statistics are mainly based on market data provided by market participants. Figure 48 provides an overview whether DHC companies are **legally obliged to provide data on DHC generation and supply**. An overview of which specific data is or has to be provided is provided in Annex 4. For seven countries the information is not available. Only in Ireland and Italy there is no obligation for DHC companies to provide data. In all other countries DHC companies must provide data and information about their activities (however, in Spain this applies only to companies, which run a DHC system under public concession). However, the level of detail differs. While in the UK and Norway only heat

[52] https://ec.europa.eu/eurostat/web/european-statistical-system/overview
[53] https://ec.europa.eu/eurostat/web/products-catalogues/-/KS-02-18-142
[54] Statistical offices in Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Poland, Rumania, Slovakia, Slovenia, Sweden, Norway, Iceland, Ukraine, UK
[55] Statistical offices in Bulgaria, Croatia, Lithuania, The Netherlands, Poland, Portugal, Romania and Slovakia publish results of the peer review and the offices in Belgium, Germany and Greece mention it.
[56] https://ens.dk/sites/ens.dk/files/Statistik/metode_flis.pdf

production and supply and in Slovakia heat supply and losses are reported in all other countries with reporting obligations at least heat production, heat supply and losses and in many countries even more parameters are provided. Heat supply is also reported by sector in several countries. Additional information, which often is reported include prices (e.g. Czech Republic, Denmark, and Finland), the share of renewables in heat generation or network lengths and number of connected customers. Heat generation capacities were only mentioned for Germany in the survey. Furthermore, countries differ in the level of detail how renewables are reported. While in some countries almost all different renewable sources are reported, in other countries only the main renewables fractions (e.g. biomass in Finland) are reported in detail and all other renewable energy sources are summarized. Furthermore, it has to be mentioned that not all data collected from DHC companies is publicly available in all countries.

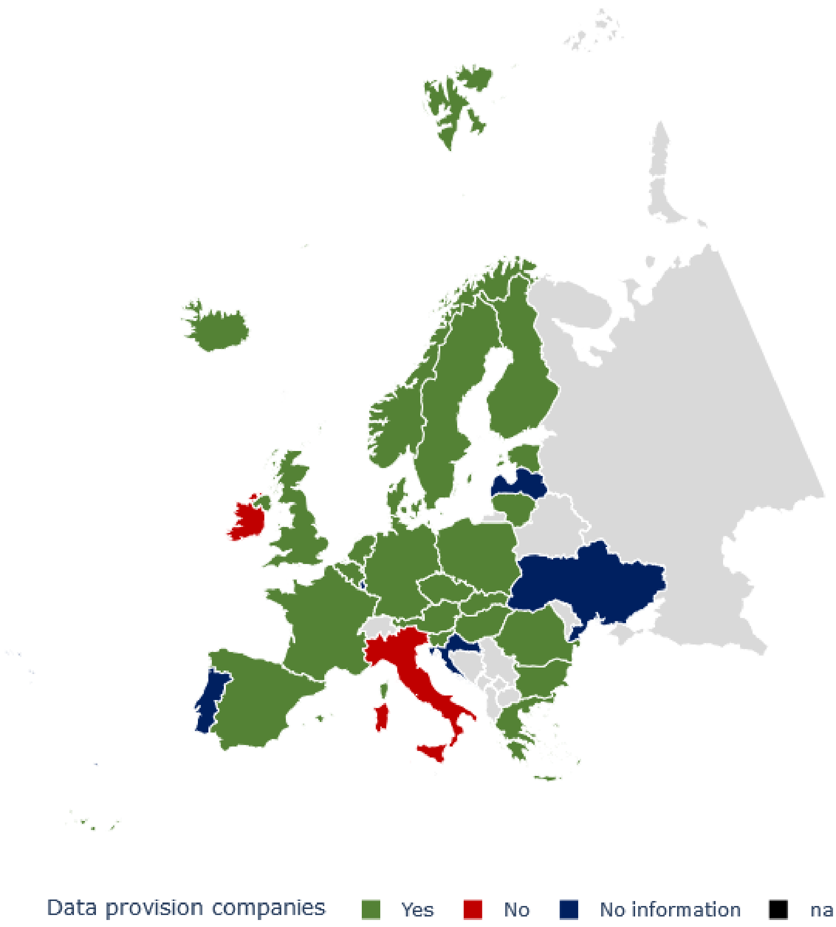


Figure 48: Map of the legal obligations for DHC companies to provide data (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

B.2 Pricing regimes and support schemes

B.2.1 Pricing regime

B.2.1.1 Regulatory requirements on pricing

The European regulation on price transparency (Regulation 2016/1952[57]) is only covering electricity and gas prices while district heating and cooling prices are excluded. For that reason, Eurostat does not publish district heating and cooling prices. However, for many European Member States as well as UK, Iceland and Norway average district heating prices are included in the biannual country-by-country survey, but not providing references to specific national data sources. In 2016 a collection of long time series of national average district heating prices in Europe has been provided by Werner [46].

The formation of district heating and cooling prices differs between countries and mainly **depends on the fundamental principles the sector is regulated upon (profit-orientation vs. non-profit principle)** and the specific design of the regulatory framework. In most European countries, the district heating and cooling sector is regarded as natural monopoly. Due to lacking competition on the retail market, a certain level of price control (ex-ante or ex-post) is in place in order to protect connected consumers against unjustified price increases. Price regulation might also be implemented in countries where municipalities foresee zoning of district heating priority[58]. In such a case, as e.g. implemented in some Scandinavian and Baltic regions, competition is restricted, leaving building owners as customers who do not have the right to disconnect from the DH system.

The following chapter investigates how Member States regulate pricing for DHC. This section is based on a detailed literature review and is completed by the input collected through the survey carried out in the various countries of the study. Figure 49 and Annex 4 provide an overview of regulations on district heating pricing in the Member States as well as UK, Iceland, Norway, and Ukraine.

DH prices can be **regulated or liberalised**. Prices may be subject to **price control** or not. Price control can be **ex-ante or ex-post**. Ex-ante means that prices need to be approved by an authority before they are published and applied. Ex-post means that prices are controlled ex-post. In such a case the competent authority checks ex-post whether the prices were reasonable (whereby the question of what price level is at all proportionate must be legally secured). Ex-post price control often only takes place if there are reasonable grounds to suspect that a district heating supplier has charged disproportionate prices in the past. Moreover, price control could be mandatory for all suppliers or only on request.

[57] Regulation (EU) 2016/1952 of the European Parliament and of the Council of 26 October 2016 on European statistics on natural gas and electricity prices and repealing Directive 2008/92/EC
[58] Zoning is given where a municipality obliges building owners to connect to a district heating network in a designated zone.

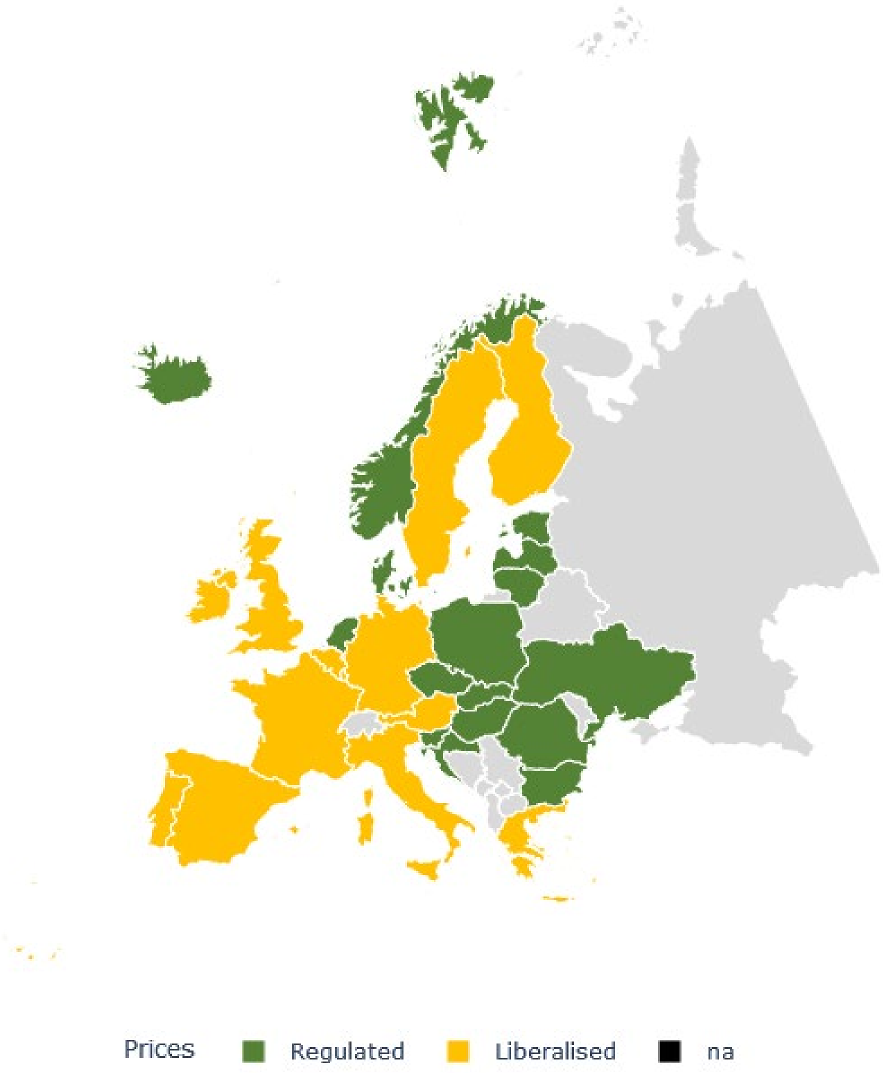


Figure 49: Map of the price regulation (regulated, liberalized) (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

Table 18 gives a more detailed overview of the price regulations for district heating and cooling in the ten focus countries. A tabular overview of the price regulations in all Member States, the UK, Iceland, Norway and Ukraine is provided in Annex 4.

Table 18: Detailed overview of price regulations in the 10 focus countries (Source: Own survey with input from national DHC stakeholders)

Country	Price regulation
Bulgaria	DH prices are regulated by the Energy and Water Regulatory Commission (EWRC) in accordance with the Energy Sector Act[59] and the Ordinance No 5 as of 23 January 2014 for the heat energy prices regulation. Prices are regulated ex-ante for all DH suppliers. Price regulation is based on the Capital Asset Pricing Model (CAPM) method. EWRC has the right to exclude from the pricing model certain cost elements in order to retain the regulated prices for heat at reasonable

[59] https://www.me.government.bg/en/files/download?hash=75c204b53f734ec7bb86aec1a6fb0788a2c8a4fc

Country	Price regulation
	levels. During the pricing period EWRC is entitled to adjust prices if gas or CO_2 prices change significantly.
Denmark	DH prices are regulated. According to §20 of the Danish Heat Supply Act of 24 July 2000, DH tariffs, cost distribution, and other conditions associated to the DH supply have to be submitted to the Energy Regulatory Authority[60]. The Regulatory Authority supervises that only cost components are included that are directly linked to DH. Due to non-profit rules (which are laid down in the Danish Heat Supply Act) pricing is more or less on cost-plus basis (based on the justified costs of heat production, distribution, maintenance/ upgrades, depreciation and maximum return on capital). Pricing is affected by transparency rules. The Energy Regulatory Authority establishes a public register for tariffs and publishes a representative summary of those at least once a year which puts a certain pressure on the district heating suppliers to keep prices low. Pricing is also affected by the general principle that district heating grids are developed only where they meet the criteria of a standardized assessment which indicates that district heating will provide cheaper heat than alternative available options [39].
Finland	DH pricing is liberalised, but the dominant market position requires pricing to be on equal terms for all customers. Based on the Competition Law the Finnish Competition and Consumer Authority can initiate investigations if they suspect an abuse of pricing considering the dominant market position of DH companies by charging unreasonably high prices [39].
France	DH pricing is liberalised, but as a public service, pricing should be on equal terms for all the customers benefiting from the same service. This can however lead to tariff differences on the same DH networks in some specific cases (for clients connected after a ramp-up period for example). When a private company operates a public DHC network prices are negotiated with the local public authority during the tender procedure and will then be incorporated in the agreement between the contractual partners, for the duration of the agreement. Prices can be adjusted following specific indexing formulas and revised in certain circumstances defined in the contract. For public DHC networks operated by the local authority and private DHC networks, prices are also set in the terms and conditions of the service and may be revised at the owner's discretion notwithstanding the right of customers to disconnect or unless otherwise provided by the terms and conditions.
Germany	DH pricing is liberalized. Due to the high investment costs associated with district heating, the " Ordinance on General Terms and Conditions for the Supply of District Heating (AVBFernwärmeV)" allows contract terms of up to ten years for heat supply contracts. Due to the long contract term, heat supply contracts may typically contain price change clauses. If prices are changed, DH suppliers must state clearly to their customers the relevant calculation factors used to set a price, and the breakdown of the fuel costs. However, there are many complaints about lacking transparency on pricing. In recent years the Federal Cartel

[60] https://forsyningstilsynet.dk

Country	Price regulation
	Office initiated proceedings against several DH suppliers for excessive pricing [47]. However, this ex-post control is only on request.
Lithuania	DH prices are regulated. According to the Lithuanian Law on Heat[61] prices are set on cost-plus basis. The National Energy Regulatory Council (NERC) approves the methodologies DH companies apply for calculating DH prices. Prices are controlled ex-ante by the National Control Commission for Prices and Energy (NCC). Prices are set for a 3-5 years period. Prices are recalculated annually if the amount of heat sold, inflation, fuel structure and other factors change.
Poland	DH prices are regulated based on cost-plus methodology. DH suppliers are required to submit their tariff calculations for approval to the Energy Regulatory Office (URE). Tariff setting is based on justified costs of heat production and distribution, justified costs of modernisation, development and environmental protection, as well as the return on capital [39]. Prices are calculated for one year. Detailed rules for the development and calculation of tariffs are laid down in the Polish Energy Law and the Ordinance on Prices and Tariffs.
Slovakia	DH prices are regulated. Price regulation is established by the Act on Regulation in Network Industries (Act 25/212) and the Decree 248/216 Coll. Prices are controlled ex-post by the Office for Network Industries (URSO). Tariff setting is based on the cost-plus method.
Sweden	DH pricing is liberalized. However, the District Heating Board, an independent organizational unit of the Swedish Energy Agency, mediates negotiations between DH suppliers and customers about prices and other conditions, as well as between surplus heat producers and DH suppliers. It creates incentives for the self-regulation of DH companies by increasing the public visibility of complaints, and pressuring companies to make price strategies transparent without the use of formal price regulation. DH suppliers are required to submit annual reports so that prices can be compared [39].
The Netherlands	DH prices are regulated. The Netherlands Authority for Consumers and Markets (ACM, which is the regulatory body) sets maximum DH tariffs each year based on the price of natural gas. In this regard the gas price constitutes a price cap. According to the Dutch Heat Law (Warmtewed) pricing is underlying the principle, that DH consumers must not pay more than they would if they had a domestic gas condensing boiler, which serves as reference heating system. This "No-More-Than-Alternative" principle is laid down as one of the key principles of the Heat Act adopted in 2014. However, in 2019, the revised Heat Act extended the price-cap regulation by introducing more flexible elements and by acknowledging that the previous strict and rigid price cap (reference natural gas) jeopardizes the expansion of district heating. Furthermore, it was argued that the use of natural gas as a reference for determining the heat price does not reflect climate protection targets. Under the revised law, ACM has set tariff caps on the supply of heat at various temperatures, as well as for the different types of heat exchangers, for connections, and for disconnections. The new tariffs apply from 2020.[62] Furthermore, an experimentation clause has been introduced in which deviations from the legal conditions (e.g. maximum

[61] http://extwprlegs1.fao.org/docs/pdf/lit67651E.pdf
[62] https://www.acm.nl/en/publications/revised-dutch-heat-act-effect and [215]

Country	Price regulation
	heat prices) can be made. Specifically, the focus here is on projects for the use of renewable energies or the efficient operation of a heating network.

Main findings

In more than half of the analysed countries DH prices as well as the mechanism for setting prices is regulated whereby the depth of regulation is differing substantially. In less than half of the countries DH prices are liberalized. Most of the countries have some form of price control. Price control is carried out ex-ante and ex-post. In some countries with price control, this control is mandatory for all DH suppliers. In other countries price control is only on request. The latter applies when the authority checks the prices of only selected suppliers, e.g. due to complaints from individual customers.

In Austria, price control is under the responsibility of the regions (Bundesländer). Some of the regions have implemented ex-ante price control and in other states prices are liberalized [48]. In Spain prices are regulated for DH networks that are developed under a concession regime while prices are liberalized for private networks.

Regarding the ten focus countries examined, two main concepts can be distinguished in price regulation:

1. Liberalised DH prices with ex-post price control on request

   In Finland, Germany and Sweden DH **prices are fully liberalized and prices are defined on the market**. In order to protect customers from excessive prices, competition authorities are entitled to investigate prices in the case of DH suppliers are suspected of misusing their dominant market position by charging disproportionate high prices. Thus, price control is ex-post and **on request only when there is a reasonable suspicion of abuse of pricing**.

   In Sweden, some form of indirect price control is introduced by stringent transparency rules. DH suppliers must provide to the public information about DH prices and price setting mechanisms. Moreover, DH companies have to submit annual reports so that prices can be easily compared by the consumers. The strategy behind ensuring transparency is to make prices and pricing mechanisms so visible and comprehensible that it would be easy for consumers to detect abuse. As most Swedish DH suppliers are municipally owned, they are more or less prevented from making excess profit which also contributes to be an effective protection against monopoly abuse.

2. Regulated DH prices with mandatory price control

   In Bulgaria, Denmark, Lithuania, Poland, Slovakia and the Netherlands **DH prices are regulated by law**. DH prices of all DH suppliers are controlled ex-ante or ex-post by the regulatory authority (mandatory price control). Calculating DH prices is based on a regulated methodology. Prices are calculated for one year (e.g. Poland), or a longer period (e.g. Lithuania). In the latter case, prices generally can be adjusted if specific factors (e.g. gas price, CO_2 price, inflation) change over the time.

   In Denmark, apart from price control, additional factors contribute to low prices. Due to the non-profit rule imposed by the Danish Heat Supply Act, DH supply and grid operation are either performed by consumer-owned cooperatives or municipal-owned companies. Similar to Sweden**, this ownership structure prevents the DH sector to abuse its dominant market position**. Furthermore, for new investments, DH operators are required to conduct a comprehensive socio-economic assessment including the effect on heat prices. DH systems can only be built where the assessment indicates that DH will provide cheaper heat than alternative available options. And finally, transparency rules similar to Sweden (e.g. a public register for DH tariffs) puts pressure on the DH suppliers to keeps their prices low.

In France, indirect price control is introduced as part of the tendering and awarding process for the DH supply concession. Companies that apply for operating a public DHC network need to negotiate prices with the local public authority during the tender procedure. The negotiated price will then be incorporated in the concession agreement for the whole concession period (typically 20-30 years).

For some time, the Netherlands took the approach of capping the price of district heating so that a customer would not pay more for district heating than for heat supplied by a gas boiler.[63] However, this "**no-more-than-alternative**" principle was considered too restrictive to ensure significant district heating expansion. It was also criticized that the reference system (natural gas) is not compatible with climate targets. For this reason, the rigid price cap was abandoned, and a more flexible system introduced.

B.2.1.2 Pricing models and price components

Countries follow different price model approaches. **In countries with liberalised DH prices, prices more or less are formed on the market**. However, the Netherlands and Norway have / had introduced a price cap which is determined by the price of a reference fuel (NL gas, NO electricity), following a "No-More-Than-Alternative" approach.

In countries with explicit price regulation, a cost-plus method is usually applied. Cost-plus describes a method in which the price is determined by adding a specific mark-up to a product's unit cost. In the case of district heating and cooling the unit costs involve all expenses that a district heating or cooling supplier has had in the course of a given period or that it forecasts for a coming period. Relevant cost elements include fuel prices, investment and operational costs for the maintenance and further development of the complete infrastructure (generation, network, and supply), concession charges, metering etc. However, a pure cost-plus approach does not automatically provide incentives for an efficient district heating and cooling supply. For that reason, some countries have implemented in their pricing models elements of an incentive-based regulation. By benchmarking and/or indexing specific cost components over several years the district heating or cooling supplier has an incentive to keep its costs as low as possible (to increase its own profit). For example, the regulatory authority sets the initial cost level based on average comparative values and indexes it over a longer period. Various elements can be included in the indexing, e.g. the development of the average wage level, the inflation rate, or an efficiency factor (e.g. 1 % per year).

B.2.2 Targets and support schemes

In this section, provisions and goals of EU Member States regarding the annual increase of RES in the heating and cooling (H&C) sector are analysed. Subsequently, an overview is

[63] A similar approach is being taken in Norway. Customers that are obliged to connect to DH (mandatory connection customers) cannot be priced higher than the alternative cost of other heating sources (mainly electric heating) in the respective concession areas. The district heating price is therefore capped by electricity prices, including grid tariffs and electricity taxes (see NO Energy Act).

presented for the available support schemes to reach the defined goals with focus on the DHC sector.

B.2.2.1 National targets and estimated trajectories regarding annual increase of renewable energy in the heating and cooling sector

In order to meet the EU's energy and climate targets for 2030, EU Member States need to establish a 10-year integrated national energy and climate plan (NECP) for the period from 2021 to 2030. The NECPs demonstrate the approach and plans of Member States regarding energy efficiency, renewables, greenhouse gas emission reductions, interconnections as well as research and innovation. Member States had to submit the final version of their NECPs until 31 December 2019 to the European Commission (EC). Furthermore, a progress report must be submitted every 2 years. The NECPs of Member States are shared on the website of the EC [49]. At the time of writing this report (November 2020), NECPs from all 27 Member States were available on the EC's website. In order to also display the United Kingdom, which has not complied with its obligation to submit a NECP, the draft version of the UK´s NECP was used in this report [50].

In this section, the national targets and estimated trajectories in H&C and DHC sector in relation with requirements from Article 23 and Article 24 of the Renewable Energy Directive (RED) 2018/2001/EU [51] are brought together. The Article 23 of the RED states that in the period of 2021 to 2030, Member States should annually increase the RES share[64] in the H&C sector by at least 1.1 percentage points (pp) or by 1.3 pp if waste heat and cold are considered. The Article 24 of the RED, on the other hand, asks Member States inter alia to ensure the increase of RES share in the DHC sector by 1 ppt annually (the increase can be met by waste heat as well). The following section provides an insight to the national targets for increasing the share of RES in H&C and DHC sectors besides the overall targets.

Table 19 summarizes whether the RED II requirements have been fulfilled by Member States or not. An extended version of this table with more details on national targets and estimated trajectories for the annual increase of RES from respective NECPs can be found in Annex 5. In Table 19, only the 1.1 pp related targets (for MS not using waste heat and cold) are addressed. This is due to the fact that in order to correctly differentiate between the 1.1 pp and 1.3 pp targets, it would be required to include information about national history and future plans for the expansion of heat and cold power plants and the use of industrial waste heat. The analysis of the national efforts in increasing the share of RES in heating sector and in DHC shows that a considerable proportion of Member States are struggling to fulfil their targets. Therefore, it seems to be the natural consequence that objectives on the share of RES in DHC are even less often achieved by the Member States.

Table 19: Status of national targets for the annual increase of RES from respective NECPs

Member State	Target from RED Art. 23 fulfilled (RES share in H&C)?	Target from RED Art. 24 fulfilled (RES share in DHC)?
Austria	not clear in NECP	No
Belgium	not clear in NECP	No
Bulgaria	Yes	No
Croatia	No	Yes
Cyprus	No	No
Czech Republic	No	No
Denmark	Yes	No

[64] Exception I: RES share in H&C is already above 60%: average annual increase is fulfilled. Exception II: RES share in H&C is between 50 % and 60 %: increase must only be half of the average annual increase

Member State	Target from RED Art. 23 fulfilled (RES share in H&C)?	Target from RED Art. 24 fulfilled (RES share in DHC)?
Estonia	Yes	Yes
Finland	Yes	No
France	Yes	Yes
Germany	Yes	Yes
Greece	Yes	Yes
Hungary	No	Yes
Ireland	WEM: No / WAM: Yes	No
Italy	Yes	No
Latvia	Yes	Yes
Lithuania	Yes	No
Luxembourg	Yes	No
Malta	No	No
Netherlands	No	No
Poland	No	No
Portugal	No	No
Romania	No	No
Slovakia	No	Yes
Slovenia	No	Yes
Spain	Yes	No
Sweden	Yes	No
United Kingdom (draft)	No	Yes

B.2.2.2 National support schemes and supporting measures regarding district heating and cooling

This section aims to give an overview of support schemes and supporting measures for the DHC sector in EU Member States. Insight shall be given into national support schemes for DHC concerning the existence (see section A.3.2), the intensity and phasing, as well as the available (and /or spent) budget.

Support schemes are diversely structured and applied in EU Member States. In this report, in the first step solely the RES LEGAL database [52] was used to investigate national support schemes for the H&C sector in the Member States. In a next step, the information gathered from this database was supplemented as far as possible through the results of the comprehensive survey, which was conducted by the project consortium for all EU Member States in order to fill information gaps.

Concerning the support of DHC, the most widely used instruments are financing grants, premium tariffs, low interest loans and tax exemptions. Four types of support schemes have been distinguished. These include subsidies and financial incentives for:

- DHC grid infrastructure (Figure 50),
- renewable and efficient DHC generation (Figure 51),
- research, technology development and demonstration of innovative DHC systems (Figure 52), and
- connecting end users to DHC networks (Figure 53).

While the following figures refer only to the availability of the support schemes, a comprehensive analysis of them is provided in the Annex 4. According to the screened support schemes, subsidies and financial incentives targeting DHC grid infrastructure as well as renewable and efficient energy generation are largely available in most EU Member States. On the other hand, subsidies and financial incentives on research and innovation as well as on the connection of end users to DHC networks are less common in the majority of the Member States.

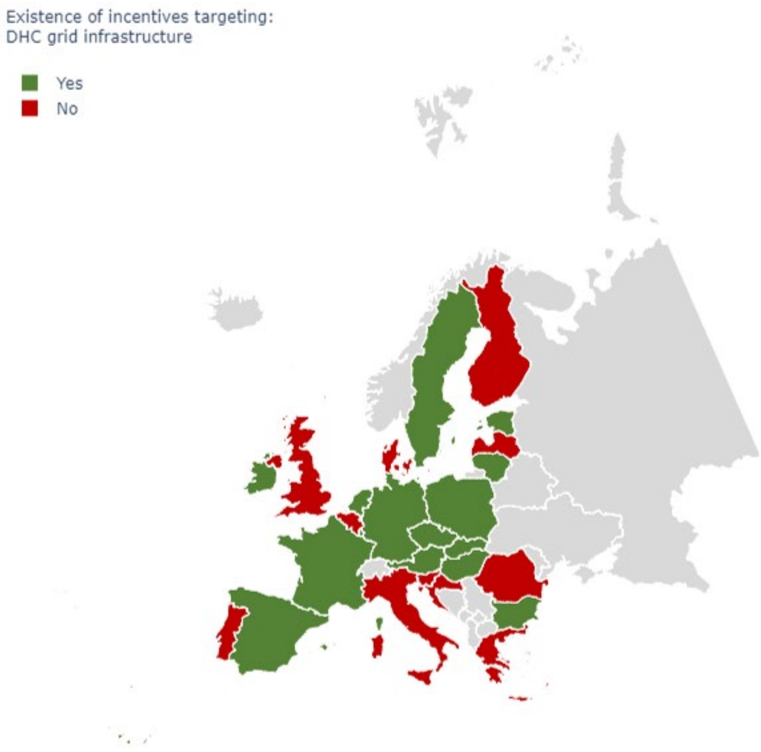


Figure 50: Overview on subsidies and financial incentives targeting DHC grid infrastructure (detailed information in Annex 4)

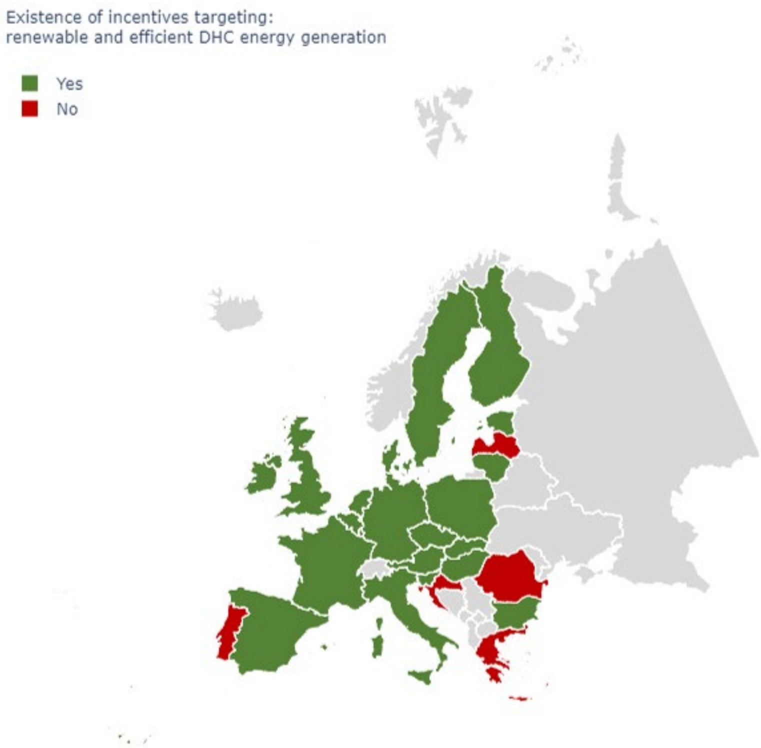


Figure 51: Overview on subsidies and financial incentives targeting renewable and efficient DHC energy generation (detailed information in Annex 4)

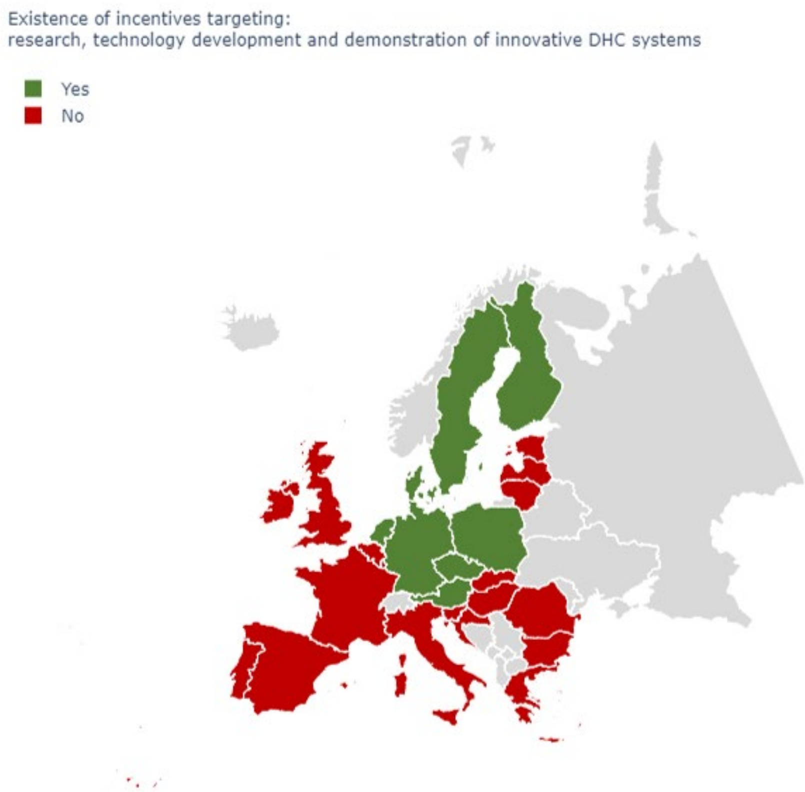


Figure 52: Overview on subsidies and financial incentives directly targeting research, technology development and demonstration of innovative DHC systems (detailed information in Annex 4)

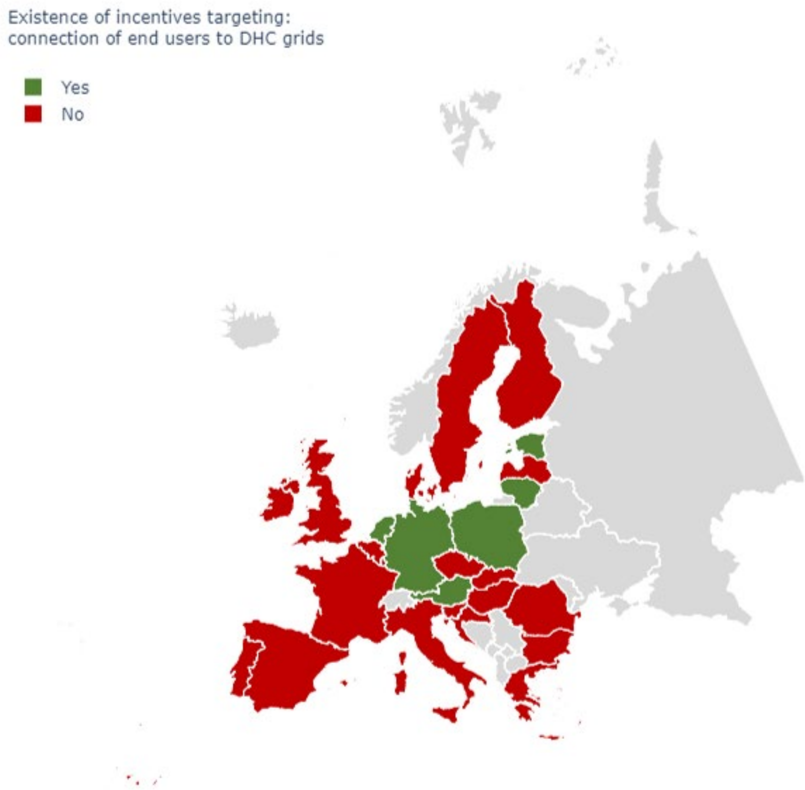


Figure 53: Overview on subsidies and financial incentives directly targeting connection of end users to DHC grids (detailed information in Annex 4)

B.3 Connection and access to DHC networks

B.3.1 Regulatory framework for third party access

B.3.1.1 Conceptual background

DHC systems are **natural monopolies** [53]. A natural monopoly exists whenever, due to high fixed costs and low marginal costs, it is cheaper if only one company and not several competing companies supply the market. Natural monopolies occur primarily in the area of grid-bound supply systems. In the energy sector, these include, for example, grid operation in the electricity, gas, and district heating markets. In all these markets it would not make sense for several companies within a city or region to operate supply networks in parallel. Instead, parallel operation would lead to higher overall costs. Due to lower connection densities (the connections would then be distributed between the two or more parallel networks), the network costs per kilowatt hour would also rise.

To prevent natural monopolists from abusing their market dominance, the markets concerned require a **minimum level of regulation**. In particular, this applies to network operation. The core of regulation is typically the connection and usage conditions of the infrastructure.

The liberalization (market entry or exit) of the electricity and gas sectors has introduced competition in the respective markets on both the supply side (generation) and the demand side (retail). Different producers can feed in energy at different grid levels, consumers can choose between different suppliers. In the DHC market, a comparable opening of the market is lacking in most European countries. In many European countries, the **DHC sector is seen as an integrated infrastructure in which generation, grid operation and distribution are operated in an integrated manner by one company** in a city or region.

However, while the DHC grid can be regarded as a natural monopoly, this does not automatically apply to the other elements of the supply chain, e.g. the production side and/ or retail. For these elements a second competitor would not face high sunk costs. While technical restrictions, especially for smaller grids, might inhibit an economic operation of more than one production unit, a competitive heat production market is generally possible in larger networks.

The Renewable Energy Directive II (Directive (EU) 2018/2001) calls on the Member States to increase the share of renewable energies in the grid-based heating and cooling supply. Art. 24 of RED-II opens up two ways of doing this,

- either by the implementation of measures aimed at increasing the share of RES in heating and cooling networks by 1 % per year,

- or by granting producers of renewable heat/cold or waste heat access to the grid (Third Party Access TPA).

So far, there is only little scientific literature **on third party access to heating and cooling networks**. In particular, cooling networks are almost never explicitly mentioned in this context. A distinction is made between network access models and single buyer models [54] or "regulated" and "negotiated" TPA [55].

- Network Access Model: Producers have access to heat networks provided that they supply heat to their own end-customers, which could be new customers or existing customers of the incumbent vertically integrated grid operator

- Single Buyer Model: Producers are entitled to feed heat into a DH grid while the grid operator (single buyer) is obliged to accept and pay for the heat. Under such an approach, consumers do not have any choice between different suppliers, they are all supplied by the single buyer. Regarding grid access different models apply:

- **negotiated voluntary network access** under which "the DH operator and supplier" (requesting grid access) "determine, on a voluntary basis, how to set up the heat dispatch order to the DH network" [54];
- **negotiated mandatory network access** with a clear obligation to grid operators to enable grid access. However, the (technical and economic) conditions for grid access still need to be negotiated between the parties involved;
- **fully regulated network access**, where the regulator determines ex-ante access provisions for grid access. Here, the network operator is obliged to provide access to the network if these conditions are met by the heat producer requesting grid access.

Söderholm and Wårell [55] distinguish between systems called "**regulated TPA**" and "**negotiated TPA**". Whereas "negotiated TPA implies that the DH network owners are required to negotiate about access to the network with the producers of heat", regulated TPA refers to a regime "where the network owner has a legal obligation to allow access to the network" while the conditions for access to the network are negotiated between the network operator and the third party in advance [55]. In both cases, customers have the right to choose their own supplier. Moreover, Söderholm and Wårell [55] describe single buyer models and a system called "extended producer market". The latter is a certain form of a single buyer model, extended by high transparency rules for all market actors. The idea of this model is that due to clear unbundling rules and high transparency requirements regulation efforts can be reduced.

Bürger et al. [56], however, work out that there are many more conceptual options to open heating networks for third parties. This includes the option - over and above the requirements of RED-II - of opening heating networks to competition at the supply side, referred to as "**full TPA**" instead of restricting network opening on the generation side, referred to as "**producer TPA**". Figure 54 shows the different options for market/infrastructure opening.

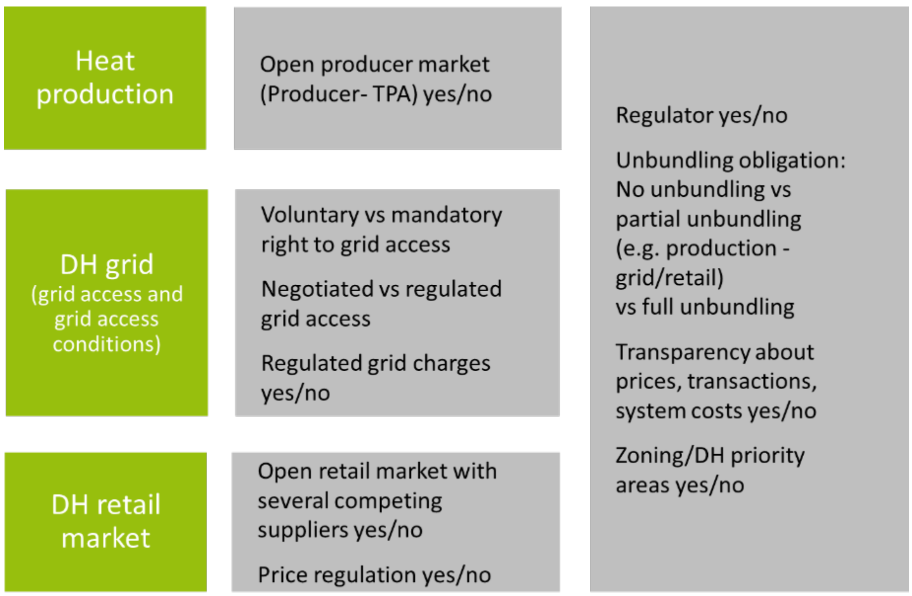


Figure 54: Design features of third party access to district heating (Source: Bürger et al. [56])

Following the broader approach from Bürger et al. [56], various models can be derived from this as examples, which are shown in Figure 55. From top to bottom, the degree of grid opening and thus the competitive nature of the DHC system increases. The degree of unbundling also increases towards the bottom. At the top is a classic DHC system, which sees itself as a fully integrated supply system in which generation, grid and supply are all handled by a territorial monopolist. There is no provision for third party access to the grid. Below are different variants of how the grids could be opened to third parties. These are partly independent of the extent to which the incumbent supplier or network operator is vertically integrated, i.e., covers generation, network, and heat distribution. At the very bottom, a DHC system is shown in which generation, grid, and supply are completely separate (**full unbundling**). The grid operator sees itself as an infrastructure operator open to all heat producers on equal terms. At the same time, different utilities compete to supply customers. The latter can be limited to large customers, but in principle can also be extended to all customers.

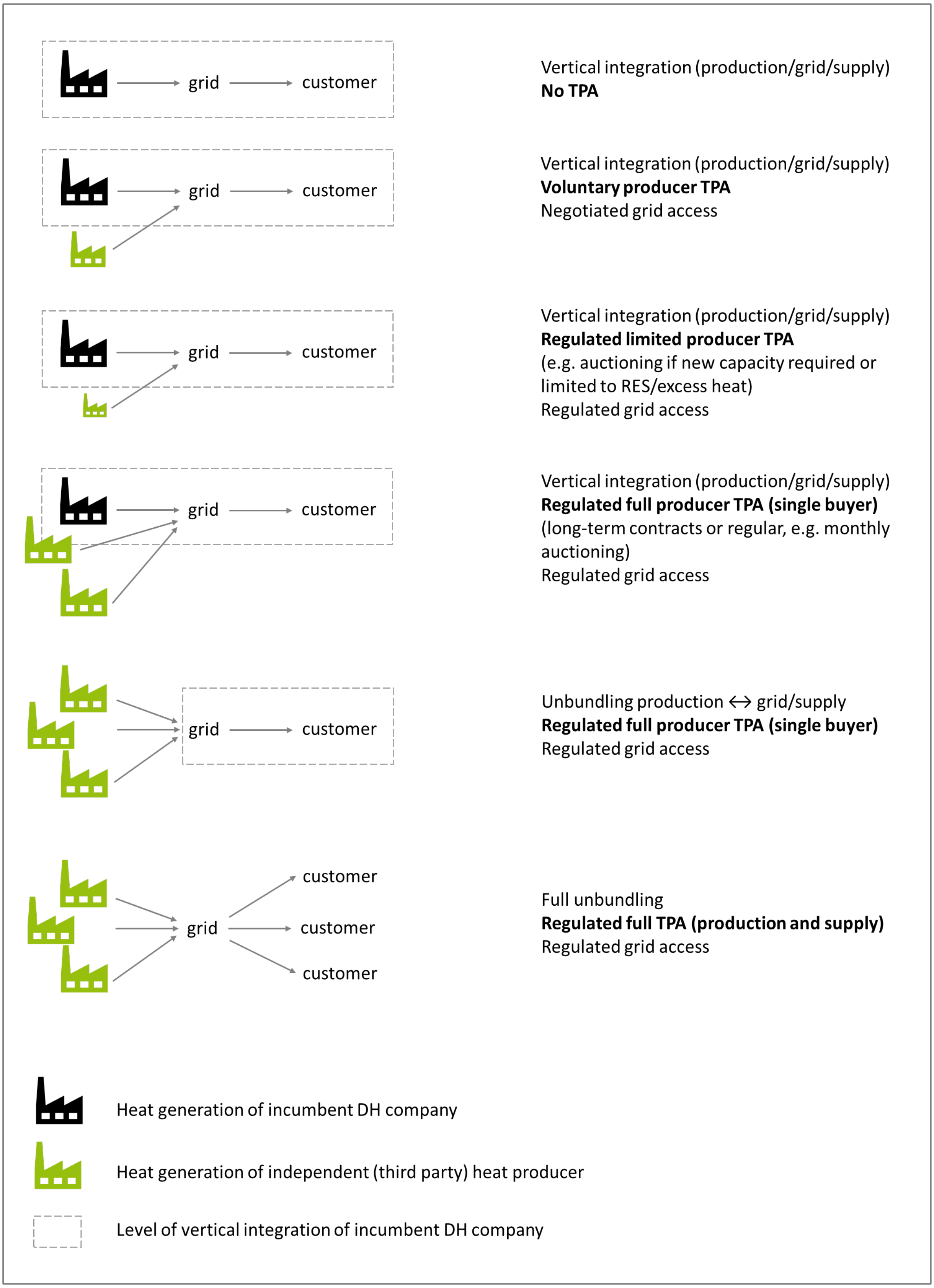


Figure 55: Variants of third party access

The following section investigates the TPA regimes implemented by the Member States, the UK, Iceland, Norway, and Ukraine. This section is based on a detailed literature review, the consortium's operational experience of TPA and is completed by the inputs collected through the survey carried out in the various countries of the study.

B.3.1.2 TPA regimes in the European district heating and cooling markets

There is no Europe-wide overview of whether and in what form the different Member States allow third party access (TPA) in their district heating and cooling sectors. Moreover, research analysing TPA from a more conceptual perspective is also lacking. Specific investigations on TPA in the district heating sector have been carried out for specific market conditions, e.g. for Sweden [57], in Germany by the Federal Cartel Office [47], in Finland [58] and in Lithuania [59].

The following chapter describes **whether, to what extent and under which regulations TPA is addressed in the district heating and cooling sectors** in the EU-27, the UK, Iceland, Norway, and Ukraine. First, the fundamental question is whether the regulatory framework provides for TPA at all. But even if TPA is not explicitly regulated, TPA might in principle still be possible. For all countries where this is the case it is investigated which type of TPA regime/concept is applied (see Figure 55 above). It is analysed

- to which extent there is an open retail market with competing heat suppliers in which consumers can choose between different DH suppliers;
- whether TPA is restricted to the production side (open producer market with competing heat producers, so-called Producer-TPA).

For DH markets with TPA **specific restrictions** might apply, e.g. regarding

- the occasions at which TPA might be required (e.g. TPA might be required when new demand needs to be covered or existing heat production capacities need to be replaced);
- the heat sources eligible for TPA (for instance TPA might be restricted to RES or waste/excess heat);
- the type of district heating and cooling system: TPA might be restricted to large DHC systems or to certain types of legal structures/ownerships.
- In the case of TPA, grid access must be organized. Here, different concepts can be distinguished: mandatory vs. voluntary grid access: Under mandatory grid access, grid operators are obliged to grant grid access if certain technical minimum requirements are met. Voluntary grid access means that it is up to the grid operator to decide whether grid access is granted or refused.
- negotiated vs. regulated grid access: Negotiated grid access means that it is left to the market actors involved to negotiate the specific grid access conditions. If regulated grid access is applied, the regulatory authority defines ex-ante grid conditions (technical conditions, grid charges).

Where TPA is regulated, there might be **exceptions** in which the grid operator may refuse a third party to access the grid. Potential exceptions are laid down in Art. 24 (5) of the Renewable Energy Directive. For instance, exceptions may apply if

- the network lacks the necessary capacity;
- the heat producer applying for TPA might not meet certain technical parameters defined by the grid operator;

- the operator can demonstrate that providing access would lead to an excessive heat or cold cost increase for final customers.

According to Art. 24 (6) of the Renewable Energy Directive, Member States can also exempt grid operators from awarding TPA when they run

- efficient district heating and cooling systems[65];
- efficient district heating and cooling systems that exploit high-efficiency cogeneration;
- district heating and cooling systems that, on the basis of a plan approved by the competent authority, is efficient district heating and cooling by 31 December 2025;
- small district heating and cooling systems with a total rated thermal input below 20 MW.

Figure 56 provides an overview of the explicit TPA regulations in all Member States, the UK, Iceland, Norway, and Ukraine. Table 20 gives a more detailed overview about how and where TPA is regulated in the ten focus countries (based on literature review and survey results). A tabular overview of the TPA regulations in all Member States, the UK, Iceland, Norway, and Ukraine, is provided in Annex 4.

[65] Efficient district heating and cooling is defined in Article 2(41) of EED. The same definition is applied under Article 2(20) of REDII, which includes this definition by reference. Efficient district heating and cooling is defined as: district heating systems using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat.

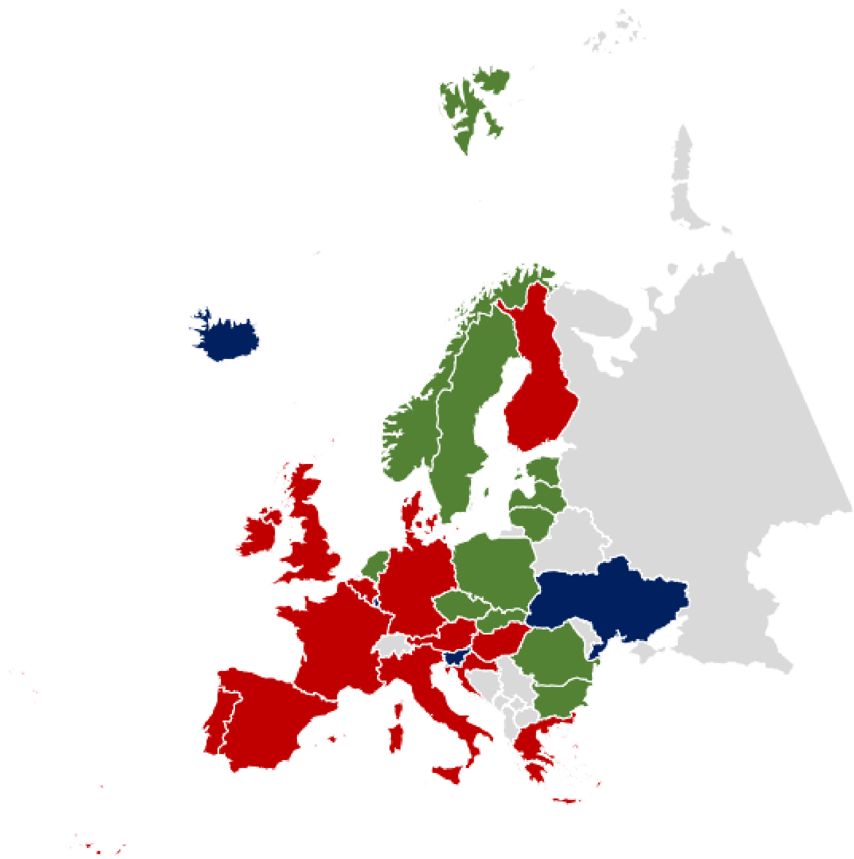


Figure 56: Map of the explicit TPA regulations (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

Table 20: Overview of TPA regulations in the ten focus countries (Source: Own survey with input from national DHC stakeholders)

Country	Overview of TPA regulations
Bulgaria	TPA is regulated by Art. 133-138 of the Energy Act[66] and is detailed in Ordinance No Е-РД-04-1 as of 12 March 2020 for the heat supply. Grid operators are obliged to connect heat producers that apply for grid connection. Costs related to grid connection have to be borne by the third party producer. Grid connection can be refused if the network does not have sufficient capacity. However, it remains unclear whether or to which extent the grid operator must reduce own generation in order to allow the third party producer to connect. Grid connection can also be refused if certain technical parameters are not met. From the TPA perspective, the system can be characterized as regulated full producer TPA with regulated grid access.
Denmark	The Danish Heat Supply Act does not regulate TPA to district heating. However, Copenhagen is seen as a good-practice example for the concept

[66] https://www.me.government.bg/en/files/download?hash=75c204b53f734ec7bb86aec1a6fb0788a2c8a4fc

	of voluntary producer TPA. Copenhagen runs an integrated DH system, including several transmission and distribution grid operators and bringing together about 50 production plants (mainly CHP plants, waste-to-energy plants, heat pumps, peak and reserve load heat-only boilers). Many of the production units are owned by the companies running the grid. A heat dispatch unit[67] allows optimising the daily production of heat and electricity on an hourly basis. Day-ahead heat plans are compiled based on bids submitted by different heat producers. The dispatch model grants priority dispatch to heat from waste incinerators and heat pumps. The rest of the required load is delivered on the basis of lowest possible cost [30]. From the TPA perspective, the system can be characterized as voluntary producer TPA with negotiated grid access.
Finland	Grid access is not regulated by law [60]. TPA is practiced on a voluntary basis. If a third party wishes to conduct business on the network, it needs to enter negotiations with the grid supplier [37]. DH suppliers, on the other hand, actively search for cost-efficient heat sources (e.g. excess heat) within their networks. If heat produced by a third party is available at a competitive price, the supplier enters into negotiations on utilizing this heat [58]. From the TPA perspective, the system can be characterized as voluntary producer TPA with negotiated grid access.
France	TPA is not regulated by law but organized on a voluntary basis. The DHC network owner or operator enters into negotiations with the third party energy supplier when common interests can be found. However, as public heat distribution is a competence of the local or regional authorities, these authorities have some means to induce the DHC operator to integrate heat supplied by a third party (usually at the creation or renewal of a Public Service Delegation contract). However, this generally only happens when technical feasibility is proven and when the economic impact for the DHC end-users is improved or considered acceptable (dedicated subsidies exist for both the DHC operator and the third party supplier). From the TPA perspective, the system can be characterized as voluntary producer TPA with negotiated grid access (private network) and regulated limited producer TPA with regulated grid access (public network).
Germany	TPA is not explicitly regulated. The Act against Restraints of Competition ("Gesetz gegen Wettbewerbsbeschränkungen" (GWB)) contains a ban on abuse under cartel law. According to this, a third party is entitled to access to the network of another company against payment of an appropriate fee "*if it is not possible for legal or factual reasons to act as a competitor of the dominant company on the upstream or downstream market without shared use*". However, the claim is excluded "*if the dominant company proves that shared use is not possible or not reasonable for operational or other reasons*". While in theory TPA would be possible, in practice the provision is irrelevant. Due to the lack of a concrete set of rules, the uncertainties for a potential heat provider in the enforcement of the law are too great to realise a substantial financial investment. There are neither regulations on how to appropriately define grid charges, nor are the rights and obligations of grid operators and third party producers regulated. Therefore, the grid

[67] https://www.varmelast.dk

	operator can easily put considerable obstacles in the way of any third party grid access request in such a way that third parties are prevented from realising their access claims. The basic right to network access thus remains of no practical significance as long as the access conditions are not specified in detail. From the TPA perspective, the system can be characterized as voluntary producer TPA with negotiated grid access.
Lithuania	TPA is regulated in the Law on Heat. Grid operators, the majority of which are municipally owned, are obliged to connect all facilities of independent heat producers. Heat production plants must be connected to the DH grid at the technically suitable point which is closest to the heating device to be connected unless there is a more technically and economically suitable connection point. The connection costs are covered by the independent heat producer. If grid access results in the network operator having to make adjustments to the overall system, these additional costs must also be borne by the third party producer. Heat dispatch is organised via monthly auctions at which independent heat producers (third party suppliers) and incumbent DH companies compete. Auctions are organised centrally by the regulator (NRA). Reserve capacity needs, capacity needs to cover peak demands and balancing responsibility are left with the incumbent grid operator (for security of supply reasons). Heat from renewables must comply with environmental and quality standards as well as standards for the security of supply. Heat supply is a monopoly by the local DH company. The system thus corresponds to producer TPA. In case of TPA refusal, the independent producer can file a claim to the National Commission for Energy and Prices (NCC). The NCC is entitled to oblige the grid operator to connect the production plant and buy the heat at a price and on conditions either negotiated between producer and grid operator or set by the NCC. From the TPA perspective, the system can be characterized as regulated full producer TPA with regulated grid access.
Poland	TPA is regulated in the Polish Energy Law. In theory regulated full TPA (including production and retail) is implemented. DH grid operators are obliged to purchase heat produced by third parties connected to the grid (and located on the Polish territory) *at the quantity not larger than the demand of the customers of that enterprise connected to the same grid*. Grid operators must accept and purchase heat from new sources (including renewables) on the condition that purchasing this energy won't increase prices for clients. If a third party producer applies for network access, the network operator checks what effect the feed-in has on the district heating price. If the producer is not satisfied with this assessment, he can submit a complaint to the Energy Regulatory Office (URE) who will investigate the calculations. In practice, TPA is practiced only in cities that are large enough for several producers. In theory, consumers can choose between different district heating suppliers (provided a competing retail company is offering such heat), but in practice producers do not supply small consumers. For that reason, competition is limited towards large consumers. Grid charges are set by URE on a cost-plus basis. From the TPA Perspective, the system can be characterized as regulated full TPA.

Slovakia	The Law on Thermal Energy regulates third party access to a distribution network, but only in a case of heat produced from renewable sources of energy or combined heat and electricity production [61]. The grid operator is obliged to take heat produced from renewable energy sources or high-efficiency CHP at an approved price, provided technical connection conditions specified in the operating regulation of the grid operator are met. The obligation does not apply when TPA would result in higher prices for the consumers or when it would displace renewable or efficient CHP production which is already connected to the grid. From the TPA perspective, the system can be characterized as regulated limited producer TPA with regulated grid access.
Sweden	DH grid operators are obliged to enter into negotiations with an interested heat producer if a producer wants to sell heat or use the network for distribution of heat (process is mediated by the District Heating Board, which is an independent organizational unit within the Energy Agency). All technical and economic aspects (quantity, profile, temperatures, location of feed-in, price of heat input, back-up capacities, securities, etc.) are up for discussion. The obligation means that the DH company must attempt to reach an agreement but can refuse to give the access if it states reasons for the refusal, e.g. if it would harm business. The obligation only applies to those heat producers that are selling heat as a by-product (e.g. excess heat), not purpose-built heat producers such as CHP. If no agreement is reached, the grid operator must grant a so-called regulated access [62]. The grid operator offers a draft contract in which the location of the feed-in and other technical requirements are specified. The regulated access must be granted for 10 years. The grid operator is obliged to pay for the heat provided to the extent that he benefits from it (this means that the grid operator is only obliged to offer a remuneration corresponding to the avoided variable costs, [63]). The third party producer bears the investment costs of the grid connection. Discrepancies in connection with regulated access are clarified by the Swedish Energy Markets Inspectorate (regulator). From the TPA perspective, the system can be characterized as voluntary producer TPA with negotiated grid access.
The Netherlands	TPA is regulated in the revised Heat Act (Warmtewet) that came into force in the beginning of 2019. The Heat Act introduces negotiated access, requiring the operator of a network to inform a heat producer, at its request, on certain key data in relation to the DH network (such as the available transport capacity on the grid, the tariffs charged for the transport of the heat, technical characteristics of the system, including pressure and flow, and the transport profile that provides insight into the required transport capacity at different times). The grid operator has to enter into discussions with the heat producer on TPA [37]. The Heat Act does not address TPA for heat suppliers (opening the retail market for competition), since the benefits that this would generate (such as increased competition and thus more efficient pricing) are deemed not to outweigh the additional costs resulting from more intensive supervision and grid management. From the TPA perspective, the system can be characterized as voluntary producer TPA with negotiated grid access.

Another country with interesting TPA regulation is **Estonia**: In Estonia TPA is regulated in Art 14 (1) of the Heat Act[68]. Grid operator and heat producer conclude a delivery contract for a term of up to 12 years. There is no exclusive priority rule for renewables, however preference should be given to heat produced from renewable energy sources, efficient cogeneration based on RES, waste, peat or carbonisation gas obtained from processing of oil shale, and to the best clean technologies currently available. Nevertheless, it remains unclear how this preferential treatment is actually implemented, i.e. which criteria must be met to ensure that no preference is granted. The grid operator shall obtain in advance the approval of the Competition Authority regarding any such heat purchase contracts or any investments in new production capacities. If new production capacity is required to meet demand and more than one heat producer has expressed in writing his wish to enter into contracts, the grid operator shall organise a tender for the award of the contract. The Heat Act mandates the government to establish the procedure for organizing these tenders as well as for defining methods for the evaluation of bids.

TPA in practice

In the following section, some **large urban DH systems** are outlined in which TPA is specifically implemented (additional practical examples can be found in the detailed case studies analysed in Annex 6). The implementation follows different regulatory regimes. TPA in the district heating system of Vilnius, for example, is very much based on the national TPA regulation of Lithuania (see Table 20) which introduces producer TPA. In Copenhagen and Stockholm, on the other hand, TPA is based on a voluntary basis, as the Danish and Swedish district heating regulations do not explicitly regulate TPA at all.

- Vilnius/Lithuania: The district heating system of Vilnius has a generation capacity of about 1,700 MW_{th}. It supplies about 7,200 buildings and more than 200,000 customers [64]. In addition to the municipal utility Vilnius Šilumos Tinklai (VST), there are currently 7 independent heat producers connected to the district heating network. These contribute about 40 % to the annual heat turnover of the network. The heat dispatch is organized by monthly auctions (see Table 20). In these auctions, the independent heat producers compete with the heat plants of VST for heat supply. The contract is awarded to the bids with the lowest costs. Since the plants of the independent heat producers are located further away from the district heating network than the VST plants, the independent heat producers have a competitive disadvantage, since they also have to refinance their connection costs [64]. The excess capacity in the summer results in a very low auction price level, so small independent heat generators tend to focus on the winter months and do not bid at all in the summer. From the TPA perspective, the system can be characterized as regulated full producer TPA with regulated grid access (one variant of the single buyer model).

- Copenhagen: Greater Copenhagen's DHC system includes three transmission system operators (VEKS, CTR and Vestforbraending), and 24 distribution companies (retail) owned by municipalities or consumer-owned cooperatives [30]. The distribution companies are thus integrated distribution system operators and heat suppliers. The generation capacity in the entire system is about 3,000 MW_{th}. The system supplies about 1 million consumers. The transmission grid operators own part of the generation capacity and they are responsible for providing peak capacity. Each of the distribution companies also owns some production capacity to secure its supply. In addition to own generation, distribution companies buy heat from the

[68] https://www.riigiteataja.ee/en/eli/520062017016/consolide#

transmission companies or nearby distribution companies. Heat dispatch is organized by the heat dispatch unit Varmelast[69] 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 heat only boilers at the lowest possible cost [30]. Base load is mainly supplied by waste incinerators and CHP (natural gas, coal, different types of biomass), peak load and reserve load mainly by natural gas and fuel oil. In addition, a sewage treatment plant, a large-scale heat pump and several thermal storage units are connected to the system. From the TPA perspective, the system can be characterized as voluntary producer TPA with negotiated grid access.

- Stockholm: The Stockholm DHC system includes a generation capacity of approximately 3,600 MW_{th}. The system is owned and operated by Stockholm Exergi (until 2018 the company was called Fortum Värme) half of which is owned by the City of Stockholm and the other half by a group of investors around APG (this share was held by Fortum until mid 2021). Stockholm Exergi provides heating for over 800,000 people in and around Stockholm. The supply area consists of three networks, two of which are interconnected. Base load is mainly generated from waste incineration, biomass, and coal. Large heat pumps and biomass heat only boilers cover the medium load, pellet boilers, as well as bio-oil and fuel oil boilers the peak load. Stockholm Exergi has entered into a heat exchange agreement with the two adjacent (and physically connected) DH networks, through which the three DH companies implement a common heat dispatch [30]. The common heat dispatch allows a dynamic optimisation of the production and supply of DH within the affected supply areas. Furthermore, Stockholm Exergi makes an offer to potential waste heat suppliers to connect the waste heat to the DH system[70]. From the TPA perspective, the system can be characterized as voluntary producer TPA with negotiated grid access.

Main findings

TPA regulation is not yet well developed in most of the countries studied. In about half of the analysed countries, TPA is regulated in some form. However, there are significant differences in the regulation depth. In the other half of the countries there is no explicit regulation of TPA.

In the countries with regulation, TPA is subject to certain restrictions. In the Czech Republic, mandatory TPA is limited to heat from renewable energies (including waste incineration) and waste heat. In Slovakia, a similar limitation applies to heat from renewables and efficient CHP. In Sweden, TPA only applies to those heat producers that are selling heat as a by-product (e.g. excess heat), not purpose-built heat producers such as CHP. In Estonia, the grid operator must conduct a bidding process if additional generation capacity is needed and more than one producer applies. If this involves generating facilities that are not owned by the grid operator itself, this also automatically leads to third party access.

In countries with TPA regulation, third party access can usually be denied **whenever technical or economic reasons prevent it**. These include, for example, the technical parameters of the heat fed into the grid (for more details see section B.3.2.4.1), possible capacity bottlenecks in the grid or excessive costs**. Economic restrictions usually relate to the costs of generation**. In Lithuania, for example, grid operators must buy heat from third party producers (auctioning). However, this only applies if the heat fed into the grid

[69] www.varmelast.dk/
[70] https://www.opendistrictheating.com

is cheaper than or offered at the same price level as the offers from competing producers including the grid operator's own production (see also section B.3.2.4.2). Comparable restrictions apply for instance in Latvia, Poland, Slovakia, and the Czech Republic. Furthermore, in Slovakia, TPA exemptions apply for systems where feeding in external heat would lead to renewable heat or heat from efficient CHP being pushed out of the system.

The requirement that third party heat must not result in higher prices is a significant barrier to the installation of new generation intended to be connected to replace existing generation. If the grid operator's generation fleet is already depreciated to a large extent, the full costs of the new generation plant (CAPEX+OPEX) are compared with the variable costs of the existing generation plants (OPEX). This cost comparison is usually in favour of the existing plants. **For that reason, the cost comparison usually limits third party access to situations where the system operator needs to install new generation capacity**.

TPA is often also permitted in countries that do not explicitly regulate it (**voluntary TPA**). In most countries where TPA is possible in principle (regardless of whether it is regulated or not), third party access is limited to the producer side (producer TPA). An opening of the DH system also on the supply side so far only exists in Poland and Norway. In Poland, in theory, consumers can choose between different district heating suppliers, but in practice competition is limited towards large consumers. In Norway the grid operator is obliged to negotiate with any third party requesting access to the grid in order to directly supply own customers [65]. On other countries, e.g. Belgium and Croatia, the regulatory regime is not preventing competition on the supply side. But in practice, customers are almost always supplied by the incumbent DHC company.

In about half of the countries where TPA is in principle possible, grid access is mandatory. Mandatory grid access means that a grid operator is obliged to grant grid access if certain minimum requirements are met. This mainly applies to countries with regulated TPA while grid access conditions are laid down in the regulatory regime. But there are also several countries in which grid access is mandatory, but the specific conditions are negotiated between the parties to the agreement. In Sweden, for instance, DH grid operators are obliged by law to negotiate TPA, if a producer wants to sell heat or use the network for distribution of heat. The obligation means that the grid operator must attempt to reach an agreement but can refuse to give the access if it states reasons for the refusal, e.g. if it would harm business. While it is not specifically regulated which criteria must be met in order for such a case (harm business) to occur, the exemption implies that TPA can be refused if it would lead to higher prices for consumers. Comparable regulations apply in the Netherlands. Where there is no mandatory grid access, the whole TPA system is based on voluntary agreements.

In some district heating systems, however, TPA is practiced successfully. Functioning TPA systems, in which different heat generating plants compete with each other or in which plants of independent heat generators feed heat into an existing heat network according to certain criteria, are **mainly found in very large district heating systems supplying several thousand customers** (see examples above). However, as can be seen from the examples of Copenhagen and Stockholm, this **does not depend on national regulatory frameworks but mainly on private/municipal initiative**.

B.3.1.3 Unbundling requirements

Unlike the electricity and gas market, the EU has not yet made any provision for unbundling the DHC market. There are three different levels of unbundling, which were analysed during the online survey (also see Annex 4):

- no unbundling obligation;
- partial unbundling (e.g. unbundling of production and grid operation/retail); and
- full unbundling of all three levels of the supply chain (production, grid, supply).

Figure 57 gives an overview of unbundling requirements in place in Member States as well as Iceland, Norway, the UK, and Ukraine. Unbundling requirements for DHC only exist in very few countries.

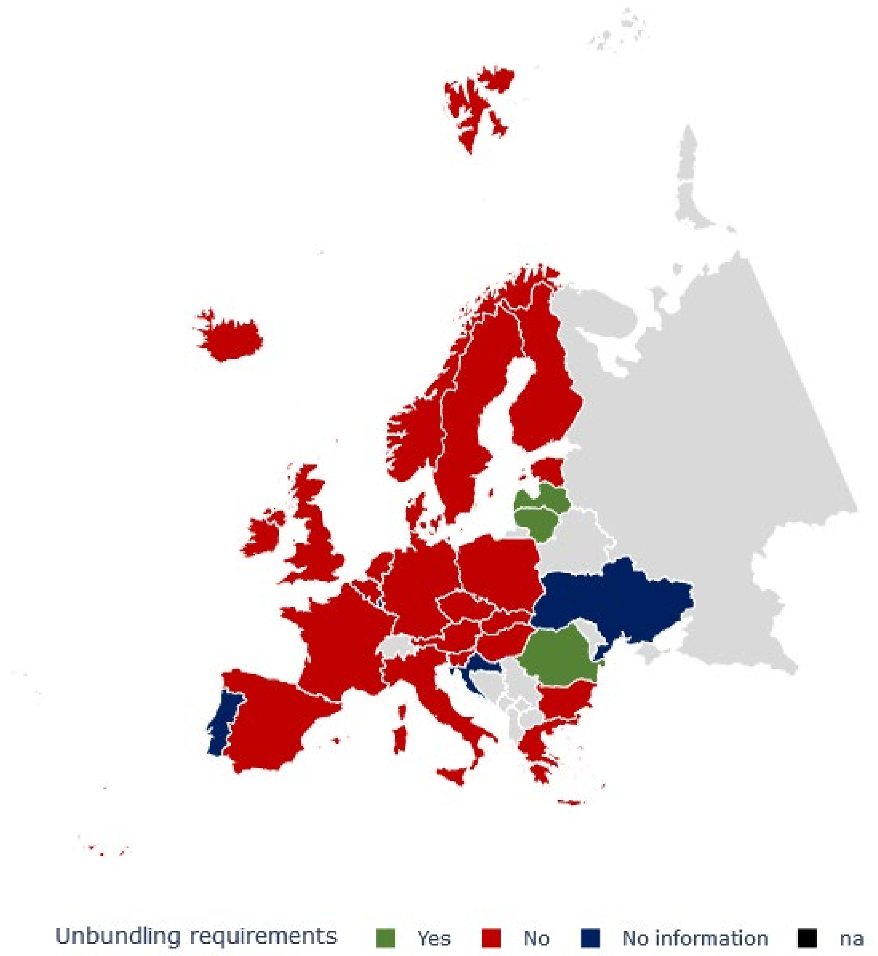


Figure 57: Map of unbundling requirements (Source: Own survey with national DHC stakeholders; detailed information in Annex 4)

According to the survey results, **most countries consider district heating as an integrated supply in which unbundling is neither planned nor necessary**. Some reasons for that are summarized in the study "International Review of Heat Network Market Frameworks" [66] conducted on behalf of the UK Department for Business, Energy & Industrial Strategy. One reason for only few unbundling activities and regulations named in the study is that unbundling might lead to **higher heat prices for end customers**. This is one of the main reasons why stricter unbundling requirements were not introduced in Finland, Sweden or Germany and why they will not be introduced in the UK. Furthermore, the authors of the study argue **that heat networks need to have a specific minimum size to allow several suppliers to operate at the same time**. In a study conducted by Pöyry Management Consulting Oy [67], the authors calculated additional costs associated with different levels of unbundling. The study focused on the Finnish market, where the median size of district heating networks is about 50 GWh annual heat sales. Their results show that unbundling of production and distribution as well as full unbundling and full network access increase the aggregate production costs by about 10-20 % and in small networks by about 50 %. Only in large networks with annual heat sales of at least 5,000 GWh the cost increases are moderate (1-3 %).

Only three countries seem to apply certain unbundling requirements, namely Latvia, Lithuania and Romania.

According to the National Energy Regulatory Council of Lithuania, there are currently 52 companies providing services of heat supply, 44 independent heat producers (17 non-regulatedCouncil[71]. Until then, regulated DH companies have received a fixed income to maintain heat production. They only purchased heat from IHPs if it was cheaper than heat from own production units (only variable costs). Thereby, reliability of heat supply and the principle of the lowest cost were assured. The new regulation established competition at the production side at full cost. Heat producers participate in a monthly auction by the operator of the Energy Exchange Baltpool. If a production unit has too high prices in a month, it can happen that it will not be able to sell heat and has no income for one month. According to the survey, in 2019 there were 12 DH companies purchasing at least part of the heat distributed in their networks from IHPs. IHPs currently have a market share of around 34 % of total heat delivered to the networks. Furthermore, accounting and cost calculation is unbundled. DHC companies must calculate and price costs for heat generation, heat distribution, retail service provision, hot water generation and distribution, and maintenance of the system separately.

In Latvia, **financial unbundling** is mandatory for price-setting purposes. This applies for the generation, transmission, and distribution. Nevertheless, DHC-companies can be (and in most cases are) vertically integrated companies from heat generation to distribution to final customers.

According to the Romanian Energy Regulatory Authority, there is full unbundling in the DHC sector.

In addition, in Hungary the 2015 annual report of the Hungarian Energy and Public Utility Regulatory Authority [68] describes how district heating production and services are licensed (production only for production plants with a thermal output beyond 5 MW). The description shows that generation and system operation or retail are not necessarily organised by one company and it is possible to only receive a license for one of the elements of the DHC supply chain. This implies the possibility of an unbundled service and corresponds with one interviewee who indicates that production and grid operation/retail were unbundled. However, there is no regulation on/ requirement of unbundling in place.

B.3.1.4 Incentivisation of renewables and excess heat

Based on the information collected in the previous working steps, there is **no obvious correlation between the share of renewables or excess/waste heat and the degree of third party access in DH systems**. A similar conclusion can be drawn from looking at different case studies investigating the successful integration of RES/excess/waste heat in DHC. Detailed investigations on the integration of renewable heat generation and excess/waste heat based on specific case studies can be found in Annex 6 as well as in the studies by Galindo Fernandez et al. ([30] and [64]). In particular,

[71] https://eseimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.383246/asr

the specific contextual conditions under which decarbonisation measures take place are investigated.

Nine of the countries surveyed in this study (EU Member States plus Iceland, Norway, the UK, and Ukraine) have in their DH sector a RES/excess/waste heat share above 40% (see section A.1.3). These are Iceland, Denmark, Lithuania, Sweden, France, Norway, Latvia, Austria, and Estonia. Five out of these countries have explicit TPA regulations while the other countries do not have comparable regulations. However, the analysis also shows that **Lithuania seems to be the only country where the opening of the grids for independent heat generators has led to a significant increase in the share of renewables in the DH sector**. This is due to a shift in heat generation from expensive natural gas in favour of (often locally produced) biomass. At the same time, TPA combined with monthly auctioning led to lower district heating prices for consumers. In all other countries, other factors were mainly responsible for the relatively high RES/excess/waste heat shares.

In other words, **countries that today have a high share of renewables or excess/waste heat in their district heating systems do not automatically open their district heating systems to third parties, nor do they have particularly sophisticated TPA regulation**. It can be concluded that the incentives associated with opening the heating networks to third parties are at least not sufficient on their own to significantly increase the connection rate of renewable heat generation or excess/waste heat to district heating networks. TPA may be a necessary condition, but in any case it is not a sufficient one.

This may be due to the fact that existing TPA regulations are often restricted in a sense that the production costs of third party generation need to be competitive to generation that is already connected to the grid. At the same time, the case studies detailed in Annex 6 show that TPA only plays a role in large urban grids with several 100,000 connected consumers, whereas smaller grid systems with only a few generation units connected do not seem to be suitable for TPA. However, it is not possible to deduce from previous experience at what minimum size grid opening makes sense. This depends, among other things, on the **existing generation fleet** and the **existing grid typology**.

In the case study section, eight different **key success factors** for the integration of RES and excess/waste heat into DHC are identified. These are national policies and support schemes, support of the municipality, DHC operator's governance, business model, strategic technical choices for DHC supply, DHC - buildings nexus, collaboration and innovation and consumer empowerment.Generally speaking, these key success factors can be specifically addressed through political measures. Possible policy measures to strengthen the key success factors are, for example:

- Implementing **strategic long-term local/urban heat planning**, including measures such as obliging, encouraging and/or supporting municipalities to screen which areas could be used for centralized RES-H generation, or the geological potential for seasonal heat and cold storage;

- Obliging DHC companies to develop **long-term transformation plans** describing measures and milestones on how the system will be decarbonised over the years;

- Providing **financial support** for decarbonisation measures, including use of RES, excess/waste heat, low-temperature grid transformation (grid and buildings).

Other measures that improve the competitiveness of decarbonised alternatives include, for example:

- Ensuring a **steady and sufficiently high CO_2 price for fossil fuels** (one of the main drivers for the successful development of renewable heat in the DH sectors of Sweden and Denmark);
- Strengthening **citizen/customer participation** in DHC systems (ownership structures) and energy communities;
- Improving **transparency** by e.g. strengthening the information obligations for DHC companies (e.g. by expanding reporting requirements on the generation mix, RES/excess/waste heat share, CO_2-value etc. to the companies' websites);
- Introducing RES/excess/waste **heat quota/obligations** for DHC companies;
- Incentivising/facilitating use of **excess/waste heat** by e.g. obliging companies to provide data on their excess/waste heat flows, to develop excess/waste heat utilization concepts, establishing risk hedging structures (in order to hedge the risk of failure of the excess/waste heat source and sink), introducing excess/waste heat levies.

B.3.2 Contractual modalities for third party access

As previously exposed, DHC grid access undergoes different regulation schemes in different countries and can be voluntary or mandatory. However, in any case, technical and financial efficiency of the DHC network shall be sought and strict conditions shall be guaranteed:

- Competitive price for the whole system and end-customers
- Connection conditions – both technical and commercial
- Security of supply

In addition, while a DHC network operator is usually seen in a locally dominant position towards third party heat/cold producer(s), the situation might be more balanced or even reversed in some cases (where a local public authority imposes a DH operator to enhance excess heat from a local industry for example).

Therefore, regardless of the local context, the agreement between the DHC operator and the third party heat supplier must be negotiated and carefully framed by a contract. This contractual agreement shall clearly define the role and responsibilities of each part and allow the contractual parties to balance their respective financial risk exposure, which can be significant for both.

This section is based on the consortium's operational experience of TPA and is completed by the inputs collected through the survey carried out in the various countries of the study and through the operational case studies presented in Annex 6. It lists and comments the different key issues that shall be addressed in such contracts and specifies special topics that may apply depending on the national regulatory framework for TPA and on the type of third party energy supplier. The latter will be split into two different configurations: suppliers with excess heat/cold as a by-product of their main activity (wastewater treatment plant e.g.) and suppliers with heat/cold production as their main activity (independent biomass-based heat plant e.g.).

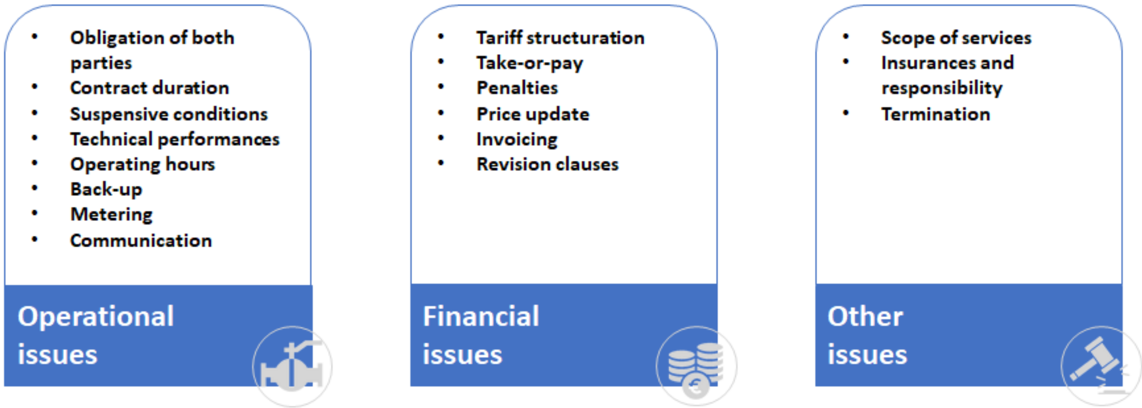


Figure 58: Contractual modalities for third party access

B.3.2.1 Operational issues

B.3.2.1.1 **Obligation of both parties**

The contract shall first provide a global overview of the agreement and the mutual obligations of both parties. In particular, it shall:

- Define and describe succinctly the activity of the DHC operator on one side, and of the third party heat/cold supplier on the other side.
- Define who is in charge of the construction (in the sense of Engineering, Procurement, Construction and Commissioning), operation and maintenance of the different heat/cold transmission facilities implied (heat exchanger and substation a minima), as detailed below in paragraph B.3.2.3.1. Both parties shall state that the respective facilities will be built and operated under the applicable regulation.
- State the obligation for the heat/cold supplier to provide heat/cold to the DHC network operator in exchange for a remuneration covering the different charges (construction and/or operation and maintenance…) under a fixed and/or proportional tariffication (detailed below in paragraph B.3.2.2.1).
- State the obligation for the DHC network operator to off-take the heat/cold provided under the conditions detailed in the contract. This section might highlight some particular conditions of the contract (obligation for the DHC network operator to prioritize the imported heat/cold over its own production units for example, as discussed below in paragraph B.3.2.2.2).

B.3.2.1.2 **Duration of the contract**

On the contract duration, a wide variety of agreement can be found. Indeed, different types of contract exist for different national regulatory frameworks and different local contexts, both on the DHC network side and on the third party heat/cold supplier side.

- **Long-term contracts**

  Long-term contracts (at least several years) are set up when one or both parties need to secure the heat/cold exchange on the long term. This applies when the local heat/cold supply is limited and the DHC operator needs to secure its energy mix. This also applies when the excess heat/cold generated by the third party supplier is not only a by-product of its main activity, i.e. when the sales of this excess energy are critical for its business model. In these situations, securing in the long-term the energy supply for the DHC operator and the energy sales for the third party provider is vital and usually required for the financial close of the project.

The key issue with long-term contracts is then to find a good match of the timing of the heat/cold exchange project on the DHC network side and on the third party side. Therefore, if the DHC operator is requested by the municipality to secure its heat/cold prices to the end-users over 20 years, it is necessary to obtain the commitment of the third party supplier over these 20 years (except if other local solutions are available of course).

The inverse problem may arise as well. For example, if the third party needs to secure its excess energy sales over 20 years to be able to finance its investments related to excess energy production and/or transmission, then it is necessary for the DHC operator to guarantee its demand on the same period of time, which is not always straightforward. In the case of a DHC operator operating a network owned by the municipality, the contract might have to involve the municipality as well and stipulate that the municipality will take over the operator's obligations at the end of the DHC operation contract. An alternative solution might be to contract over a shorter period of time, but with an impact on the tariff (which would increase therefore).

- **Short and medium-term contracts**

  Short-term (one hour to several weeks) and medium-term (several months) contracts are found under specific local context, where the heat/cold supply and demand market is diverse and flexible, or where it is regulated. Depending on the context, these agreements can be set up to answer both regular demand and/or peak load or back-up.

  On the DHC network side, this may correspond to networks located in or close to industrial areas with a large panel of potential third party energy suppliers. This may also correspond to countries where the heat/cold production for DHC is strongly regulated. In Lithuania for example, public and private companies producing heat have to bid during auctions organized by the DH network operator (according to the national regulator requirements) to access the grid. These auctions are driven by price and lead to contracts for either 1 week, 3 months or 6 months.

  On the third party heat/cold supplier side, the possibility to contract on short or medium-term basis usually requires that either:

– the excess heat/cold export involves limited investments that can be covered by a reasonable access to one or several heat/cold markets over time (DHC operator, industries…),

– the heat/cold production and/or transmission facilities are already amortized, so that the company only has to bear the operational costs, which are proportional to its sales (no fixed cost),

– the capital expenditure related to the heat/cold production and/or transmission facilities is financially supported (subsidies for the investment, compensation mechanism with guaranteed minimum revenue…).

B.3.2.1.3 **Suspensive conditions**

Heat/cold supply contracts can include suspensive conditions, that can be of particular importance for long-term contracts. These suspensive conditions can be related to:

- the DHC network operation: absence of recourse or litigation with the relevant public authority, completion of the DHC project (and possibly its commercialization) as described in the contract for new networks…
- the third party heat/cold supply project: subsidies to be granted, permitting to be obtained…
- their mutual obligations: on-time completion of the EPCC commitments, validation of performance tests by external assessors…
- contractual requirements: any term of exclusivity or priority (could be both on the demand and on the supply sides)…

These suspensive conditions must be considered carefully and their impact on project management must be clearly understood by both parties. In particular, for new projects, long and uncertain processes like obtaining subsidies or land permits by the heat/cold supplier are heavy conditions that can jeopardize the whole DHC project in some cases.

In the case where one of the stated suspensive conditions is not achieved, and depending on the condition that is not achieved, the contract may either be deemed null and void, or stipulate that both parties meet again to try to find a new agreement.

B.3.2.1.4 **Technical performances**

The expected technical performances of the energy exchange operation shall be clearly and precisely defined in the contractual agreement, and supported by any kind of tables and figures if necessary. The corresponding statement shall demonstrate the capacity of the heat/cold supplier to produce the required amount of energy over the period of time considered.

The technical criteria provided by the heat/cold supplier are usually:

- The operating temperatures at the delivery point. This delivery point being usually at a heat exchanger (see paragraph B.3.2.3.1 for illustration), the energy supplier shall provide the minimum and possibly the maximum temperature at the entrance of the heat exchanger on its side. The DHC operator shall also be required to provide a maximum temperature of the return from the DHC network on the DHC side of the exchanger.
- The minimum and possibly maximum capacity (in MW) available at the delivery point. Different levels of minimum capacity can be guaranteed over different period of time (wintertime/summertime for example).
- The operating hours. Details are discussed in paragraph B.3.2.1.5.
- The minimum and possibly maximum quantity of heat/cold available on an hourly, daily, weekly, monthly, seasonal (winter/summer) or yearly basis. According to the technical processes at stake, this can be more or less precisely forecasted on the heat/cold supply side, and it quantifies the commitment of the heat/cold supplier. These quantities can vary and be detailed by year in case of a ramp-up period for example. The quantities of energy effectively off-taken by the DHC operator are usually much harder to predict and constitute in some cases the core of the contractual agreement through the “take-or-pay” mechanism discussed in paragraph B.3.2.2.3.

The different technical constrains that have to be taken into account to assess the feasibility for a third party supplier to a DHC network are discussed in section C.1.3.

B.3.2.1.5 **Operating hours**

First of all, the start-up date of the energy exchange operation must be discussed between the two parties by taking into consideration their respective project constraints. The agreed date must be specified in the contractual agreement.

Then, the basis for operating hours must be defined and can vary over the years in case of a ramp-up period for example. The expected operating hours are usually defined in percentage of the total number of hours in one year (or in weeks or months for short and medium-term contracts) and shall be specified by the heat/cold supplier based upon:

- the maximum number of hours for scheduled downtime (for maintenance e.g.), with a possible maximum set for wintertime,
- the maximum number of hours for unscheduled downtime (for operational issues e.g.),
- the maximum number of hours when the delivered capacity is lower than the guaranteed minimum capacity while the demand is higher than this minimum.

Non-compliance with this clause is sanctioned by penalties discussed in paragraph B.3.2.2.4.

These expected operating hours are taken into account when specifying the quantity of energy that can be provided by the supplier in paragraph B.3.2.1.4. In the same way, the quantities of energy off-taken by the DHC operator that are the object of the "take-or-pay" mechanism discussed in paragraph B.3.2.2.3 shall also be calculated by taking into consideration the scheduled and unscheduled downtime of the DHC network.

B.3.2.1.6 **Back-up**

In case of schedule or unscheduled downtime or in case of major shutdown of the heat/cold production unit, the DHC operator must plan short and long-term back-up solutions.

Depending on the type of production facilities and on the availability of heat/cold, back-up solutions can be proposed by the third party energy supplier. This would generally rather be the case for energy suppliers exporting excess heat/cold (as a by-product of their main activity) if additional existing capacities can ensure back-up heat/cold production. This can be the case for a power generation plant or for another DHC networks with extra capacity for example. The obvious advantage of this scheme is to benefit from a back-up solution from the same fuel, with the same properties and maintaining the CO_2 content of the DHC network and the possible tax incentives applicable (for renewable and waste heat/cold e.g.).

Third party energy supplier whose main activity is the production of heat/cold (a biomass plant for example) may also propose back-up solutions. However, the back-up production unit would generally be a gas boiler (flexible and relatively cheap solution) and the corresponding investment and operating costs will be reflected in the exported heat/cold price. Therefore, except for special constraints (space limitation at the DHC operator's site e.g.), it is usually more convenient and more efficient that the DHC operator owns and operates its own back-up solution in this case. As an alternative, the third party could also propose to rent some available space on its own site to the DHC operator so that the latest can build and operate its back-up production unit (issues related to insurances and decommissioning need to be carefully addressed in this case however).

B.3.2.1.7 **Metering**

The installation of metering devices shall allow to record the quantity and characteristics of the energy exchanged between both parties, to validate the operating hours, and to check the absence of malfunctions and/or the need for maintenance (leaks, deterioration of the exchange capacity…).

Even though the metering devices used for invoicing are usually operated by the energy supplier, both parties usually have their own metering systems on their respective side in order to check the data communicated by the other party and to provide back-up in case of malfunction on one side. As the delivery point is usually the heat exchanger (see paragraph B.3.2.3.1 for illustration), the typical arrangement is:

- Metering devices installed, operated and maintained by the DHC operator on the network side, to monitor supply and return temperatures (and flow rate and pressure for operational issues),
- Metering devices installed, operated and maintained by the third party heat/cold supplier on the energy production unit side, to monitor supply and return temperatures (and flow rate and pressure for operational issues).

Each party should grant access to its metering devices to the other party for data collection.

In case of litigation between the two sides, each party should be entitled to require the verification of the metering device in question by an external neutral auditor. The cost associated to the audit and the possible replacement of the device should be allocated to the defaulting party.

B.3.2.1.8 **Communication**

Both parties shall commit to collaborate on communication to facilitate their respective activities. This commitment may address the following topics:

- Provide production and off-taking forecast, usually on a yearly and monthly basis, in order to facilitate the operations in the other party's facilities (technical management, purchasing…).
- Warn each other of any incident occurring or likely to affect the operation or safety of the other party, indicating the presumed cause, the probable duration of the disturbance and the measures taken to remedy the incident and/or to avoid a recurrence of the incident.
- Share the data recorded by the metering devices discussed in paragraph B.3.2.1.7. Additional data related to their respective activity might be requested as well (total heat/cold sales on the DHC network, heating/cooling degree days, heat/cold production on the third party side, instantaneous capacity reading, fuel tonnage…).
- Notify each other if the quantities of energy delivered or off-taken do not meet their respective obligations. This notification shall be addressed officially with the corresponding supporting documents.
- Optimize the dates selected for scheduled downtime.
- If necessary, obtain the different permits required for the construction and operation of their respective facilities.

B.3.2.2 Financial issues

B.3.2.2.1 **Tariff structuration**
The tariff for exported heat/cold can be structured in various ways according to the type of energies, the availability, the load profiles on the demand side... The two main dimensions that are used to establish tariff structuration are:

- Period-dependent rates: the tariff evolves according to the time period (peak/off-peak period, winter/summer…).
- Quantity-dependent rates: the tariff decreases by tranche according to the quantities off-taken (for example in Figure 1, the winter tariff is 27 €/MWh for the first 35 GWh, 24 €/MWh for the next additional 15 GWh, and 22 €/MWh for any additional GWh).

None, one or both of these dimensions can be applied to build tariff structuration. The choice of the selected option must be carefully assessed by both parties and should be supported by evaluating both the technical and economic impacts on their activity in a global approach.

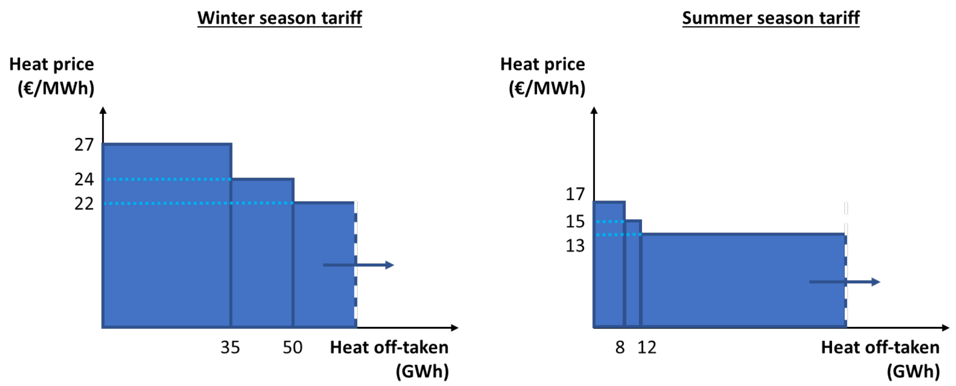


Figure 59: Example of tariff structuration using both period-dependant and quantity-dependant rates (Source: own display from a theoretical example)

Regardless of the selected option, the tariff could be usually structured in two ways:

- With one fixed term, usually covering the related investment costs, proportional to the available capacity usually and expressed in €/MW, and one proportional term, usually covering the operation and maintenance costs, proportional to the quantity of energy exchanged and expressed in €/MWh.
- With only one proportional term, proportional to the quantity of energy exchanged, expressed in €/MWh. In this case, fixed costs are covered through an additional "take-or-pay" condition (discussed in next paragraph).

Covering the related investment cost may not always be necessary, if the installation is already amortized (case of a wastewater treatment plant e.g.) or if the required investments supported by the third party supplier to allow this heat/cold exchange are limited and/or subsidized for example.

B.3.2.2.2 **Take-or-pay**
The third party heat/cold supplier usually needs to cover significant fixed costs associated to the heat/cold export (exceptions exist in contexts where short to medium-terms contract

are found as discussed in paragraph B.3.2.1.2). When a tariff structuration with a single term proportional to the quantity of energy exchanged (in €/MWh) is proposed, an additional mechanism needs to be implemented in order to secure a minimum revenue to the heat/cold supplier, regardless of the energy effectively off-taken by the DHC operator.

This mechanism is usually a "take-or-pay" condition, which guarantees a minimum sales volume, expressed in MWh of heat/cold. If the DHC operator effectively off-takes more than the "take-or-pay" minimum quantity, the condition is suspended; if not, the DHC operator is charged for this minimum quantity, according to the tariff structuration defined (discussed in paragraph B.3.2.2.1).

Depending on the constraints of both parties, the "take-or-pay" quantity can be expressed on hourly to yearly basis. As the heating/cooling demand of a DHC operator varies very significantly over the year (see Figure 2 illustrating demand seasonality), and as its thermal storage capacities are usually limited, the "take-or-pay" quantity is usually adjusted on seasonal basis *a minima* (winter/summer periods, to be defined in the contract). Furthermore, the "take-or-pay" quantity can vary and be detailed by year in case of a ramp-up period for example.

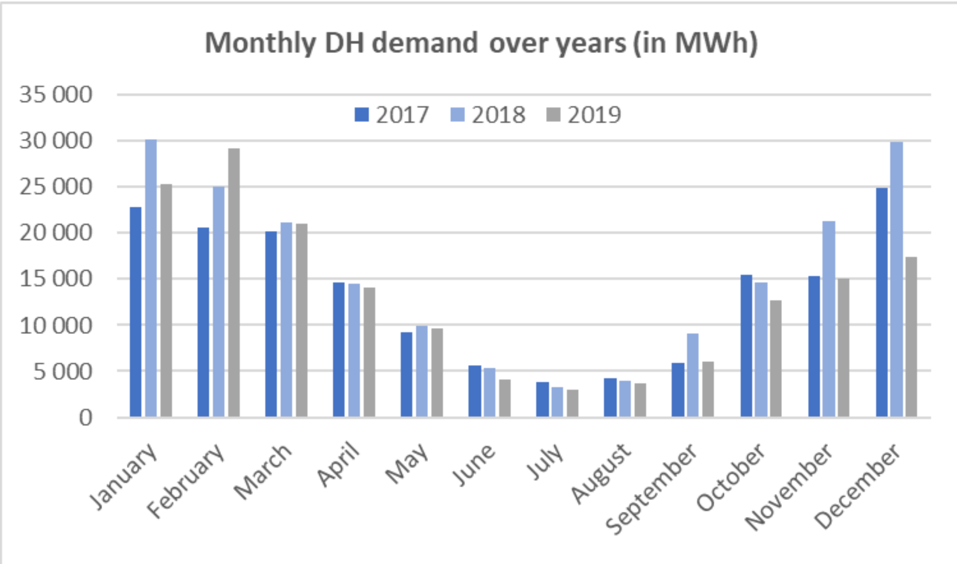


Figure 60: Example of monthly demand on one DH network (Source: own display from a theoretical example)

As this "take-or-pay" level commits the off-taker to purchase a minimum quantity of energy over the whole duration of the contract, this quantity is usually negotiated with great caution. Here, the DHC network operator has to carefully assess its production forecast over years in order to find the maximum "take-or-pay" quantity that it can bear with limited risk.

In situations where the third party heat/cold supplier is in a dominant position, this party may request the DHC operator to prove that the heat/cold demand on the network is supplied in priority with the heat/cold from the third party (which can also be a request from the local public authority) and add an additional clause of priority off-take: for example, the "take-or-pay" level can be set at 50 GWh but the DHC operator might commit itself to off-take 60 GWh in priority from the third party supplier when the network demand is sufficient. This additional clause can also turn to be an efficient leverage for the DHC operator to negotiate a lower "take-or-pay" level.

The impact of prioritizing the third party heat/cold supply over other production units is illustrated in Figure 3. In this example, the annual production profile is provided for a DHC with a 4 MW biomass unit, 3 MW available from imported waste heat, and 12 MW gas unit for peak load and back-up. It can be seen that leaving the biomass unit as the first priority in production with no minimum quantity of imported waste heat (option on the left) allows to maximize production from the biomass unit (in green) over the year, while setting the imported waste heat as the first priority in production with a possible minimum quantity of energy imported (option on the right) will increase significantly the quantity of imported waste heat (in orange) and reduce the quantity of heat produced by the biomass unit. Therefore, the impact of such options for the DHC operator is clearly significant, both on operational and economic dimensions.

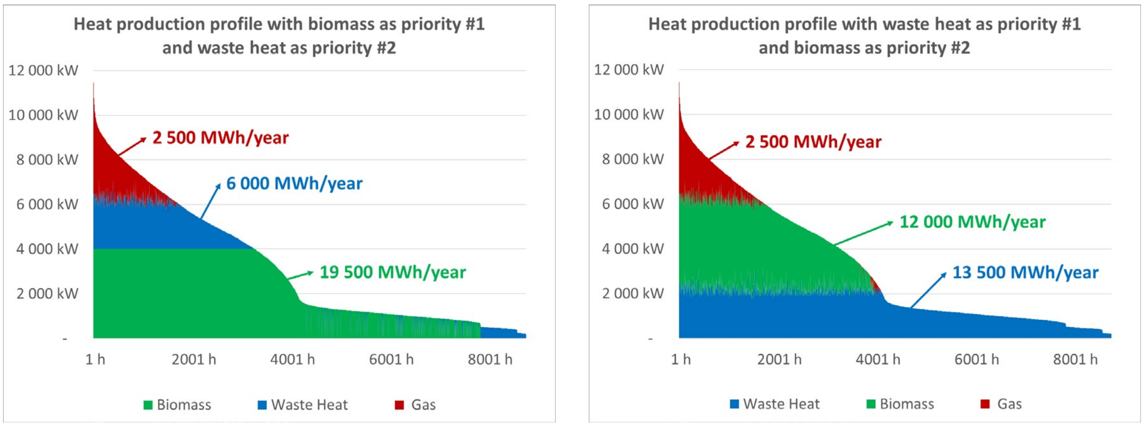


Figure 61: Heat production profiles illustrating the impact of prioritizing the different production units available (Source: own display from a theoretical example)

B.3.2.2.3 **Penalties**

The risk of occurrences of contract breaches and the amount of corresponding penalties must be considered and assessed carefully by both parties.

- Penalties in favor of the third party heat/cold supplier:
  - These penalties are usually gathered under the "take-or-pay" clause, so that if the DHC operator has not imported the minimum quantity of energy over the period agreed (week, month, season, year…), it has to pay at the end of the period for this minimum quantity at the tariff defined in the contract. In the case of priority clause for extra-waste/cold on top of the "take-or-pay" level (as discussed at the end of previous paragraph), this extra-waste/cold might be charged at a reduced rate.

- In the event of failure to supply heat/cold on the agreed date, of interruption or insufficiency of heat/cold supply, the DHC operator may also call for penalties:
  - To cover the extra cost of the substitute fuel for the missing quantity of energy over the period agreed (week, month, season, year…). As the associated extra costs (start-up of an additional boiler, additional maintenance, extra fees on fuel spot markets…) are complicated to evaluate and to justify and as they remain negligible compared to substitute fuel cost, there is usually no cost coverage other than the strict cost of the substitute fuel in €/MWh (MWh of gross energy). The content of the supporting documents accompanying the claim (total net cost of the substitute fuel, performance reports to calculate the yield of the substitute

boiler, quantity of energy produced and sold on the DHC network over the period…) shall be detailed in the contract.

- To cover the associated extra costs and taxes that could apply due to the use of a substitute fuel that might be fossil (gas in most cases today). These extra costs could be linked to a degraded CO2 quotas balance (European Union Emission Trading System) or to a dedicated tax on the consumption of fossil fuel for example, and will depend on the national context and on the DHC network characteristics. These additional extra costs shall be considered carefully by the DHC operator in order to have them covered as well by the penalties. Special care might be taken as well to anticipate the calculation and payment of such penalties since the timing of these extra costs might not be the same as the "take-or-pay" level (annual CO2 quotas calculation vs. monthly minimum heat/cold available from the third party e.g.).
- To cover the loss of tax incentives that may be granted to DHC operators according to their energy mix (reduced VAT for DHC networks using a certain share of renewable and/or waste energies e.g.). However, the negotiations of this point is usually a thorny issue since the failure of the third party heat/cold supplier alone might not justify entirely the decrease of the renewable and/or waste energies share in the DHC energy mix (as other renewable and/or waste energies back-up solutions could be implemented by the DHC operator). Therefore, this clause shall be assessed in very precise details by both parties in function of the DHC production features. A practical solution might be to adjust the level of penalty proportionally to the weight of the third party waste heat/cold in the global energy mix of the DHC network.

B.3.2.2.4 **Price update**

Like other energy supply contracts of this type, a price update mechanism shall be implemented to manage inflation for mid and long-term contracts. The mechanism is usually defined by the following price update formula:

$$\mathbf{P_n = P_0 \times F_n}$$

where P_n is the price for the ongoing period n

P_0 is the initial price as defined in the contract at the date of signature

F_n is the following update function

$$\mathbf{F_n = x_f + \sum_{i=1}^{m} x_i \times \frac{index_{i_n}}{index_{i_0}}}$$

where x_f is the fixed part of the tariff and x_i are the weights of the different components of the variable part ($x_f + \sum x_i = 1$)

$index_{in}$ is the value of the selected index i for the ongoing period n

$index_{i0}$ is the initial value of the selected index i as defined in the contract at the date of signature

The variable part of the tariff is therefore composed of a weighted sum of different indexes ratio, quantifying the upward or downward evolution of these indexes over time. These indexes are published by professional organizations and are based on statistics to reflect the different cost evolutions by business sector (construction, energy, manufacturing, services…) and by activity (raw materials supply, fuel supply, manpower…).

The choice of these indexes and the associated weights in the update function F_n shall reflect the cost structure of the third party energy supplier that varies with time, i.e. the operational expenditure and the capital expenditure incurred over time if any. This is a very important point of the contract since some indexes may turn to be very sensitive to inflation (fuel supply for example) and may therefore significantly impact prices over time.

Another important issue to consider carefully is the value of the fixed part. This value shall reflect the cost structure of the third party energy supplier that does not vary with time, i.e. the initial capital expenditure and some constant operational expenditure if any. Therefore, the value of the fixed part can be very different from one project to another: a biomass unit built for the purpose of exporting heat to a DH network will have a much higher fixed part than a running steel factory that only exports excess heat from its main process. As this value determines the share of tariff that is not exposed to inflation, it usually has a strong impact on prices over time (the higher the value, the less volatile the prices).

B.3.2.2.5 **Invoicing**

The invoicing process shall be defined as well in the contract. The timing of this process shall be related to the period (weekly, monthly…) used for the tariff structuration and the "take-or-pay" level if any. Two levels of due date can be introduced:

- A short-term due date (monthly for example) to charge the quantity of energy that was effectively exported (or the "take-or-pay" level if this quantity is lower and if the "take-or-pay" level is defined over this short-term period) at the updated price (according to the update function discussed in the previous paragraph).
- A long-term due date (yearly for example) to regularize accounting records by taking into account the "take-or-pay" level if applicable and other possible penalties (discussed in paragraph B.3.2.2.3).

Payment due date and additional penalties for delay might be defined as well.

B.3.2.2.6 **Revision clauses**

For mid and long-term contracts, specific clauses shall be implemented to revise prices and their indexes over the contract period. Both parties may agree to meet expeditiously and discuss new terms for prices and indexes in the following cases (additional cases can apply for specific situations):

- After a first commercial period (5 years for example) and then regularly (every 5 years for example).
- If the quantity of heat/cold available on the supply side or required on the demand side has increased by a certain amount (+25% for example).
- In the event of the application of new regulations, in particular tax or environmental regulations unknown at the time of the conclusion of the contract and affecting the economic equilibrium of one of the parties. In this case however, the economic impact of such event might be shared between the two parties and/or the price revision might be capped.

The contract may define a maximum period of time to reach agreement and precise that the on-going terms are applicable during this period.

B.3.2.3 Other issues

B.3.2.3.1 **Scope of services**

The scope of services shall define the ownership of both the buildings and the facilities involved at the delivery point, and the associated obligations regarding operation and maintenance. As the delivery point is usually the heat exchanger, this scope will detail precisely which party is in charge of, at least, the following:

- Construction, operation and maintenance of the heat exchanger.
- Construction, operation and maintenance of the network and associated equipment (piping, valves, regulation, instrumentation, pumps…), upstream and downstream of the heat exchanger. This should comply with the heat exchanger technical specifications.
- Fluid supply and water treatment, upstream and downstream of the heat exchanger. This should comply with the heat exchanger technical specifications.
- Construction, operation and maintenance of the metering system, upstream and downstream of the heat exchanger (as detailed in paragraph B.3.2.1.7).
- The construction and maintenance of the building hosting the heat exchanger (the so-called "substation"). Access conditions to this building by the other party might be detailed (as already discussed in paragraph B.3.2.1.7).
- The re-invoicing of some services when applicable (electricity and water supply like in the example below for example).

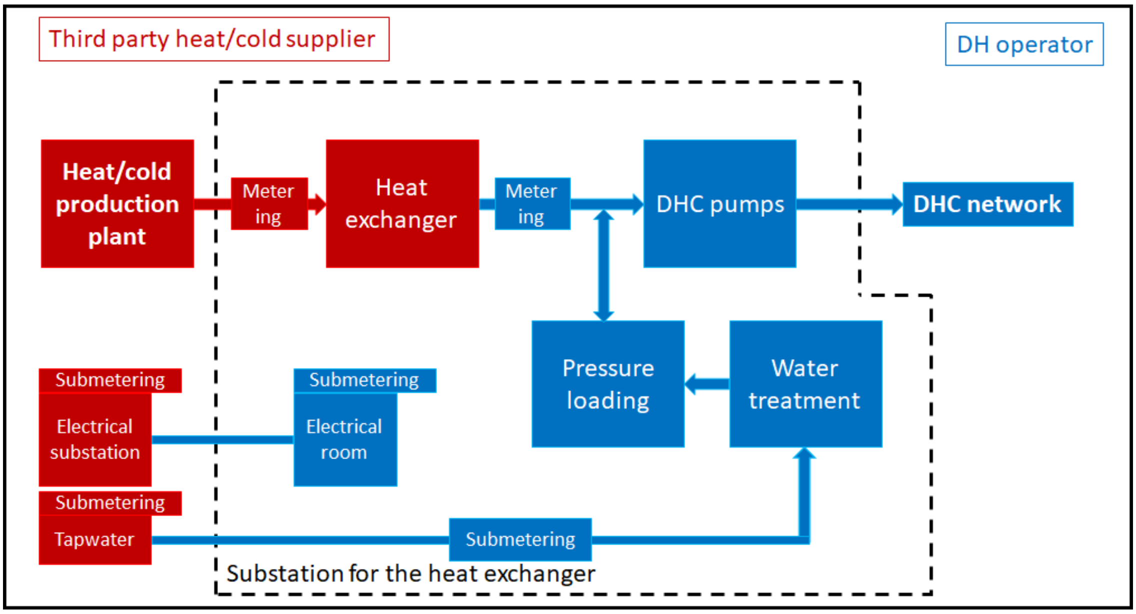


Figure 62: Example of diagram defining the scope of services (in this example, the substation is owned by the third party supplier and located on its site) (Source: own display from a theoretical example)

According to the choices made on the previous points and on the substation ownership, an occupancy agreement might be edited separately to set the terms of the operation. This might include an occupancy fee in some cases.

B.3.2.3.2 **Insurances and responsibility**

Both parties shall commit themselves to assume all responsibilities related to the operations, services and activities incumbent upon them under the terms of the contract. They shall be responsible for their respective staff and for safety.

The contract shall detail that each party shall be responsible for any dispute of any nature whatsoever relating to its activities and services. Each party shall fully indemnify the other party against all operating losses, charges, liabilities, costs, damages and interest (without this list being exhaustive) which it may incur as a result of its own fact or fault or of its possible subcontractors.

To this end, both parties shall undertake to take out all useful and sufficient insurance to cover the said commitments with an approved and solvent company.

The contract shall also define the cases of Force Majeure and their consequences (suspension of the different obligations, contract termination with or without compensation…).

B.3.2.3.3 **Termination**

The conditions for contract termination shall be detailed in the contract, and describe and quantify:

- the possible causes: serious breach, default of payment, force majeure…
- and the associated consequences: compensation or not.

In the case of a DHC operator operating a network owned by the municipality, the contract may specify that the third party heat/cold supplier automatically agrees to assign the present contract to the municipality or to any company that may replace the current DHC operator at some point. The counterpart of this proposal (having the municipality or another company take over the current operator’s obligations) is not necessarily automatic as it has been discussed in paragraph B.3.2.1.2.

B.3.2.4 Special case of TPA-regulated countries

In countries where TPA is regulated like Estonia or Lithuania (see section B.3.1.2), these contractual modalities are set by law. In these countries, the heat supply is organized by a tendering process over relatively short periods (monthly to annually).

B.3.2.4.1 **Technical issues**

The technical issues described in sections B.3.2.1 and B.3.2.3 are well detailed by the law and required in the tender contract for heat supply. Most of them are also already required when the independent heat producer establishes a connection request to the DHC operator. In Lithuania for example, to apply for the connection to a DHC network, an independent heat producer must comply with the following technical conditions set by the DHC operator [69]:

- the connection point to the heat transmission network,
- the heat exchanger installation location,
- the minimum technical requirements for the heat exchanger,

- the preliminary heat metering location,
- the location of heat metering devices,
- the location of valves,
- the connection technical requirements (network data at the specified point of connection: pressure in supply and return lines, pressure differences, minimum and maximum heat carrier flow rates, temperature graphs and other technical requirements),
- any other requirements necessary for technical and economic reasons in the opinion of the heat supplier, including requirements for commercial metering devices and data transmission.

B.3.2.4.2 **Financial issues**

The financial issues described in section B.3.2.2 do not directly apply to this tendering process. In Lithuania for example, auctions are organized by the DHC operator on a monthly basis [64]. Both the independent heat producers and the DHC operator compete in these auctions. To organize these auctions, DHC operators update every month their heat demand forecast and estimate the corresponding heat volume (70% in Lithuania) that enter the competitive tender. Additional volumes are reserved for the DHC operator itself to ensure peak and back-up production.

The competitors submit their offers by providing a minimum available capacity, a minimum heat volume available on the given period, and a corresponding heat price in €/MWh. The tendering process is driven by the lowest prices available, and a ceiling heat price is set upfront by the DH operator according to a methodology set by the national regulator (to consider the updated cost of fuels and to integrate minimum energy yields). This way, the DHC operator books for the period certain volumes of heat supplied by different producers and at different prices (on the example depicted on Figure 63, the DHC operator puts 18 GWh in auction, and finally off-takes 7 GWh from competitor 1, 9 GWh from competitor 2, and the remaining 2 GWh from competitor 3). When competitors bid at the same heat price, a priority order applies based on technology and energy criteria (ranging from high-efficiency cogeneration units using renewable energy sources or incinerating waste to fossil fuel boilers in Lithuania).

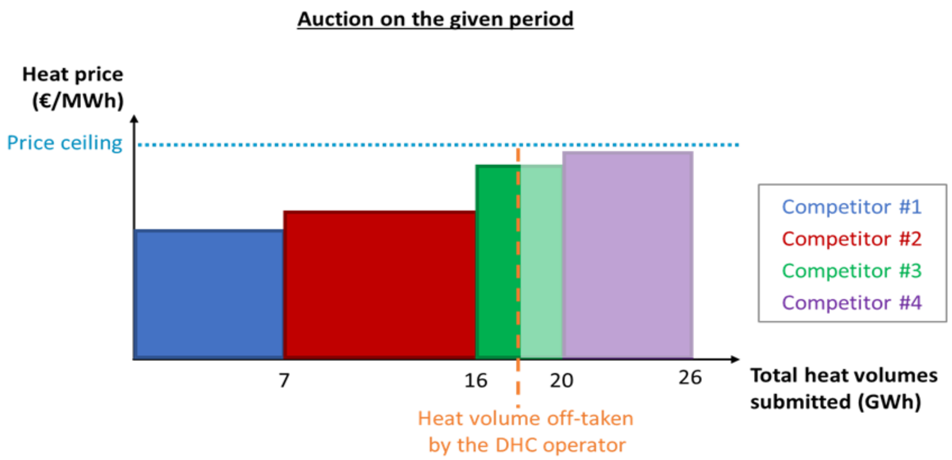


Figure 63: Heat auction principle (source: own display from a theoretical example)

In this system, the independent heat producers bear all the expenditures related to the connection to the DHC network (including the heat exchanger). These expenditures can be significant in some cases (e.g. when the heat producers is located far away from the DHC infrastructure) and are a key element of the producer's competitiveness in the tenders. The different technical constrains that have to be taken into account to assess the technical and economic feasibility for a third party supplier to a DHC network are discussed in section C.1.3.

B.4 Overview of national building regulations, urban planning and other urban regulations affecting the use of district heating and cooling in buildings

In this section, an overview of the impact of national building regulations and urban planning regulations on DHC system in EU-28 countries is provided. A thorough investigation of building regulations and its impact on DHC systems in 10 focus countries[72] as well as detailed analysis of 13 city case studies[73] with regard to H&C planning and DHC development can be found in Annex 5.

B.4.1 Mutual impacts of national building codes and DHC

According to the Article 9 of the Energy Performance of Buildings Directive (EPBD), Member States have to ensure that all new buildings are nearly zero-energy buildings (nZEB) from 2021 onwards (public buildings from 2019 onwards). New buildings constructed between 2020 and 2050 are expected to have a significant share of 20-25% in the building stock by the year 2050 [18]. In the remaining 75%, renovations can push the building stock toward low carbon and more nZEB. Therefore, nZEB can characterize energy consumption in the future European building stock as its share via construction of new buildings and renovation of existing buildings increases. The increasing share of nZEB will have a direct influence on the heat demand and therefore, heat supply options. This chapter provides an overview on the mutual impacts of nZEB and DHC systems based on the most recent national nZEB definitions and Primary Energy Factors (PEF) of DHC systems in the Member States.

In recent years, many studies have traced building renovation activities and the uptake of the nZEB in the Member States [70] [71] [72]. The primary goal of these studies is to trace or identify the impact of EPBD on decarbonisation in the building sector. However, none of them investigated the mutual dependency of nZEB and DHC systems, i.e. how the availability of DHC has affected nZEB and vice versa.

A cross-country overview of the key aspects of national nZEB definitions in EU-28 countries was provided in 2015 by Buildings Performance Institute Europe [73]. This overview provides a good insight to the definition of the nZEB in Member States. It includes among all, the status of the nZEB definition, year of enforcement, maximum primary energy consumption and the share of renewable energy in new and renovated, public and private buildings. Since 2015, national nZEB definitions have evolved and have been updated by some Member States. Considering the fact that EPBD does not prescribe a common approach to implement nZEB nor describes the assessment categories in detail, it is important to first screen and highlight the most recent development of nZEB definition in the Member States. Subsequently, the potential impacts of nZEB definitions on DHC systems will be investigated by putting maximum PEC, minimum share of RES and temperature demand levels of nZEB in correlation with PEFs, share of RES and temperature supply levels in DHC.

Overall, the design and interpretation of national nZEB definition have implications for the technical configuration of DHC. For example, if the national nZEB definition includes a renewable energy component, in the mid-term, the DHC supply should shift further toward renewable heat and cold generation or increase the energy efficiency in the system in order

72 Focus countries for this section are: “Advanced” Nordic countries: Finland, Denmark, Sweden; Significant markets: Germany, Poland, Austria; Eastern countries: Slovakia; Baltic country: Lithuania; “Emerging” markets: France and the Netherlands

73 City case studies are: Vilnius (Lithuania), Tallinn (Estonia), Plovdiv (Bulgaria), Frankfurt (German), Warsaw (Poland), Copenhagen (Denmark), Stockholm (Sweden), Helsinki (Finland), Ljubljana (Slovenia), Graz (Austria), Miskolc (Hungry), Oradea (Romania) and Bolzano (Italy).

to keep existing customers and obtain new ones. Therefore, the share of RES and the PEF of DHC systems are two crucial elements in studying the impact of nZEB definition on DHC systems. Beyond the significance of these two indicators on DHC systems, both can be applied to describe and evaluate the DHC technology compared to other heating and cooling solutions.

Furthermore, DHC must provide heat temperature levels that fulfil the thermal needs of the supplied buildings which are indicated by the required flow temperatures (see corresponding technical insight in sections A.2.1.2 and C.1.1.1.2). Technically, necessary DHC temperature levels may vary depending on the heat/cold distribution systems in new and renovated nZEB (using e.g. underfloor heating or radiators). As only limited temperature levels can be achieved by low temperature renewable (and waste heat based) DH, its application is only reasonable if there is sufficient low temperature heat demand by nZEB. As long as this is not the case, temperature boosters or decentral heat pumps may help to provide the required temperature level for an intermediate period. Therefore, if heat supply shall be met mainly by renewable DH, it is inevitably necessary to build new nZEB as well as to renovate the existing building stock with the aim of reaching low temperature nZEB standards. At the same time, it is also necessary to make sure that nZEB standards as defined in national building codes also explicitly include low temperature levels in the heat emission system.

In the next sections, research and review are carried out to collect information on the different national nZEB definitions and PEFs. Concerning national nZEB plans, the European Commission (EC) is collecting information on its website in the framework of the implementation of the EPBD. This website serves as a hub, where information on national nZEB definitions can be found [74]. Regarding the PEF, in 2017, Latosov et al. carried out an overview of the PEF for DHC networks in EU [75]. This study serves as a starting point. In the scope of this project, the overview will be supplemented based on overview of regulations, grey literature as well as inputs from discussions with experts across Europe and updates of the PEF for DHC networks.

B.4.1.1 Overview of the nZEB definitions in Member States

According to the EPBD, from 2021 onwards (public buildings from 2019 onwards), all new buildings in EU Member States have to be nearly zero-energy buildings. The EPBD sets requirements for EU Member States to draw up national plans for increasing the number of nZEB. The national plans shall include national definitions of nZEB that express a numeric indicator for primary energy consumption (PEC) in kWh/(m^2*y). By definition, this PEC should be covered to a significant extent by energy from renewable energy sources (RES) in new buildings and existing buildings undergoing major renovation [76].

The methodology for definition of nZEB on a national level must be based on the requirements of the EPBD; however, since these requirements are not detailed, Member States elaborate the requirements in a way that fits them best. This results in diverse national definitions of nZEB. For example, while in Hungary the mandatory share of RES for nZEB is set to a minimum share of 25 %, Germany offers several options for reaching a minimum RES share in new nZEB, which can be met diversely, e.g. using 15 % of solar heating, 50 % solid biomass or many other combinations of RES.

B.4.1.1.1 **Primary energy consumption in new and renovated nZEB**

The latest versions of national nZEB plans of EU-28 countries were investigated. In this section, we provide an actual and accurate overview of nZEB definition with regard to the primary energy consumption. Information were mainly extracted from official nZEB documents accessible under "EU countries' nearly zero-energy buildings national plans" via the EC website [74].

Table 21 shows the requirements concerning maximum PEC of nZEB in the Member States. It is important to mention that Member States do not apply indicators on PEC of nZEB in an identical manner. Even though PEC is defined numerically in kWh/(m^2*y) by all Member States, there are differences between them when it comes to details. In order to illustrate these differences, six categories were defined, which are indicated by "(1)", "(2)", "(3)", "(PE)", "Class" and "EPC" in Table 21. The comparison of different Member States in term of maximum PEC value can be performed within each category only. In the followings, the meanings of these categories are elaborated for the better understanding of them.

(1) - Non-renewable share Category:

Even though EPBD considers nZEBs as buildings with very low energy demand that is supplied mostly by RES, some Member States allow significant energy supply by non-renewable energy sources. For example, Austria and Denmark define a non-renewable maximum PEC for nZEB and therefore, allow a PEC coverage by non-renewable energy carriers.

(2) - Max. PEC in absolute values Category:

It is often the case that Member States (e.g. Estonia or Poland) define a reference building and then set a range or specific values (both in absolute values) for the maximum PEC in nZEB. In Table 21, the range for the respective PEC is depicted by a hyphen symbol (-), and in case of two values (defined for two different locations or different technical building equipment) it is shown by a slash symbol (/).

(3) - Depending on location Category:

Some Member States like Croatia and Romania use indicators for PEC depending on the location of the building in a certain climate zone. For example, in Croatia different values for PEC are applied depending on whether buildings are located in continental Croatia or coastal Croatia.

(PE) - Max. PEC in percentage share Category:

In some cases, PEC is given as a percentage value of a reference building. For example, maximum PEC for renovated non-residential buildings in France or for new non-residential buildings in Ireland. The abbreviation "PE" that is used for this category, follows the naming convention of BPIE [4] and provides a number in percent (%).

(Class) - Building Class Category:

Some Member States like Bulgaria and Lithuania indicate PEC of nZEB with reference to existing Building Classes. In such case, PEC of nZEB is not directly defined in respective nZEB plans but rather uses provisions from other national documents (e.g. building codes).

(EPC) - Energy Performance Coefficient Category:

A non-dimensional number is used by the Netherlands to indicate the energy performance of a building. The so-called Energy Performance Coefficient (EPC) is determined by dividing the calculated energy requirement of a building by a standardized energy performance. In case of a completely zero-energy building, EPC equals zero (EPC = 0). In Netherlands, the aim is to get close to EPC = 0 in nZEB.

Table 21 shows the cross-country overview on how Member States aim to implement maximum values for PEC in their respective national nZEB framework. As it can be seen in the table, some countries still have not provided a value for PEC of nZEB. It should be noted that the PEC calculation in different Member States is based on national standards, using different methods, system boundaries and default values, making a direct comparison of PEC values even more difficult. Therefore, a clear comparison between values from Table 21 is not always possible. For example, renewable PEC values should not be compared with non-renewable PEC values.

Table 21: Requirements concerning maximum primary energy consumption (PEC) of nZEB, Indicator definitions: (1) national long-term renovation strategies; (2) Max. PEC in absolute values Category; (3) Depending on location Category; (PE) Max. PEC in percentage share Category; (Class) Building Class Category; (EPC) Energy Performance Coefficient Category

Country	References	Maximum PEC for new nZEB [kWh/(m²*y)]		Maximum PEC for renovated nZEB [kWh/(m²*y)]	
		residential	**non-residential**	**residential**	**non-residential**
Austria	[77]	41 (1)	84 (1)	44 (1)	87 (1)
Belgium-Brussels	[78]	45	~90 (2)	45	~90 (2)
Belgium-Flanders	[78]	not defined yet	not defined yet	not defined yet	not defined yet
Belgium-Wallonia	[78]	not defined yet	not defined yet	not defined yet	not defined yet
Bulgaria	[79]	Class A	Class A	Class A	Class A
Croatia	[80]	41/33 (3)	-	41/33 (3)	-
Cyprus	Source: own survey with national DHC stakeholders	100 (2)	125 (2)	100 (2)	125 (2)
Czech Republic*	[81]	not defined yet	not defined yet	not defined yet	not defined yet
Denmark	[82]	20 (1)	25 (1)	20 (1)	25 (1)
Estonia*	[83]	100-145 (2)	65-170 (2)	100-145 (2)	65-170 (2)
Finland	[84]	not defined yet	not defined yet	not defined yet	not defined yet
France	[85]	50 (3)	70-110 (2,3)	80 (3)	60 % (PE) (3)
Germany	Source: own survey with national DHC stakeholders	75 % (PE)	75 % (PE)	14 % (PE)	14 % (PE)
Greece	[86]	80	85	95	90
Hungary	[87]	100	85-90 (2)	100	85-90 (2)
Ireland	[88]	45	50-60 % (PE)	125-150	-

Country	References	Maximum PEC for new nZEB [kWh/(m²*y)]		Maximum PEC for renovated nZEB [kWh/(m²*y)]	
		residential	**non-residential**	**residential**	**non-residential**
Italy	Source: own survey with national DHC stakeholders	Class A4	Class A4	Class A4	Class A4
Latvia*	[89]	95	95	95	95
Lithuania	[90]	Class A++	Class A++	Class A++	Class A++
Luxembourg	[91]	45	55 % (PE)	45	-
Malta	[92]	75	220	75	220
Netherlands	[93]	close to EPC=0	close to EPC=0	close to EPC=0	close to EPC=0
Poland*	[94]	30-50	50-60	30-50	50-60
Portugal	[95]	-	-	-	-
Romania	[96]	68-298 (2,3)	32-129 (2,3)	68-298 (2,3)	32-129 (2,3)
Slovakia	[97]	32-54 (2)	34-96 (2)	32-54 (2)	34-96 (2)
Slovenia	[98]	75-80 (2)	55	90-95 (2)	65
Spain	[99]	-	-	-	-
Sweden	Source: own survey with national DHC stakeholders	75 (2)	75 (2)	~75 (2)	~75 (2)
United Kingdom	[100]	-	-	-	-

B.4.1.1.2 **Share of renewable energy in nZEB**

In this section, a summary of the minimum share of RES in nZEB is provided based on the nZEB definition in the Member States. The screening of national nZEB plans revealed a broad diversity in Member States when it comes to the regulations about the mandatory share of RES in nZEB. Examples of France, Luxembourg and Slovakia can illustrate this diversity.

<u>France:</u>

France provides numerical values for the minimum share from RES in nZEB. For new buildings, the following options exist:

- solar heating for hot water is mandatory OR
- the energy input in DH must come from RES or recovered heat to at least 50 % OR
- the PEC of buildings requires at least 5 kWh/(m²*y) of RES.

For existing buildings in France, the options are:

- energy for heating from burning solid wood must be >50 % OR
- PEC requires electricity from RES >25 kWh/(m²*y) or PV area >10 % of usable floor area OR
- share of solar heating for hot water >50 % or at least 3m² per dwelling.

Luxembourg:

Luxembourg has not defined a minimum share of RES using numerical values; but to a certain extent, mentioned the intention for increasing RES share via qualitative statements. It is stated that the incorporation of the largest possible proportion of renewable energy is an important step to nZEB. The remaining energy demand must be produced and supplied by choosing the most efficient technical building equipment.

Slovakia:

Slovakia is among countries that the minimum share of RES in nZEB either not mentioned at all or not in detail in their nZEB definitions. The national nZEB plan of Slovakia states that the construction of buildings to meet nZEB criteria will require use of RES. It is also said that it will be necessary to prepare an analysis of the effective use of RES for each energy consumption point and with emphasis on the building category.

Considering the existing diversity among the Member States, it is important to see how they approach to this topic. Therefore, to provide a better picture of the nZEB definition with respect to the minimum share of RES in buildings, three categories are suggested:

- **Min. RES Share - Category 1**

  includes Member States that have defined a minimum share of RES in nZEB using a numerical indicator.

  Countries: Austria, Bulgaria, Croatia, Cyprus, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Slovenia
- **Min. RES Share - Category 2**

  includes Member States that have not defined a minimum share of RES in nZEB in terms of numerical indicators; but, to a certain extent, have mentioned their intention through qualitative statements.

  Countries: Estonia, Latvia, Luxembourg, Malta, Netherlands, Sweden
- **Min. RES Share - Category 3**

  includes Member States that so far have not defined nor included a minimum share of RES in their nZEB definitions.

  Countries: Belgium, Czech Republic, Denmark, Finland, Poland, Portugal, Romania, Slovakia, Spain, United Kingdom

The references for the allocation of Member States to above categories are presented in Annex 5.

B.4.1.2 Overview of the primary energy factors of DHC systems in Member States

PEC values, in order to fulfil the PEC criteria of nZEB definitions described above, need to be calculated based on the primary energy factor (PEF) per energy carrier. The PEF is defined as a numeric value that indicates the ratio between the amount of primary energy needed (energy that has not undergone any conversion or transformation process) to supply one unit of delivered energy [101]. The following equation describes the calculation of the PEF:

$$\boldsymbol{PEF} = \frac{\textbf{primary energy input}}{\textbf{delivered energy output}}$$

A significant number of EU Member States have already identified PEF for different energy systems including PEF for DHC networks. The EPBD does not provide a strict methodology to calculate PEF for different energy carriers. Therefore, it is up to the Member State to choose the exact methodology for the PEF calculation. This results in diverse methodologies for determining PEF of DHC systems.

In 2017, Latosov et al. [75] classified the PEF into **three categories**, which will be used in this report as well:

- **Single fixed:** PEF is described as a default value that is valid for all DHC networks in the country.
- **Differentiated:** The values for PEF are explicitly assigned for each technology according to the energy production technologies and energy carriers used in the DHC system.
- **Independent calculation:** The PEF for DHC is calculated independently for each DHC network by using an official, predetermined calculation method.

An overview of the PEF of DHC networks in EU-27 and UK is presented inTable 22. The “single fixed” and “differentiated” categories are presented by numerical values. The category “independent calculation” is distinguished by a “X” in the last column of the table (no numerical value is given as this will be calculated independently in each DHC network). While most Member States use only one category for PEF, some others (e.g. Croatia, Italy and Lithuania) provide information using more than one category.

Table 22: Primary energy factors for district heating and cooling for respective countries

Country	Reference	PEF for DHC							
		Single fixed	Differentiated						Calculated independently
			CHP fossil	CHP RES	DH fossil	DH RES	Waste heat	DC	
Austria	[102]	-	0.88	0.88	1.51	1.60	1.00	-	-
Belgium-Brussels	[103]	2.00	-	-	-	-	-	-	-
Belgium-Flanders	[103]	2.00	-	-	-	-	-	-	-
Belgium-Wallonia	[103]	2.00	-	-	-	-	-	-	-
Bulgaria	[104]	1.30	-	-	-	-	-	-	-
Croatia	[80]	1.523	-	-	-	-	-	-	X
Cyprus	[105]	no DHC	no DHC	no DHC	no DHC	no DHC	no DHC	no DHC	no DHC
Czech Republic	[106]	-	-	-	-	0.10 - 1.00	-	-	-
Denmark	[107]	0.85	-	-	-	-	-	-	-
Estonia	[83]	-	-	-	0.65 - 0.90	0.65 - 0.90	-	0.20 - 0.40	-
Finland	[108]	0.50	-	-	-	-	-	0.28	-
France	[75]	1.00	-	-	-	-	-	-	-
Germany	[109]	-	-	-	-	-	-	-	X
Greece	[110]	0.70	-	-	-	-	-	-	-
Hungary	[111]	-	-	-	-	-	-	-	X
Ireland	[112]	-	-	-	-	-	-	-	X

Country	Reference	PEF for DHC							
		Single fixed	Differentiated						Calculated independently
			CHP fossil	CHP RES	DH fossil	DH RES	Waste heat	DC	
Italy	[113]	1.50	-	-	-	-	-	0.50	X
Latvia	[114]	-	0.70	0.00	1.30	0.10	-	-	-
Lithuania	[115]	0.40 - 0.91	-	-	-	-	-	-	X
Luxembourg	[116]	-	-	-	-	-	-	-	X
Malta	[117]	no DHC	no DHC	no DHC	no DHC	no DHC	no DHC	no DHC	no DHC
Netherlands	[118]	-	-	-	-	-	-	-	-
Poland	[113]	-	0.80	0.15	1.20 - 1.30	-	-	-	-
Portugal	-	no info	no info	no info	no info	no info	no info	no info	no info
Romania	-	-	-	-	-	-	-	-	-
Slovakia	[119]	-	0.70	-	1.30	1.30	-	same as DH	-
Slovenia	[120]	-	1.00	1.00	1.20	1.20	-	-	-
Spain	Source: own survey with national DHC stakeholders	no PEF	no PEF	no PEF	no PEF	no PEF	no PEF	no PEF	no PEF
Sweden	[121]	-	-	-	1.00	1.00	-	1.00	-
United Kingdom	[122]	-	1.051	1.051	1.090 - 1.180	1.042 - 1.501	1.063	-	-

B.4.1.3 How nZEB definition can affect heat supply by DHC

In order to understand the impact of the nZEB definition on DHC, at least three points should be studied: **first**, the mutual impacts of DHC and maximum PEC in fulfilling nZEB requirements, **second**, the mutual impacts of DHC and minimum share of RES in nZEB requirements and **third**, the correlations between temperature level demand of nZEB and temperature level supply by DHC. These points are elaborated in the following.

The PEC of a building is the product of its final energy consumption and the respective PEF of the used energy carrier. The maximum PEC of a building must be expressed in kWh/(m^2*y) in national nZEB definitions. Concerning the correlation between DHC network and maximum PEC in nZEB, the decisive factor is the PEF of the DHC network. As previously shown in Table 22, most Member States have already elaborated PEF for DHC individually by themselves. Naturally, in case of high PEF, the DHC system can only be used for supplying nZEB with a lower final energy demand in order to still comply with the maximum permitted PEC of nZEB. In other words, DH systems can be used for the heat supply of nZEB as long as the application of respective PEF for DH does not result in failure to comply with the maximum permitted PEC.

In addition, the minimum share of RES in nZEB imposes restriction on the heat supply by DHC. If the minimum share of RES is pointed out numerically in a national nZEB definition (which is not always the case as it was shown in section B.4.1.1.2), the heat and cold supply of nZEB by DHC depends on how countries assess their DHC networks regarding used energy carriers and thus, PEF. For example, some Member States consider DHC supply equivalent to RES (e.g. Austria) or permit to cover PEC of nZEB by DHC regardless of the energy carrier used (e.g. Denmark and Finland). Such cases can be considered as supportive measures for the DHC systems since DHC can be used for heat and cold supply of nZEB anyway. Most Member States, however, do not consider DHC heat or cold supply purely as renewable or non-renewable source. Considering the fact that the generation mix of the DHC systems in different networks is also different and may even vary from year to year, based on economic or climatic changes, no valid general statement regarding the heat and cold supply of nZEB by DHC can be made. Therefore, the mutual impact of the nZEB requirements and DHC systems in such cases should be investigated independently within each single DHC network and based on its generation mix.

Thus, considering the PEC constraints imposed in nZEB regulations, the connection of nZEBs to DHC systems is feasible as long as the energy mix applied to the respective DHC system (i.e. PEF) ensures the maximum PEC value imposed to nZEB. However, from a more technical point of view also the demand and supply temperatures of nZEB and DHC need to be considered.

In general, heat from a grid can be used by buildings as long as the temperature demand of the building is lower than the heat supply temperature. Basically, new and existing buildings can therefore be supplied by high temperature district heating. In case of low temperature grids, existing buildings with demand for higher temperatures can only be supplied if – on the building level – the supplied temperature level can be increased to the required level (e.g. using heat pumps).

Existing old buildings tend to have high heat demand due to their inefficient envelope quality, which typically require to be supplied with high temperature heating systems. The increase of existing and new nZEB share in the building stock will lead to lower heat demands in the building stock, which can facilitate the low temperature heat supply, e.g. via low-temperature DH systems. This principle is followed by DH operators. While the supply temperature during cold seasons is high, it is normally reduced during the warm seasons due to lower heat demand. On the DH side, reduction of temperature levels can potentially reduce the grid losses and facilitate the integration of local low temperature excess heat sources e.g. from data centers or super markets (see corresponding technical insight in section C.1.1.1.2). In this way, lower emission levels can be achieved. The feasible minimum supply temperature level in a DHC grid should of course be defined based on the individual requirements in connected buildings and feasible adjustments in the DH system. **Hence, the type of buildings connected to a DH system and the type of the DH system are closely interrelated.** This shows the relevance of building codes and in particular nZEB definitions for the development of the DHC sector.

In addition to the links between nZEB evolution and possible DH supply temperature levels, there is also a feedback loop between the DH supply temperature level, the PEF of this DH systems and thus the possible accountability of DH with nZEB requirements. If a decrease in temperature levels in DH is feasible, the DH operators are able to feed-in a higher share of renewable heat sources, in particular solar, ambient and geothermal heat. This will reduce the PEF and thus increase the attractiveness for DH for future nZEBs.

B.4.2 National regulation and urban planning

Spatial planning refers to the methods used largely by the public sector to influence the future distribution of activities in space [123]. Spatial planning sets boundaries for energy production, distribution and consumption [124]. Spatial heating and cooling planning is part of spatial planning because also energy infrastructures have to be planned and their locations, right-of-way determined and granted.

Urban planning also includes the planning of energy infrastructures usually in line with regional and national spatial planning. The potentials for decarbonising the H&C sector highly depend on spatial planning issues for optimal interlinking of demand and supply. Spatial H&C planning considers political framework conditions and feeds into the political discussion. Hereby, policies can be developed to implement conditions that allow energy savings and the development of renewable H&C technologies.

In promoting the decarbonisation of the H&C sector, both Member States and local authorities play an important role. National legal provisions and policies can trigger spatial H&C planning on local level e.g. by setting general goals and principles for spatial planning. Although the local authorities are usually dependent on national laws, the development of the municipal energy system lies to a large extent on the municipal government. It is often the municipal governments who set land use plans for building schemes or priority zones for development of DHC. In this section, national urban policies and their impact on urban regulations on local level are investigated.

B.4.2.1 Overview of the spatial heating and cooling planning in national urban regulations

A National Urban Policy (NUP) is an essential policy instrument for the control of urbanization in order to achieve national goals. NUP can complement local urban policies to create necessary conditions for a sustainable urban development. In this section, NUPs in Member States are screened to see if energy related topics are part of these legislations.

The Territorial and Urban Strategies Dashboard (STRAT-Board) provides a summary of NUPs in EU Member States [125].

Members States in terms of availability of NUP fall into 3 categories of countries with:

- **Explicit NUP**: There is an explicit NUP in place.

  Czech Republic, France, Germany, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden.

- **Partial NUP**: Countries in this category have national policies in place that guide urban development. However, these policies are not brought together in form of NUP.

  Belgium, Denmark, Estonia, Finland, Greece, Hungry, Ireland, Latvia, Lithuania, Luxembourg, Malta, Romania, Slovenia, United Kingdom

- **No NUP**: There is no explicit NUP in place.

  Austria, Bulgaria, Croatia, Cyprus and Italy.

The STRAT-Board [125] also shows which common EU Thematic Objectives (TOs) are targeted in the NUPs or national urban strategies via the European Structural and Investment Funds (ESIF). The TO4 is relevant for the focus of this report. It deals with supporting the shift towards a low-carbon economy in all sectors by:

a) promoting the production and distribution of energy derived from renewable sources;
b) promoting energy efficiency and renewable energy use in enterprises;
c) supporting energy efficiency, smart energy management and renewable energy use in public infrastructure, including in public buildings, and in the housing sector;
d) developing and implementing smart distribution systems that operate at low and medium voltage levels;
e) promoting low-carbon strategies for all types of territories, in particular for urban areas, including the promotion of sustainable multimodal urban mobility and mitigation-relevant adaptation measures;
f) promoting research and innovation in, and adoption of, low-carbon technologies;
g) promoting the use of high-efficiency co-generation of heat and power based on useful heat demand.

Screening of the STRAT-Board revealed that all Member States with an exception of Malta benefit from ESIF for targeting TO4 in their NUPs and national urban strategies. It is however, not clear, to which extent heating and cooling planning is addressed in the strategies.

Furthermore, it was revealed that heating and cooling planning are seldom a direct focus of the NUPs; however, it is affected by other aspects of NUPs. For example, the section 4 in paragraph 19 of the Danish Planning Act states: "*The municipal council shall exempt from a local plan's provisions for connection to a collective heat supply plant as a condition for commissioning of new buildings when the buildings are listed as low-energy buildings, cf. paragraph 21 a*" [126]. In case of Germany, heating and cooling planning is rather a focus of Klimaschutzplan 2050 [127] than Germany's NUP. In France, Law no. 2015-992 on Energy Transition for Green Growth (Energy Transition Law) addresses heating and cooling networks. In Sweden, the Law (1977: 439) on municipal energy planning states that municipalities shall provide current plans for the supply, distribution and use of energy. In countries with no NUP in place (Austria, Bulgaria, Croatia, Cyprus and Italy), other regulations are in place for the topic of urban energy planning.

It can be inferred that NUP, in term of spatial heating and cooling planning, often plays as a complementary regulation to other regulations that address energy planning or heating and cooling planning.

B.4.2.2 Spatial heating and cooling planning in urban regulations and plans

Successful H&C planning requires close collaboration between local authorities and central governments [128], [129], [130]. The Danish heating supply law for example lays down that city councils, in cooperation with utility companies and other stakeholder, have the responsibility for heat planning in municipal areas. City councils can therefore impose buildings to connect to the public heat supply, which results in strengthening DHC [131]. However, these steps can be taken on a local level because respective national regulations from the government exist (namely Heat Supply Act No. 347 of 2005). The question that arises in order to promote DHC in the EU is: which examples can be taken to show how to achieve successful spatial H&C planning?

Local authorities have a strategic role to play in future H&C planning. The United Kingdom (UK), Denmark and Sweden can be taken as examples, in which effective spatial H&C planning is supported on a local level. Detail can be found in the national explanations below.

United Kingdom: Local governments are playing a pioneering role in responding to climate change and energy security, often by being more pro-active than the national government. In the UK, the Local Government Act of 2000 and the Local Government White Paper of 2007 allow local governments to be a strategic leader by coordinating, facilitating and directly engaging in the development of community energy projects. To achieve successful H&C planning, the companion guide to the Supplement to PPS1 (national Planning Policy Statement 1) is provided and gives advice on how to approach heat planning [132].

Denmark: Due to the effective spatial H&C planning, DH systems provide heat for around 60 % of Danish households. The Danish Energy Agency is the authority to enforce policies that enable local heat planning. Municipalities develop heat plans to identify existing and future heat demand of buildings as well as current and potential heat resources in a given area. The planning process includes assessments on most cost-effective and appropriate heat supply options. The municipalities are the only entities that are responsible for preparing and updating municipal heat plans and approving heat projects. In other words, the City Council makes the final decision on heating planning and expansion of heat supply in the municipality [131].

Sweden: The 1977 Law on Municipal Energy Planning (SFS 1977:439) was the first national regulatory instrument in Sweden for local energy and climate planning. It served as a cornerstone for linking energy and climate issues in spatial planning and was a prime example of a soft regulation. This law, however, resulted in a very poor municipal implementation. It lacked precise time frames for introduction and update of local energy plans and no clear statement was made about municipal planning powers under the Planning and Building Act (PBL). Furthermore, national authorities never audited if and how municipal implementations are carried out. The circumstances led to a situation that in 2004, a governmental survey revealed that a large part of municipalities have energy plans in place that are not effective [133]. Following this survey, the situation evolved rapidly and by 2006, the local energy planning had visible impacts on local actions [134]. Today, Municipalities play an important role in the energy planning in Sweden. Most of the development in the municipal energy system is made by municipal government. The Energy planning has become a popular tool for municipalities (and not the state) for integration of their comprehensive planning processes [129].

The examples of the UK, Denmark and Sweden show that urban H&C planning requires national commitment via regulations in order to be implemented across a country. Additionally, the potential positive and negative influence of national regulations on energy planning was illustrated as well. Local authorities can also solely implement a successful heating and cooling planning, e.g. Oradea in Romania [135]. EU and national regulation have also motivated certain municipalities to make a self-commitment for taking climate protection related steps. For example, the city council of Frankfurt has committed to certain climate protection targets and drew roadmap with concrete steps which are summarized in the report "Master plan 100% climate protection"[74]. Such commitments can initiate practicing heating and cooling planning as well as decarbonising the DHC systems. In this report, the influence from national and local urban regulations on H&C planning and therefore, DHC systems in municipalities is further analysed for 13 city case studies (namely Bolzano, Copenhagen, Frankfurt, Graz, Helsinki, Ljubljana, Miskolc, Oradea, Plovdiv, Stockholm, Tallinn, Vilnius and Warsaw), implemented in Annex 5. From the analyses of the city case studies, it can be inferred that the approach for developing an efficient DHC system differs significantly from one city to another depending on the context such as climate targets, supply mix of DHC systems, ownership, urban planning and urban regulations.

[74] in German: Masterplan 100 % Klimaschutz

C. Integration of renewable energy and waste heat/cold sources in district heating and cooling

Block C strives to provide technical information and operational feedback on the integration of renewable energy and waste heat/cold sources in DHC. This section thus analyses the technical conditions required to ensure an optimized and efficient integration of these energies, and how this integration affects the operational characteristics of the DHC system and its connected end-users. More particularly, this section addresses:

- 6 sources or carriers of renewable energies: biomass, geothermal, biogas, solar thermal, ambient energy, and renewable electricity

- Waste energy from 5 different origins: power generation, industrial production, tertiary buildings, data centres, underground railway

- The technical conditions for heat suppliers to connect to a DHC

This analysis, which is based on a literature review and benchmarks, is also supported by 10 case studies across Europe in order to provide a true operational feedback on the different topics. These case studies have been selected by considering their operational excellence, but also by ensuring a wide geographical and technological coverage. Therefore, each of the above renewable or waste energy sources are illustrated by at least one case study, in the form of text boxes providing operational insights.

The complete analysis of the 10 case studies tackles various dimensions of the integration of renewable energy and waste heat/cold sources in DHC: the national and local contexts, the technical features of the DHC system, the business model, and the sector integration approach. The detailed analysis of these case studies is provided in annex 7 of this report.

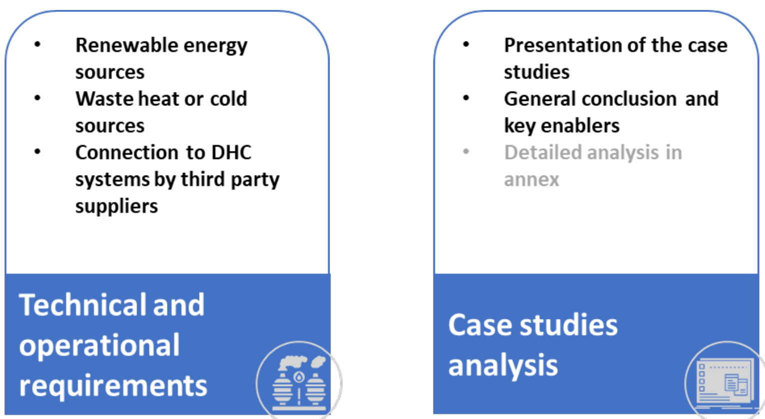


Figure 64: Block C overview of chapters and subtasks

C.1 Technical and operational requirements

C.1.1 Renewable energy sources

C.1.1.1 Biomass

C.1.1.1.1 **Key technical and operational factors**

The following table aims at setting a general presentation of the key parameters of **biomass heat-only boilers**. Each value is an **average of the values encountered in the scope of biomass production for district heating.**

Table 23: Overview of key technical parameters for biomass boilers

Key parameter	Definition	Value
Installed capacity	Maximum power achievable under ideal conditions	1 – 15 MW (for 1 boiler)
Yield	Proportion of energy recovered (secondary energy) from the input energy (primary energy)	85% at commissioning (decreases with time) [136]
Load factor	Proportion of energy produced with respect to the maximum possible	Min: 25% / Max: 99% [137]
Required floor space[75]	Surface occupied by the installations per unit of power	90 m²/MW [138]
Downtime	Period of time for which the facility does not produce due to maintenance or regulation	1 to 2 weeks during summer
Greenhouse gas emissions	Emission of CO_2 in kilograms per MWh of heat produced	10 to 25 $kgCO_{2eq}$/MWh [139]
Atmospheric pollutant emissions	Emission of major pollutants in milligram per normal cubic meter	Dust: 40 mg/Nm³ CO: 90 mg/Nm³ NOx: 200-375 mg/Nm³ [137]

75 Including fuel delivery area and fuel storage facilities

C.1.1.1.2 **Technical conditions**

Different types of biomass fuel

Five types of fuel can be used in biomass boilers designed for district heating. **Wood chips and wood pellets are the most common fuels**. **Agricultural residues**, **wood waste** and **wood industry residues** are also considered. A detailed description and comparison of the 5 main types of biomass fuels is provided in annex 6.

Ensuring **the quality of the fuel is essential**. Characteristics such as energy density, moisture content, particle size or ash properties can affect significantly the performance of the technology [140].

A boiler can be fuelled with a mix of fuel. The majority uses only one fuel due to logistic constraints or local context (e.g. proximity with sawmill) [141]. The most powerful boilers can operate in a larger range of moisture content, heat value and particle size, and thus accept various fuels. Furthermore, wood waste and wood industry residues are often mixed with other fuels to optimize combustion yields. The more important when choosing a fuel or a mix of fuel is to ensure that the general properties are adapted to the boiler.

As depicted in Figure 65 for Denmark (where solid biomass represents a very significant share of the renewable energy mix), wood pellet is the most used fuel, followed by agricultural residues (straw and biodegradable waste), wood industry residues, wood chip and wood waste. Wood pellets and wood chips are a growing part of the biomass mix.

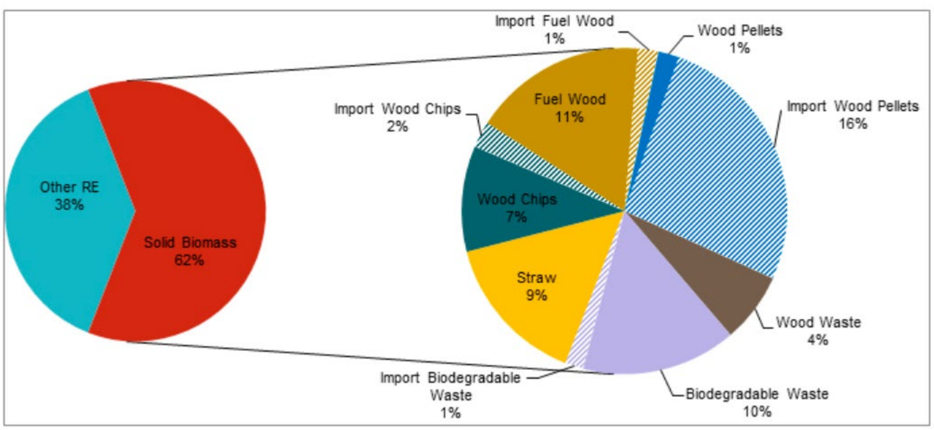


Figure 65: Use of solid biomass in renewable heat and electricity production in Denmark in 2015 with share of imports (Source: Danish Energy Agency 2015)

Facility overview

The facility is composed of different parts:

- The fuel transport (delivery, storage, and conveyors);
- The boiler;
- The flue gas treatment;

– The connection to DH, with a possible thermal storage.

As can be visualised in the following figure (see Figure 66: Installation overview diagram (Source: Venissieux energies)), the parts requiring the most space are the parts concerning the fuel transport to the boiler (numbers 1 to 7 in the figure) and the flue gas treatment (numbers 11 to 19). The heat exchanger (number 10) allows to convey the heat generated in the combustion chamber to the water circuit that will connect to the DH system.

The required floor space varies between 55 m²/MW [138]**,** 92,5 m²/MW [142] and 102 m²/MW [143] depending on the type of project and the feeding technology. The facility occupies 90 m²/MW in average.

A detailed description of the different types of boiler is provided in annex 6 along with an explication of the combustion principle.

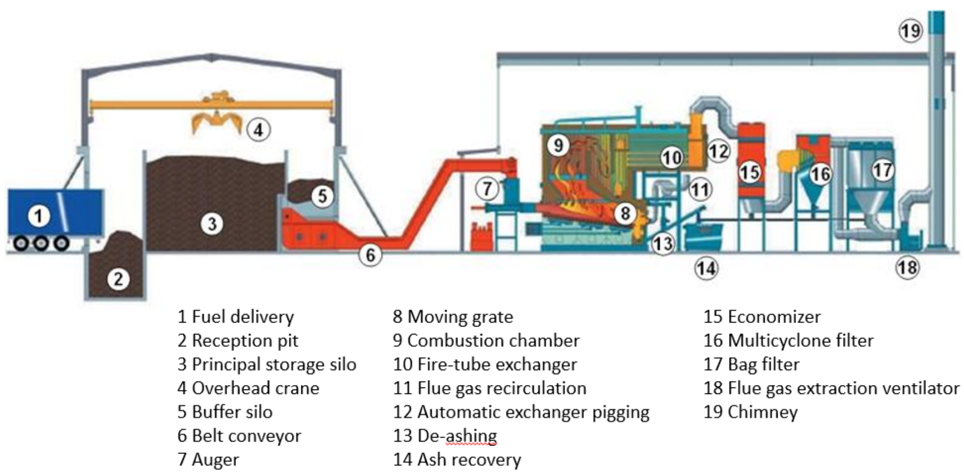


Figure 66: Installation overview diagram (Source: Venissieux energies)

Design of the installed capacity

Biomass in DH systems is usually a base energy and needs to be supported by a complement energy to ensure peak demands. Therefore, the interest of biomass is not to satisfy the peak demand but to operate in the largest amount of the annual needs. Biomass boiler is **generally designed to cover 80% of heating needs** (or less if it is connected to a larger network), while an auxiliary fuel boiler (using fossil fuel usually) designed for 100% of peak demand secures heating deliveries in case of emergency or maintenance [141].

Another option could be using **multiple biomass boilers** with a cascade regulation. Splitting the power needed into multiple boilers enables to have a larger range of power modulation and optimise biomass coverage. However, this strategy usually implies highest investment costs due to economy of scale.

Not oversizing the installation allows to minimize both investments and constraints associated with biomass. Furthermore, **operating at low loads alters yield and lifetime, and causes an increase of pollutants and ashes**. Biomass boilers operate with the best performances close to the nominal power, the nominal power being the maximum power for which it is design to be effective [144].

The **load factor** is the proportion of heat produced in a period of time compared to the maximum heat production that could have been achieved at nominal power. It reflects the consistency of the design of the boiler with respect to the heat needs. A low load factor means that the installation is oversized and that the combustion is not optimised, thus degrading the yield and increasing pollutant emissions.

In DH systems, the load factor of a biomass boiler evolves all year long as the heat needs evolve. The minimum load factor acceptable (corresponding to "$P_{minimal}$" in the figure below) is usually set at around 25%, inducing a yield reduction to ca. 75% [145].

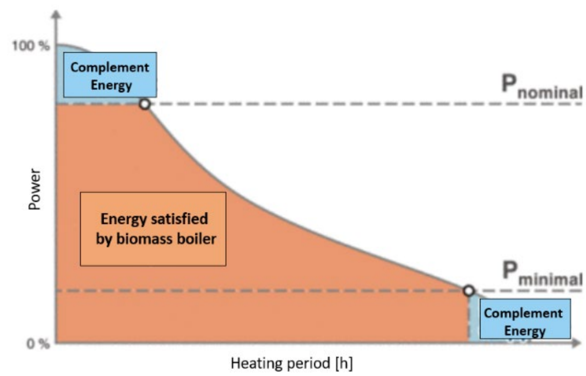


Figure 67: Design of biomass boiler [141]

When designing the boiler, it is important to take into account the final use of the heating system and anticipate as much as possible future needs. Building renovations can decrease significatively the needs and leave the boiler oversized.

Operating temperature

The supply temperature of the water is a key parameter for the optimisation of the design. There are four regimes of temperature [141]:

- Low temperature, below 80°C;
- Hot water, between 80°C and 110°C;
- Superheated water, above 110°C remaining in liquid state (with operating pressures above atmospheric pressure);
- Vapor.

Biomass, unlike other renewable energies (e.g. geothermal or ambient energy), enables to produce at high temperature (superheated water or vapor) and is thus **compatible with any kind of heating equipment at the end-user's site** (see discussion in the text box below). However, **the majority of the installations is designed to operate with hot water**. Indeed, it is less dangerous and more efficient than superheated water or vapor. As a general rule, the lower the temperature, the lower the heat losses. Furthermore, it enables a better adaptation to other types of energy sources (solar, geothermal) and heat storage. If the system operates at low temperature, a secondary network with adapted emitters is required.

Focus on the heating equipment at the end-user's site

The operating temperatures of the heating equipment ("emitters") at the end-user's site **vary significantly according to the heating equipment technology, its integration in the building** (e.g. wall- or floor-mounted)**, and the type of insulation of the building**. These operating temperatures are of prime importance for the DHC operator in order to **design its DHC network and deliver heat with an appropriate capacity and temperature** at the substation.

Therefore, the building design and its overall energy efficiency has a clear impact on the technological choices that will be made for the DHC network. **New buildings built according to new thermal regulations integrate high-efficiency heating equipment that can be operated at lower temperature regimes.** As a result, the DHC network itself can also be designed at a lower operating temperature, enlarging the field of energies that can be mobilized. This is particularly important as this section shows that **many renewable and waste energy sources are operated at relatively low temperature** (when compared to the operating temperatures of fossil fuels boilers).

The orders of magnitude of temperature regimes (supply - return) for the most common emiters found today in Europe are:

- Cast iron radiators: 100 – 60°C
- Steel panel radiators: 70 – 40°C
- Air handling unit (tertiary and industry): 70 – 60°C
- Radiant floor system: 50 – 30°C

For Domestic Hot Water, the typical temperature regime is about 60 – 50°C (the supply temperature must remain above 50°C to avoid any risk of legionellosis).

Therefore, the overall thermal efficiency of the potentially connected buildings must be carefully assessed when designing the layout of a low temperature DHC network. Even if it is always technically possible to develop tailor-made solutions to connect less efficient buildings to efficient low temperature networks (through dedicated high temperature loops or complementary boilers at the buildings substations e.g.), the operator has to assess the costs and benefits of such solutions on the economic, environmental and operational dimensions.

Yields

The yield represents the proportion of energy recovered (secondary energy) from the input energy (primary energy). It then measures the energy losses during the production process.

The biomass boiler has its **maximum yield close to the nominal power**. Below 25-30% of the nominal power the combustion process has poor quality and degrades the yield. **The average yield is 85% at commissioning**, and then decreases with time. Adapted design and operation make it possible to increase the yield to more than 90% [145].

The **combustion** is a complex process and any parameter can affect the yield and pollutant emissions (air proportion, amount of fuel, fuel properties, combustion temperature, time in the combustion chamber, etc.). If the combustion is incomplete, energy is lost so the yield decreases. All the combustion parameters need to be carefully optimised.

There are specific designs and parameters that enable to reduce losses and take advantage of energy that would otherwise be lost:

- The **temperature** choice of the network. As previously detailed, operating temperature is an essential parameter for heat losses.
- **Insulating** the installation avoids heat losses.
- An **economizer** is an additional exchanger on the flue gas exhaust. It enables to recover the heat of the flue gas for heating use.
- A **condenser** has the same role but also benefits from the energy released by the condensation (latent heat) of the water present in the flue gas. The condensates are then collected.

Plant management integration

As discussed previously, biomass in DH systems is usually a base energy and needs are supported by a complementary boiler (usually operating with fossil fuels) to cover peak demand and secure heating deliveries in case of emergency or maintenance. The corresponding production profile was presented in Figure 68 and in Figure 69 below. In these figures, biomass is clearly designed to supply most of the heat demand, except for:

- peak demand in winter for which the biomass boiler capacity it too low to cover the entire demand
- and for the lowest demand (usually in summer when heat is needed only for Domestic Hot Water), for which the corresponding load factor would be too low (under the minimum of 25% defined earlier) to justify the engagement of the biomass boiler.

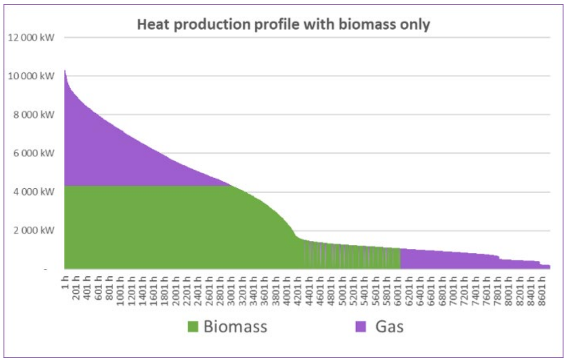


Figure 68: Heat Production profile with biomass only (Source: own simulated case)

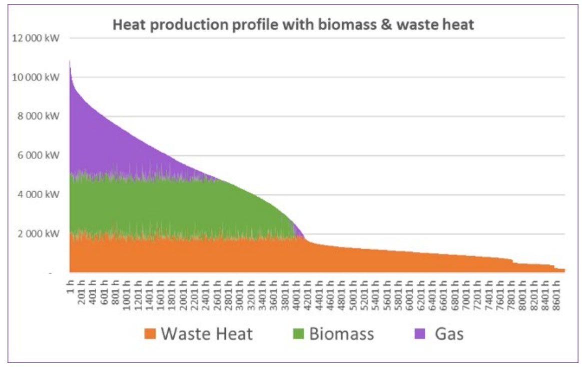


Figure 69: Heat production profile with biomass & waste heat (Source: own simulated case)

This typical scheme can be modified however if other RES or waste heat sources are to be valorised before biomass (due to lowest cost fuel, contractual requirements, etc.). Figure 69 shows how the use of biomass fuel (with the same constraint on minimum load) is modified if a certain quantity of heat coming from waste energy recovery has to be valorised first. This clearly illustrates why the various technical and operational constraints of each RES or waste energy sources have to be globally and carefully assessed in order to maximise the integration of these sources in the energy mix of the DH system.

A specific case can also be encountered if heat is also coming from a Combined Heat and Power (CHP) facility. If the CHP facility has been developed under a specific feed-in contract for electricity (as it is often the case), for which the operating time of the CHP is regulated (operating at full capacity from November to March for example), the use of the biomass boiler will also be modified since biomass is not used as base energy all year long. The corresponding production profile of such an example is presented in Figure 70.

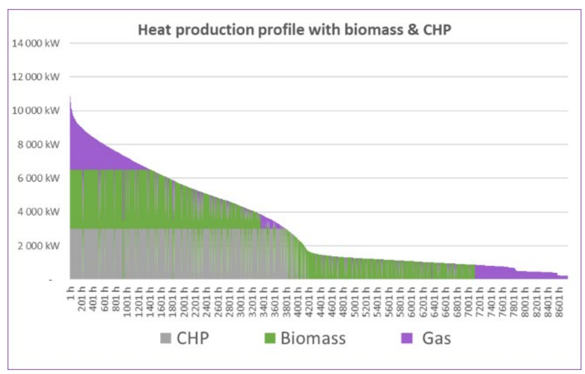


Figure 70: Heat production profile with biomass & CHP (Source: own simulated case)

Synergies with thermal storage

Synergies can be found with **medium-size thermal storage on daily basis**. Interseason thermal storage of large-size (in aquifers, pits, large tanks…) can also show good synergies but they are much more specific and much more difficult to implement, so they will not be addressed in the frame of this study.

Medium-size thermal storage is usually placed after the biomass boiler. It consists of a cylinder tank (about tens to hundreds cubic meters) filled both with hot water coming from the boiler and cold water returning from the heating system. The cold water enters at low velocity enabling **stratification of the water by temperature**. It ensures that hot water at the top is at constant temperature before entering the heating system [144].

Thermal storage takes advantage of the difference between flow temperature and return temperature. This difference should be as high as possible. However, there are conditions on the return temperature. To prevent corrosion, the minimum return temperature should be 65°C.

A thermal storage enables to **maximize the biomass coverage of the system**, enabling flexible use. When the heat demand is low, the boiler can charge heat to the storage, avoiding load factor reduction. When the demand is higher it contributes to smooth out the peak discharging the storage and thus reducing the use of complementary boilers that usually operate with fossil fuel. The energy density of the tank is usually around 35 kWh/m^3.

This thermal storage can be associated with other heating technologies, such as an auxiliary boiler or solar thermal energy.

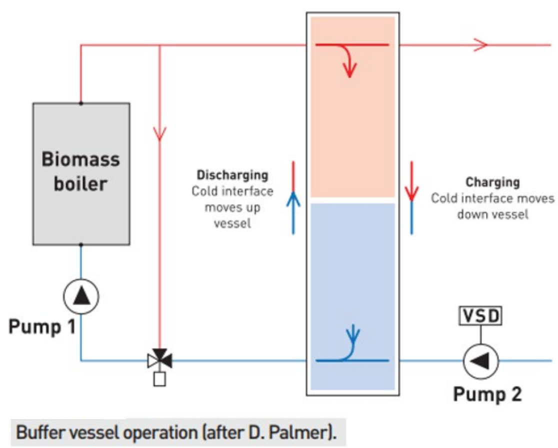


Figure 71: Thermal storage principle [144]

Filters design and performances

Pollutants emission is one of the main drawbacks of heat production from biomass. Different processes and filter technologies exist to limit these emissions and must be implemented to ensure good environmental performances.

Five types of pollutants are produced by the biomass combustion:

- Oxides of nitrogen (NOx), including NO, NO_2 and N_2O;
- Particulates Matter (PM), including salt, soot, Condensable Organic Compounds (COC), Volatile Organic Compounds (VOC), and intermediate products;
- Oxides of carbon (COx), including CO and CO_2;

– Oxides of sulphur (SOx), including SO_2 and SO_3;
– Dioxins and furans.

NOx and PM are the major pollutants of biomass combustion. All these pollutants affect human health (mainly respiratory system, but also hormonal for dioxin and furan) and environment (formation of acid rains, ozone and emission of greenhouse gases). The **fuel quality** and the **optimisation of the combustion** process play a major role in the abatement process.

NOx gases can be limited by the **optimisation of the combustion process**. Indeed, the formation of NOx comes either from the fuel, a non-controlled first stage of the combustion, or an excessive combustion temperature. For example, the recirculation of flue gases in the combustion chamber enables to decrease the temperature. The **Selective Catalytic Reduction** (SCR) and Selective Non-Catalytic Reduction (SNCR) are NOx abatement technologies. The principle is to inject urea or ammoniac that react with NOx to form N_2 and water. SCR uses a catalyser to boost the reaction. These systems can be damaged by dust particulates, so they have to be placed after a particulate filter.

There are different types of **particulate filter**, operating for various particle sizes. Flue gases pass through a combination of these filters. PM10 means particulates smaller than 10µm and PM2.5 smaller than 2.5µm. The smaller the particulate, the more dangerous for respiratory health. A detailed description and comparison of filters is provided in annex 6.

SOx gases can be captured by **neutralising agents** such as lime, active carbon, sodium bicarbonate or ammoniac. The process can be dry of wet (if the agent is injected with water).

CO gas is created if the combustion is incomplete. It is essential to ensure good conditions for the combustion process. **CO_2 gas** is created if the combustion is complete but it is counted as compensated by the growth of the biomass resource.

Dioxins and furans also come from an incomplete combustion reaction.

Finally, the depolluted gas is rejected through the chimney. The minimum height of a chimney is usually regulated in each country (e.g. 12m in France).

Biomass for CHP

Biomass can also be used to produce Combined Heat and Power. In Europe, two types of steam installations are mainly used, depending on the requirements [146]:

- **from 3 MWe** for steam applications,
- **up to several tens of MWe** for steam or hot water applications.

The energy contained in the biomass is converted into high-temperature, high-pressure steam in a boiler. The resulting steam is then:

- expanded through a turbine transmitting mechanical work to the turbine shaft which, coupled to an alternator, produces electricity,
- recovered at the turbine output and used by a heat consumer (e.g. DHC network) in the form of hot water or steam.

The system should provide an **average annual energy efficiency of more than 70% in order to comply with the recommendations of the European directive** on high-efficiency cogeneration.

There are two types of steam turbine for cogeneration:

- **Condensing turbines with extraction**

  The required amount of steam is drawn off between the turbine inlet and exhaust at the desired pressure (and corresponding temperature) level. This steam is sent to the process to cover the thermal requirements. The rest of the steam continues to expand in the turbine to a very low pressure (approaching vacuum). The exhaust steam is then condensed in a condenser. The water thus formed is pumped and returned to the boiler.

- **Back-pressure turbines**

  The steam exits the turbine at a certain pressure (and corresponding temperature), which is imposed by the downstream process and is made available to the end user. The steam in the turbine is therefore expanded to a pressure above atmospheric pressure and is then sent directly to the process (or via an exchanger for hot water requirements like for DH) which thus serves as a condenser. There is less expansion of the steam and the electrical efficiency is therefore lower.

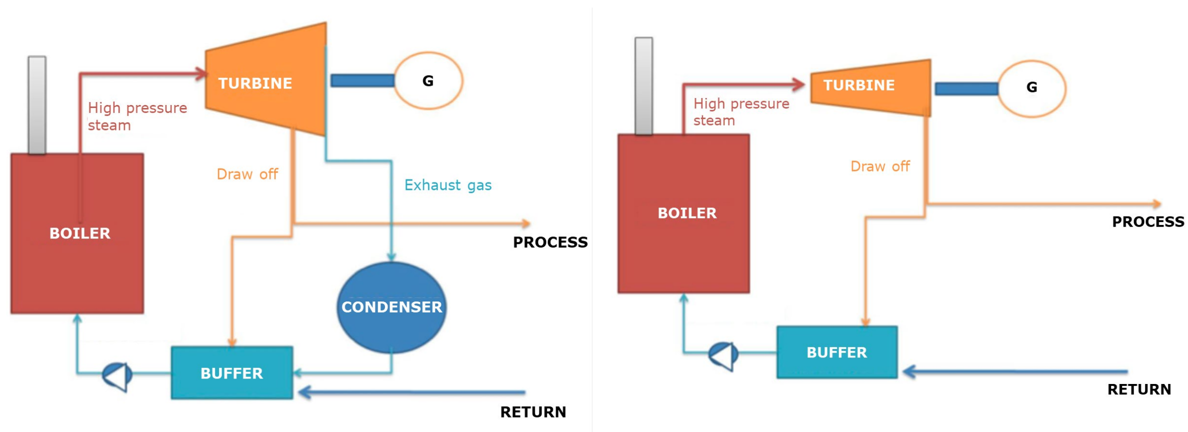


Figure 72: Condensing turbine with extraction (left) and back-pressure turbine (right) technical scheme (Source: Enertime)

Case study of Jelgava DH (LV): biomass CHP plant (Annex 6)

Jelgava has a well-developed district heating system, which **supplies about 85% of the city's total heat consumption**. Parts of the network **date back to the 1950s**.

While the network used to be 100% supplied by fossil fuels (natural gas), the current operator invested around 95 M€ since 2008 for major network renovation and interconnection, replacement of all heat production units, and the **construction of the bio-cogeneration plant based on biomass.**

This large biomass plant using local and renewable biomass provides customers with **safe, efficient and environmentally friendly DH at a competitive price (that dropped by more than 20%)**. It has enabled to drop the CO_2 emissions by 70% compared to 2010.

The installed capacity of **the biomass CHP is 45MWth and 23 MWe**. The plant is able to generate up to 230 GWh of heat and 110 GWh of electricity per year, with an efficiency of 88%. The 170,000 tonnes/year biomass (including but not limited to wood chips, sawdust, bark, wood residues, grain by-products, straw, other plant products, agricultural and forestry residues, peat) is sourced from 7 different local suppliers, and require a total of 25 to 30 trucks per day in winter.

The plant using a **Boiling Bed Combustion technology** (which offers the possibility to co-fire lower quality biomass fuels), the operator **plans today to diversify the existing types of fuel (biomass) and to integrate Refuse Derived Fuel (RDF)**.

Figure 73: Photo of the biomass CHP plant (source: Fortum)

C.1.1.1.3 **Operational constraints and requirements**

Fuel supply

Using biomass as a fuel requires a good supply management. Indeed, the heat production is dependent on the fuel resource and transport. To secure the supply, **it can be relevant to have multiple suppliers**. In some cases, the wood resource is managed by the municipalities. It allows mutualisation for various biomass boilers. The supply commonly comes from less than 50 km around the production, but can comes from further if the suppliers use a network of storage platforms [141]. Still, biomass can be considered as a **local resource** if the regulation of the sector is appropriate (requirements on the supply radius to access subsidies e.g. – 50-200 km generally according to the project size). In addition, national or regional planning are usually made to preserve forest resources and avoid devastation.

As far as **deliveries** are concerned, many logistical constraints need to be considered. An **optimised frequency of deliveries** to ensure storage is essential. It **depends on the number of days of autonomy provided by biomass fuel storage** (between 3 and 8 typically). With an efficiency of 85%, a biomass boiler consumes about 0.35 tons of chips per MWh of heat produced [147]. Biomass fuels are usually delivered by 80 m^3 capacity lorries (or 30 m^3 capacity tractors for smaller installations using wood chips) [140]. Therefore, the biggest installation in winter need ca. **10 to 20 deliveries per day**. The smallest installations will need 10 to 20 deliveries per week only.

The delivery constraints come both from the size of the on-site storage facilities and the flow of traffic. **Routing plans** are set up to facilitate the traffic of delivering lorries. Municipalities can prohibit city centres or sensible routes, and additional roads can be built to prioritize lorry circulation [148]. Once arrived the lorry has to manoeuvre through the delivery space. A delivery lasts 20 to 60 minutes. It is longer when several lorries are present at the same time, or if big impurities are found in the load.

The **fuel storage** is an important factor for biomass fuel. It enables days of self-sufficiency and can be used when demand increases rapidly. The **storage capacity** is a key parameter when designing the installation. The storage must ensure the sufficiency for a few days, in average 6 days [141]. The smallest installations are the most sensitive to external conditions so they have relatively higher storage capacity.

Many fuel parameters can degrade the storage. For this reason, **suppliers have a condition on the quality of the fuel** they provide. The fuel accepted must have a limited range of moisture content (usually between 35% and 40%) to ensure good storage conditions and an acceptable heating value.

The delivery and conveyor systems must adapt to the storage. Different access to the storage space can be arranged [140]. The more common storage **is open storag**e with a shelter offering a direct access for the vehicle. **Underground tanks** are also common. These storages have a variable capacity depending on the design of the installation. It can vary from 50 to 300 m^3. Fuels with a relatively high moisture content are dried in storage. An agitator device is placed to avoid degradation during the storage period. The CO gas rate must be checked to avoid a release of a dangerous quantity. **Wood pellets are easier to store** because of their high density and low moisture content. They are commonly stored in **sack silos** and **fed-in with vacuum extraction**. In general, the silo does not exceed 4 m high.

After being stored, the fuel is conveyed to the boiler. Different conveyor technologies are possible [140]:

- **Belt conveyors** are the most used in large installations. It can transport a great quantity of fuel over long distances.
- **Augers** or screw conveyors are used in smaller systems or only in the access part of the boiler. This type of conveyor can be blocked easily and accumulate dust.
- **Walking floors** are used in large installations for short distances.
- **Pneumatic blowing systems** are mainly used for wood pellets.

Emission limit values

As seen before, biomass combustion has the disadvantage to emit dangerous pollutants. Abatements technologies are always present in the installation and must meet with the European requirements limiting emissions. The emission limit values are set by the EU Directive 2010/75/EU on industrial emission and EU Directive 2015/2193 on medium combustion plants. These directives are transposed in each national legislation setting their own limit values.

The European values are presented in the following table. Emissions of CO are not limited by theses European directives but have to be measured.

Table 24: Emission limit values set by the EU Directive 2015/2193 on medium combustion plants

Type of installations concerned	Rated thermal input (in MW)	Emission limit values on NOx (in mg/Nm^3)	Emission limit values on Dust (in mg/Nm^3)	Emission limit values on SOx[76] (in mg/Nm^3)
New plants from 20/12/2018	*20 to 50*	300	20	200
	5 to 20	300	30	200
	1 to 5	500	50	200
Existing plants from 01/01/2025	*20 to 50*	650	30	200
	5 to 20	650	50	200
Existing plants from 01/01/2030	*1 to 5*	650	50	200

76 The value does not apply in the case of plants firing exclusively woody solid biomass.

Controls of pollutant emissions (flow rates and concentrations of the different pollutants) are regulated by national authorities according to a frequency that usually varies in function of the installed capacity.

Ashes valorisation and treatment

The biomass combustion produces two types of ashes recovered automatically [140]:

- **The bottom ash** accumulated in the grate.
- **The fly ash** present in the flue gas.

The bottom ash is the most present (98% of ashes). This ash is mainly valorised as a fertilizer, as it contains potassium. It can also be composted or used as cement or concrete.

The fly ash cannot be valorised because it contains heavy metals. It is recovered by particulates filters and buried in landfills.

Maintenance

A biomass installation is secured and a maintenance plan has to be set up [149]. The biomass fuel is subject to quality checks. The conveyors are regularly checked for wear, blockage, damage, or need for lubrication of mechanical parts.

As for the **regular maintenance of the boiler**, it consists of the emptying of ash bin along with a basic check for pressure level, leaks, valves and fire protection. The control system alerts if a cleaning is necessary or an urgent maintenance is needed. **A periodic cleaning is done at least each month**. The cleaning must include flue paths, grate, air openings, ignition tubes, refractory lining, heat exchangers, fans and sensors [150]. The major risks arising from the lack of cleaning in the boiler are:

- Slagging: adhesion of molten ashes in the very hot parts of the installation.
- Fouling: chloride and sulphur condensation on the exchanger tubes and flying ashes accumulation.

An **annual full internal and external inspection** of the boiler is required to check the yield, clean and replace when necessary. The requirements for annual inspection are regulated by national authorities.

Automatic cleaning can be installed to reduce the maintenance time. An access for maintenance needs to be anticipated when designing.

Downtime

The installation must be shut down each year for maintenance and replacements as stated in the maintenance plan**. One or two weeks are needed and are commonly planned in summer** when the heat demand is low. If there are failures or if the minimal load is not satisfied, the boiler is shut down. It is a not planned downtime.

Feedback on the technology

Heat production from biomass is now **widely used across Europe** to “green” DH networks. It is indeed **considered as carbon neutral** since the associated emissions of CO_2 are neutralized by the CO_2 content absorbed by the biomass prior to its combustion in the boiler.

This technology allows to valorised different kind of **local** biomass. However, the origin of the biomass must always be assessed precisely in order not to lose the benefits of this green resource, as its transportation in lorries may induce significant associated CO_2 emissions. In addition, **proper management of forests** must be implemented in order to avoid uncontrolled use of this natural resource. Finally, **fuel quality requirements** may be difficult to meet as problems like high moisture content, presence of a foreign matter, granulometry, dust… may arise.

The technology is well controlled today and benefit from long operational feedbacks. Innovative processes still develop and allow to optimize combustion process and minimize pollutants emissions. **High-quality filters** are required to abide by European emissions limit values, whose targets get more and more ambitious. **Proper operation and maintenance** of the biomass boiler is key to maintain good yield and limit pollutants emissions over the lifetime of the facility.

In operation, the biomass boilers are usually used as base production, but are limited by their maximum nominal power (which cannot be oversized in order to grant a good yield) and by their minimum load factor. Synergies with thermal storage can be found to maximise the use of this renewable energy source.

C.1.1.2 Geothermal

C.1.1.2.1 **Key technical and operational factors**

The following tables aim at setting a general presentation of the key parameters of **geothermal heat production facility**. Each value is an **average of the values encountered in the scope of geothermal production for district heating and cooling, from geothermal aquifer on one hand and for geothermal vertical probes on the other hand.**

Table 25: Overview of key technical parameters for geothermal heat production from geothermal aquifer

Key parameter	Definition	Value
Installed capacity	Maximum power achievable (including heat pumps) at optimized conditions	15 MW for 1 doublet
Temperature of the resource	Temperature at the wellhead of the geothermal resource	Heating: from 25°C to 90°C and above Cooling: from 5°C

Key parameter	Definition	Value
Depth of the resource	Depth of the underground reservoir containing the geothermal resource	Heating: from 200 to 3000 m and deeper Cooling: 20 – 200 m
Well flow rate	Flow rate of the fluid extracted from the production well	50 – 300 m^3/hr
COP (Coefficient of Performance)	Ratio of heat provided over the electricity needed for heat pumps	3 - 5
Required floor space	Surface occupied by the facilities per unit of installed capacity	50 m^2/MW for the plant plus 100 m^2/MW of free space for wells maintenance operations
Downtime	Period of time for which the facility does not produce due to maintenance	Total of about 5% per year plus 4 to 6 weeks every 10 years
Greenhouse gas emissions	Emission of CO_2 in milligram per normal cubic meter	0 mg/Nm^3
Atmospheric pollutant emissions	Emission of major pollutants in milligram per normal cubic meter	0 mg/Nm^3

Table 26: Overview of key technical parameters for geothermal heat production from geothermal vertical probes

Key parameter	Definition	Value
Installed capacity	Maximum power achievable (including heat pumps) at optimized conditions	100 kW – 2 MW [151]
Temperature of the resource	Temperature of the underground geothermal resource	15 – 30°C
Depth of the resource	Depth of the geothermal resource	Vertical probes: 100 – 200 m
Extraction rate	Power extracted per meter of probe depth for 1 vertical probe	40 – 60 W/m
Operating time	Duration for which the facility is running	About 20-30% of the year in order to preserve resource sustainability

Key parameter	Definition	Value
COP (Coefficient of Performance)	Ratio of heat provided over the electricity needed for heat pumps	3,5 – 4,5 [151]
Required floor and ground space	Surface occupied by the facilities per unit of installed capacity	12 m²/MW at the surface but about 1 ha/MW in the underground
Downtime	Period of time for which the facility does not produce due to maintenance	1 day to 1 week per year
Greenhouse gas emissions	Emission of CO_2 in milligram per normal cubic meter	0 mg/Nm³
Atmospheric pollutant emissions	Emission of major pollutants in milligram per normal cubic meter	0 mg/Nm³

C.1.1.2.2 **Technical conditions**

Different types of geothermal resources and European panorama

Geothermal energy is captured in the underground. **At different depths, different levels of temperature are available, allowing different uses.**

Table 27: Geothermal resources at different temperatures

Type of resource	Temperature	Depth	Use
Very low temperature	< 25°C	< 200 m	Individual or district heating, cooling
Low temperature	25°C - 90°C	In sedimentary basins: 200 – 3 000 m	District heating and cooling
Medium temperature	90°C - 150°C	In sedimentary basins: 2 000 – 4 000 m In high temperature basins: < 1 000 m	District heating and/or Power production with secondary fluid

High temperature	> 150°C	In high temperature basins: 1 500 - 3 000 m	Power production
Hot Dry Rock	Steam at high temperature	Up to 5 000 m	Power production

For DH applications, very low, low and medium temperature resources are targeted. Basins with geothermal potential for DH exist in almost every European country (see Figure 74). Geothermal energy provides a **local and renewable resource**. The use of geothermal energy for heating (the so called "geothermal direct use", by opposition to geothermal for power production) in Europe is mostly developed in Italy (where it is also used for power production applications), Hungary, France and Germany (see Figure 75).

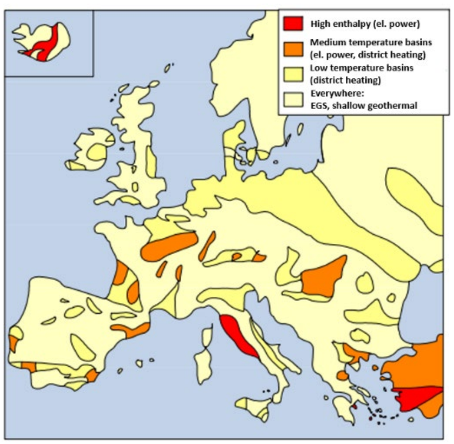


Figure 74: Main basins and geothermal resources of Europe (Source: EGEC 2014)

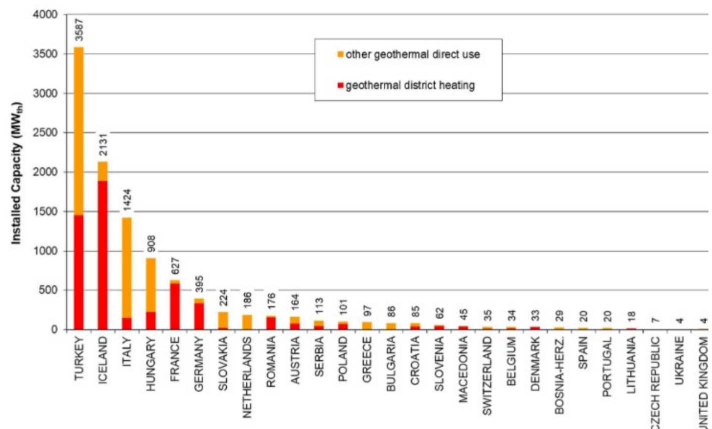


Figure 75: Installed capacity in geothermal direct use in Europe in 2018 (Source: EGEC 2019)

Facility overview

There are two types of geothermal technologies used for DH application:

- **Shallow and deep aquifers** (see): A first well is drilled down to the targeted aquifer. From this "production" well, groundwater (brine) is pumped to surface (usually using downhole pump) and its heat is captured at surface through a heat exchanger. A heat pump can be added to reach higher levels of temperature. Finally, the cold groundwater (whose calories have been taken out) is reinjected in the same aquifer with a second well (the so called "injection" well). These two wells have to be slanted from a certain depth in order to ensure a minimum distance between the wells (between 40 and 1 500 m depending on wells design and flow rates) in order to avoid that the reinjected brine cools down the hot production zone over time. Geological and hydrological studies must be carried out upfront in order to properly assess the underground resource and simulate its behaviour over the 20 – 30 years of plant operation.

- **Probe field** (see Figure 77): The principle of a probe field is to drill holes for probes at a depth between 30 and 200 m. The probes are U-tube heat exchangers placed in a conductor cement. These exchangers capture heat from the underground and are connected to a heat pump at the surface. The heat pump enables to reach higher levels of temperature. Unlike the deep aquifer installation, the geothermal heat is captured in a closed loop and does not imply any groundwater pumping. The fluid in this closed loop can be directly the refrigerant fluid of the heat pump, or an intermediate fluid (usually glycoled water, used to decrease freezing temperature).

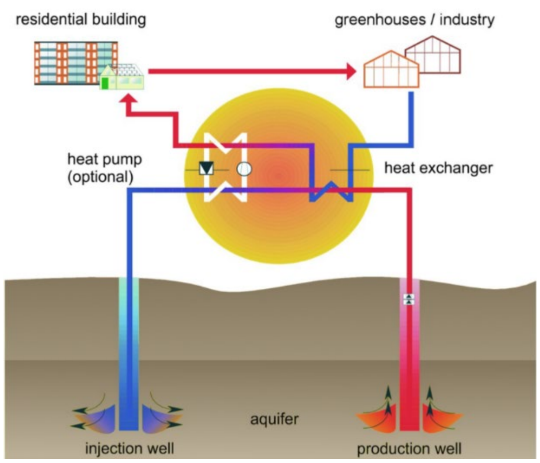


Figure 76: Aquifer geothermal installation (Source: Leibniz Institute for Applied Geophysics 2014)

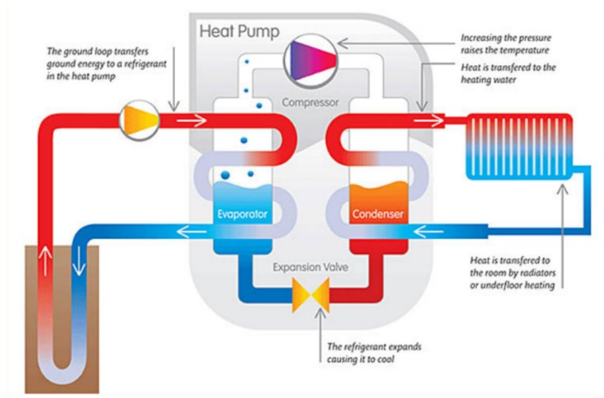


Figure 77: Geothermal probe with a heat pump (Source: Dig the Heat 2020)

For low temperature DH (operating at 50 – 65 °C) or when the temperature demand is low, the geothermal resource can be used without heat pumps.

The required space for these installations is:

- **Geothermal heat production from aquifer** requires two separated underground wells (the so called “doublet”) [152]. It is common to build a platform for both wells separated from 10 m in the surface and then deviated from a certain depth. The heat plant consists of the two well heads, the geothermal loop (heat exchanger and corrosion inhibitors system), the possible associated heat pumps, and the technical rooms (office, workshop, electrical switchboard…). Additional 1000 to 1500 m² of free space are also required in order to be able to carry out monitoring (“logging”) and heavy maintenance operations (“workover”) of the production and injection wells (cleaning, acidizing, side tracking, pump maintenance…).

- **Probe field is constructed under buildings, parking, or green spaces during the construction phase or renovation** [152]. The probes are not apparent at the surface. The borehole diameter can vary between 10 to 20 cm. The recommended space between two probes varies from 8 to 10 m, depending on ground conductivity [151]. **At the surface, the heat pump requires ca. 12 m²/MW**.

Different drilling methods are possible depending on targeted depth and ground properties (Annex 6). A closer look on well design is provided in Annex 6.

Different designs of heat pumps

The majority of heat pumps used in geothermal application are compression heat pumps. **The objective of a compression heat pump is to raise temperature**. It is composed of a first heat exchanger called an evaporator that captures heat from the geothermal resource and evaporates the internal refrigerant fluid from liquid to vapor phase. Then, electricity is used to power the compressor, increasing the refrigerant pressure and thus heating the fluid to high temperature. This heat is finally delivered to the DH system through a second heat exchanger, the condenser, that condenses the refrigerant from vapor back to liquid phase (see Figure 77 above). The technology is therefore **particularly adapted to low to medium temperature networks, but can also be implemented in high temperature network** with the support of complementary gas boilers to raise the fluid temperature if needed.

There are different designs of heat pumps for different ranges of evaporator and condenser temperatures and capacities, which depend on the temperature and flow rates of the resource on one hand and of the DH needs on the other hand. These designs can be much more complex than the basic one presented in Figure 77 and must be optimized carefully by process experts based on the available knowledge of both the geothermal resource and the DH needs in order to guarantee optimal performances of the facility during operation (see discussions on the Coefficient of Performance below).

As a general and basic rule (and by ignoring the different energy losses involved in this process), the energy coming from the geothermal loop at the evaporator plus the energy provided by electricity at the compressor is equal to the energy delivered by the heat pump at the condenser, which represents the energy that is conveyed to the DH system. Heating the fluid with a great difference between evaporator and condenser temperatures will therefore require more power than with a smaller temperature difference. **Depending on national regulations, the energy coming from electricity is treated differently for the calculation of the renewable energy share for heat pumps: it can be completely subtracted from the total energy delivered by the heat pump, or it can be partly or totally considered as renewable energy as well.**

Heat pumps system can also be used to provide cooling outputs. This is discussed in paragraph “Synergies with cooling” below.

Different refrigerant fluids can be used allowing different temperature and pressure levels. The main refrigerants are R410a, R407c and R134a [153]. Leaks must be avoided at all costs because these fluids are dangerous GHG. In addition, fluids in the probes that can be in contact with the ground need to be at least 98% biodegradable with high quality.

Yields and Coefficient Of Performance

The yield of the heat pump is called Coefficient Of Performance (COP). It is defined as the ratio of the amount of heat produced by the heat pump over the electricity used to operate its compressor. The COP depends directly on the operating temperatures of both the evaporator and the condenser (see Figure 78). For geothermal application for DH, the heat pump **COP usually varies between 3 and 5.**

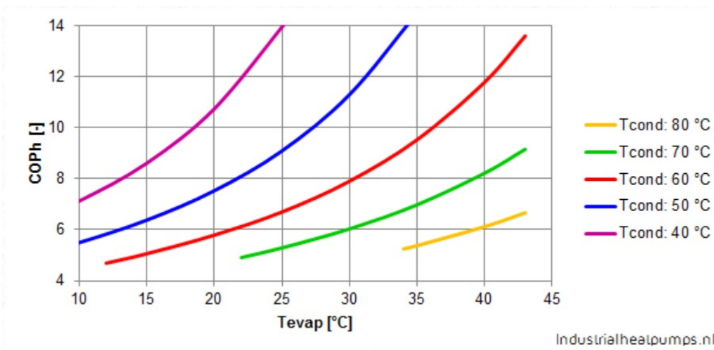


Figure 78: COP with respect to temperatures of cold and hot sources (Source: Industrial Heat Pumps 2020)

Plant management

Geothermal energy, as a local and renewable energy, is a **base energy whose capacity is dictated by the underground resource potential.** As the drilling cost (accounting for about 80% of the total heat plant investment cost for geothermal energy from aquifer) mostly depends on depth and not on resource temperature nor flow rate, and as the fuel (hot water) is completely free (with relatively low operating costs), operators will always try to take the most out of their geothermal wells and of the power provided by this natural resource. Therefore, in this particular case, the technical and economic relevance of the whole DHC project will be found in the DHC needs that can face the geothermal doublet capacity. Like for other RES sources, geothermal power plants are always associated with standby boilers (from other RES and/or fossil fuels) for peak and emergency demand.

In the case of probes fields, the annual operation hours are usually limited to about 1 800 in order to avoid degradation of the underground resource by extracting too much heat. However, if the resource is used for cooling in summer, it recharges the ground with heat. The resource is thus more stable and can be used over a larger period of time.

Geothermal heat plants from aquifer or probe fields are **not modular** since they require heavy up-front investments and access to necessary space that can usually be granted only once. It is therefore necessary to properly assess the DHC needs and secure their immediate or rapid commercialization in order to ensure the profitability of such projects.

Synergies with cooling

Geothermal energy can also be used for cooling. The principle is to **transfer the heat of the network to the underground through the geothermal loop so that the network benefit from a cold water**. Moreover, the ground recharges in heat, the resource is thus more stable. Two main technologies exist (see Figure 79) [151]:

- **Direct cooling** (or "geo-cooling") is a solution using directly a cold source without heat pump. The heat (or cold here) is transferred through a heat exchanger.
- A **reversed heat pump** is a refrigerating machine. The condenser becomes the evaporator and the evaporator, the condenser. The heat is captured from the system and transferred through the heat pump to the geothermal resource. The evaporator temperature is defined by the cooling needs (usually 12°C for a cooling temperature of 7°C). The reinjection temperature is of 20 to 30°C. With this technology cooling and heating can work simultaneously in the heat pump.

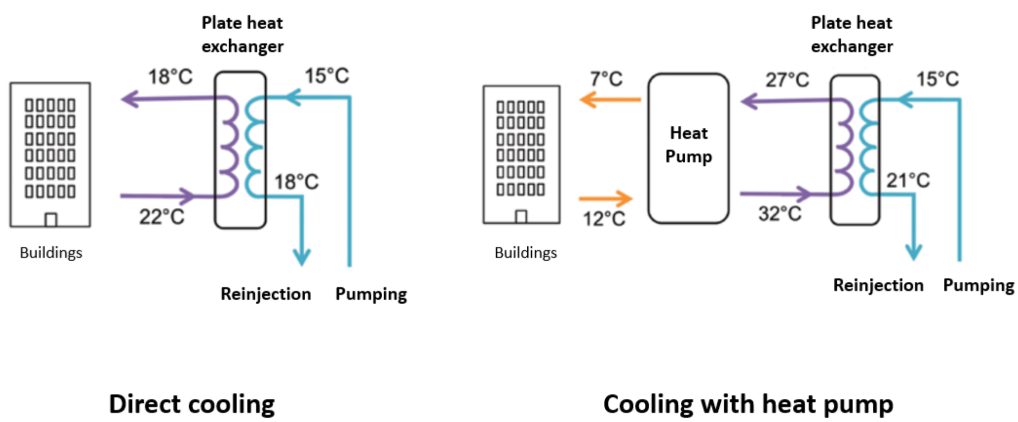


Figure 79: Technologies of geothermal cooling [151]

Case study of Bordeaux DHC (FR): Low temperature geothermal energy (Annex 6)

Designed to supply the emblematic museum "Cité du Vin" in Bordeaux, a **low temperature geothermal system coupled with heat pumps** was implemented to satisfy the cold demand of this significant client and was interconnected with the existing DHC network to meet the heat demand.

The **16°C geothermal fluid** is produced from **4 wells at 30 m depth** in the alluvial sandstone of the Garonne River (the produced fluid being rejected back to the river bed at around 32°C). The fluid is then directed to **heat pumps supplying 1 MW of cold**.

The use of geothermal energy to **produce both heat and cold is under analysis to find a profitable operating mode**. At the moment, geothermal energy is only used to supply heat as a back-up of the main DHC network (due to a low Coefficient Of Performance given the temperature levels at stake).

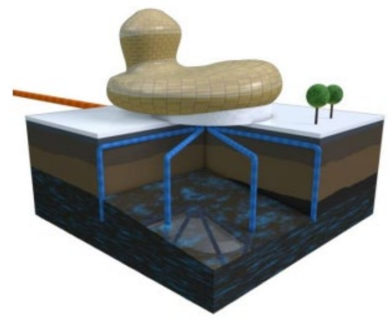


Figure 80: Illustration of the 30 m depth geothermal wells used for the production of cooling and heating on Bordeaux DHC (source: EDB)

C.1.1.2.3 **Operational constraints and requirements**

Resource assessment and risk management

From surface to 20 m deep, the temperature is constant all the year and does not depend on atmospheric variations. Between 20 and 100 m deep, the temperature is of 9 to 15 °C and then increases by about 3,5°C each 100 m in average [154]. However, in regions with geothermal activities (in volcanic arc systems or sedimentary basins for example), **underground temperature is a very sensitive parameter and can evolve very quickly in space depending on geological framework and hydrodynamism**.

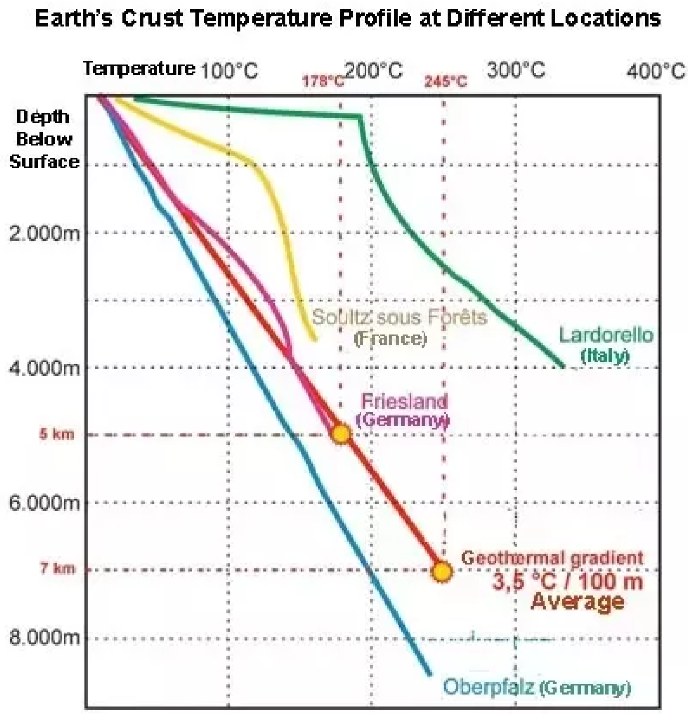


Figure 81: Variation of temperature with respect to the depth (Source: J. Flavin 2017)

The design and required depth depend on the heat extraction rate, and thus, on these underground reservoir parameter [152]:

- Temperature, depends on depth and geological settings
- Pressure, depends on depth and fluid properties
- Permeability is the ability to allow the fluid to move through the ground by pressure differences
- Conductivity allows heat to be transferred in the reservoir material. It depends on the geologic structure and can be increased by the presence of water.
- Porosity informs about the amount of water that can be contained in a reservoir material.
- The specific heat is the amount of heat needed to increase the temperature of a material. Its value varies for each material.

When designing a geothermal heat plant for a DHC project, all these parameters need to be **assessed by experts in order to properly estimate the capacity of the resource and its sustainability over time under operation conditions**. Studies include pumping trial to characterise the installation performances and the ground structure, as well as a long period pumping to simulate ground or aquifer hydraulic parameters. Geologic study also aims to anticipate difficulties in drilling, certain rocks being inappropriate for drilling.

This assessment is usually based on desktop study fed by analogues data (sub-surface data from other geothermal, oil and gas, mining… existing projects near-by). Unlike geothermal projects for power production (or oil and gas projects), the business model for geothermal direct-use projects usually does not allow to drill exploration wells nor to perform seismic surveys.

Furthermore, these assessment studies are mandatory to advance through the usually **heavy permitting process** that will grant the authorization for heavy construction work in urban areas and for the exploitation of underground resources.

For geothermal energy from aquifer, the associated risks to this natural resource are of two types:

- The **short-term risk** is related to failure of the drilling operation (stuck drill pipes, borehole collapse…), insufficient resource capacity (temperature and flow rate), or, more rarely in Europe, resource incompatibility (fluid chemistry).
- The **long-term risk** is related to the sustainability of the resource over operational lifetime: cold temperature breakthrough, reservoir pressure depletion and mineral scaling in the well or in the reservoir are the main risks for geothermal operations.

In some countries, **guarantee funds** exist in order to cover these two types of risk and to foster operators to face geothermal energy challenges.

Impact of return temperature

The return temperature **needs to be as low as possible** to maximize the power output from the geothermal heat exchanger and heat pumps. This is a parameter particularly important for geothermal direct-use projects since the efforts and risks taken to achieve a high temperature from the geothermal brine can be completely neutralized by return temperatures that would be too high. Therefore, operators usually put extra efforts to regulate and minimize the return temperatures from their DHC customers.

For aquifer applications, **the reinjection temperature in the aquifer is regulated**. Depending on the aquifer initial temperature and possible use, a minimum reinjection temperature is set. This minimum temperature must be strictly observed since a higher temperature could modify the natural hydrodynamism and chemistry of the natural aquifer.

Maintenance

The most important well workover is the **cleaning of the well casing** [155]. Indeed, the chemical properties of the fluid can degrade the well. It can generate residues of carbonate, sulphate, iron compounds, sludge and fine particulates, as well as corrosion on metal parts. The cleaning methods include preventive methods (geochemical monitoring and injection of corrosion inhibitors on weekly basis) and curative ones (reaming the well, injecting acid to dissolve chemical degradation…).

Another essential point is to control if there are any **leaks** in the well and in the valves. Several methods exist including pipe diameter and pressure-temperature logging (every 3 to 5 years). The periodic maintenance also includes cleaning of the circulating pumps and heat exchangers.

Heavy maintenance of the wells ("workover") may occur once every 10 years and usually mobilize a wide area (1 000 to 1 500 m² as stated before) for about 4 to 6 weeks. These operations can be related to wellbore reaming, acidizing, side tracking of the well, or pump replacement.

The heat pump is controlled every year (cleaning, check for leaks, lubrication) and is replaced approximatively each 20 years. It can be necessary to replace the fluid.

The lifetime of the installation can reach 50 years if it is well maintained.

Downtime

Geothermal resource does not depend on atmospheric conditions. It is a continuous resource shut down only for maintenance. Logging and geochemical monitoring operations do not usually require to interrupt operations, or can be planned in summer when the needs are much lower.

Wells workover can or cannot be planned depending on the nature and severity of the damage. As stated before, these heavy maintenance operations occur about once every 10 years and last about 4 to 6 weeks.

Feedback on the technology

Geothermal energy provides a **local and renewable resource** with potential for DHC applications in almost every European country. The two types of technology that allows to benefit from this natural resource (**drilling of a doublet** and **probe field**) have very different capacity and present very different levels of risk and profitability.

Except for low temperature DH or when the temperature demand is low, the geothermal heat output is **usually combined to heat pumps** in order to increase the temperature of the supply fluid. **Synergies with cooling** are easy to find, either by direct cooling ("geo-cooling") or through reverse heat pumps. When implemented, these synergies can improve significantly the profitability of the operation.

Heat production from geothermal energy always contains some **risks associated to the availability and sustainability of this natural resource** and require **solid assessment program to advance through the heavy permitting process**. However, as projects develop, the drilling risks and uncertainties on the resource reduce, and some guarantee schemes exist in some countries to cover this remaining risk.

The associated up-front investment cost and space requirement are usually heavy, but once it is in operation, this energy provide **baseload output with no fuel cost**. As the resource always presents specific local characteristics, operation and maintenance need to be customized but can build up on the long return of experience of this industry. Some heavy maintenance operations (usually once every 10 years) must be planned to deal with these specific local issues.

C.1.1.3 Biogas

C.1.1.3.1 **Key technical and operational factors**

The following table aims at setting a general presentation of the key parameters of biogas transformation into thermal energy, i.e. the following table provides information on the gas boiler, which are noticeably identical to a conventional gas boiler. Each value is an **average of the values encountered in the scope of biogas heat-only boiler use for district heating**.

Table 28: Overview of key technical parameters for biogas

Key parameter	Definition	Value
Installed capacity	Maximum power achievable at optimized conditions	0.5 - 20 MW per boiler
Yield	Proportion of energy recovered (secondary energy) from the input energy (primary energy)	ca. 90%
Required floor space	Surface occupied by the facilities	20 m²/MW for the boiler room
Downtime	Period of time for which the facility does not produce due to maintenance or failure	ca. one week per year
Greenhouse gas emissions	Emission of CO_2 in tonnes per unit of energy produced	- 0,159 tCO_2/MWh[77] [156]
Atmospheric pollutant emissions	Emission of major pollutants in milligram per normal cubic meter	N.a.[78]

[77] CO2 emissions are negative because the recovery of biogas and biomethane avoids emissions that would have been generated otherwise

[78] Not applicable since the recovery of biogas and biomethane avoids emissions that would have been generated otherwise. However, the combustion of "biomethane" generates the same pollutants as the combustion of "conventional" methane (NOx, SOx, CO…)

C.1.1.3.2 **Technical conditions**

Key facts regarding biogas production

Biogas is the product of **anaerobic digestion of organic matter**, i.e. digestion in a closed space with a lack of oxygen. A cubic meter of **biogas** produced is composed of about 60% of methane CH_4, 35% of CO_2 and 5% of N_2, H_2S and H_2O. This mix can vary with the type of inputs and digester. The remaining organic material is the **digestate**. It represents 90% of the input mass.

All sort of biodegradable waste can be used as inputs in the process:

- Agricultural waste and manure
- Food industry waste such as animal byproducts or fats
- Urban waste such as biodegradable municipal waste, restaurant waste, grass cutting, and sewage sludge

The installation can be fuelled by a mix of these inputs. It creates a very heterogenous resource and its quality is difficult to control. Organic sources have in average a heating value of 0.4 MWh/t (but can be as high as 4 MWh/t for some inputs, like waste grease) [157]. The methane potential of different inputs is presented in annex 6. As it comes from different variable waste sources, one key element for biogas project is that **the resource must be secured on the long-term**, which is a thorny issue since the quantities and quality of the delivered inputs may vary. These inputs are produced and collected locally (on-site to about 50 km maximum according to the type of inputs) to preserve the environmental (limited transportation by lorries) and economic (transportation cost) interest of such projects.

Inputs are treated after being imported on the production site. Before entering the digester, they are **cleaned from potential impurities** by separators and then **crushed to reduce their size**. Animal byproducts are subject to a special **hygienisation** treatment due to sanitary issues. They must be heated at 70°C for at least 1 hour before using it as inputs.

Anaerobic digestion is a complex combination of chemical biological reactions involving different bacteria. The retention time during which the matter stays in the digester depends on temperature. It is in average 60 to 80 days [158]. Three technologies of digester exist**:**

- **Wet complete mix systems** are the most mature and common technology today (see Figure 82). They operate either at 38°C (mesophilic fermentation) or 55°C (thermophilic fermentation) [159]. The thermophilic fermentation is quicker but needs heating during the process.
- **Dry systems** are adapted to inputs composed of more than 15% of solid content. Percolate is sprayed in the digester to activate the fermentation process.
- **Up Flow Anaerobic Sludge Blanket** is used for sewage sludge only.

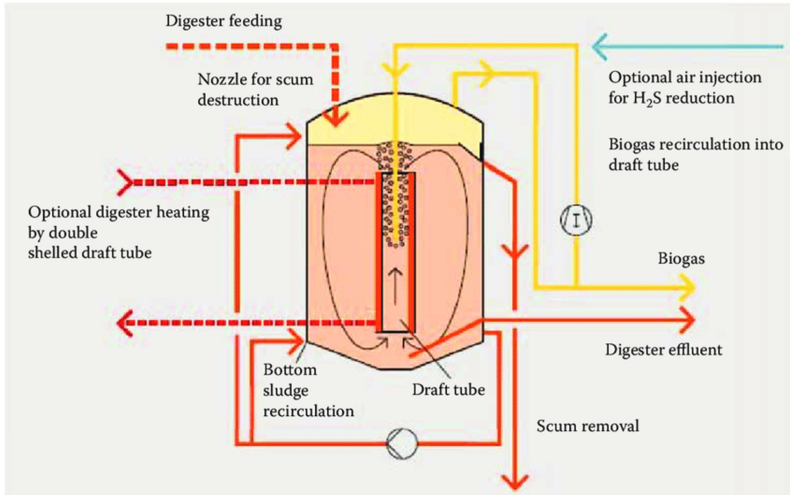


Figure 82: Wet digester system (Source: D. Stuckey 2017)

Downstream of the digester, **the biogas produced can be purified to obtain biomethane (85 to 100% CH_4):** a dehydration process retrieves water, a desulfurization process retrieves H_2S using active carbon as a neutralising agent, and finally a decarbonation process retrieves CO_2 by pressure differences or using a membrane [160].

A biogas production facility (see Figure 83) is composed of a **loading space** (reception of the inputs by lorries and access to the digester), a **storage tank**, a **digester**, a **post-digester** used to stabilise and optimize the production allowing buffer storage. Biogas **can be used directly in a boiler for DH** or in gas motor or gas turbine for CHP. The alternative solution that starts to develop significantly in some countries is to reinject biomethane into the gas distribution network after being treated. **DH can thus use a gas boiler fuelled by biomethane distributed by the gas network** (see section on "Importation of biogas" below).

The storage tank is essential because inputs are collected discontinuously and the digester needs to be filled continuously. Storage facilities can be lagoon for liquid inputs, silage or aerated buildings.

Digestate is a good organic fertilizer and is valorised by spreading in agricultural fields. Some inputs such as municipal waste or sewage sludge can degrade the quality of digestate and its spreading needs to be controlled, especially for water quality issue [161].

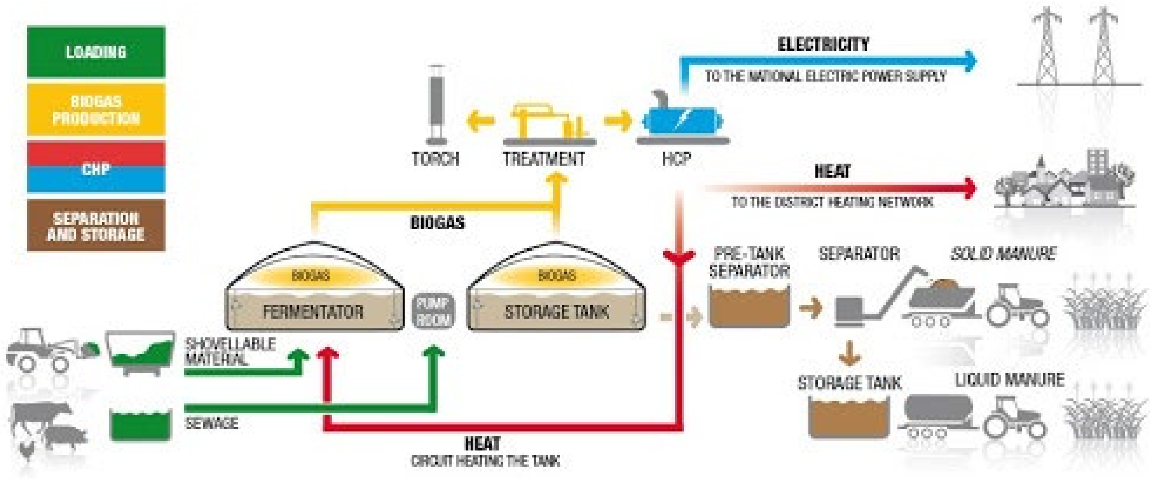


Figure 83: Biogas facility overview (Source: IES Biogas)

Conditions for on-site production and use

A biogas production project realisation depends on various local conditions. The resource can be subject to competition with other use (composting, export…). It is essential that a **local secured resource** is available and close to the production site. Furthermore, a local **valorisation of digestate** should be found before starting the project. Transport vehicles must have an easy access to the site.

To use biogas production in a DH system, the **network should be close to the production**, and a biogas storage might be required (according to biogas production capacity, heat demand, access to the gas network with enough capacity for reinjection…). A large area is required: about 30 000 m² for the production site [162] (on top of the 20 m²/MW for the boiler room and associated facilities). **Purification facilities are also required** to obtain biomethane that can be used in conventional gas boilers.

If the DH network is closed to a landfill, it can benefit from a biogas production [158]. Indeed, **a landfill can foster biodegradable waste digestion**. To do so, a liner is set over the landfill to close the waste in anaerobic conditions and a recovery system is installed (see Figure 84).

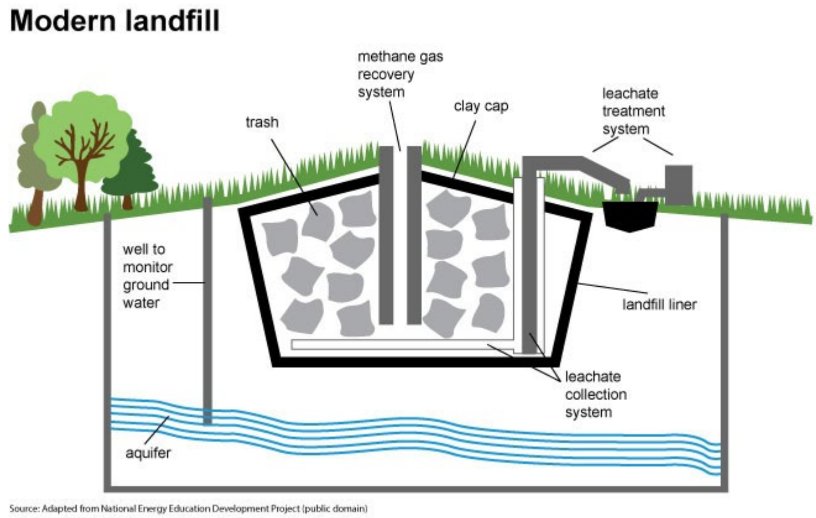


Figure 84: Landfill biogas production (Source: EIA 2019)

However, the distance between the DH network and the biogas production site shall be very limited (no more than a few hundred meters or kilometres maximum) in order not to impact too severely the economic feasibility of such projects. In addition, DHC networks are by nature found in relatively dense and populated area, that are usually not compatible with the management of the inputs and digestate (lorries traffic, odour and noise pollution, landscape impact…). Therefore, **DH on-site production is relatively limited and biogas is usually rather imported to the DH production plant through the gas distribution network**.

Importation of biogas

There is no difference between a molecule of methane and a molecule of biomethane. Most of the time today, the biomethane imported through the gas distribution network is usually not physically the biomethane that has been produced on the biogas production plant. However, this imported methane is certified as "biomethane" thanks to mechanisms of guarantees of origin that allow traceability of this non-fossil source of energy.

The extra-cost associated to these guarantees of origin (that are contracted on energy markets when purchasing gas) can sometime double the price of gas. In return, the use of this imported "biogas" in DH networks allows to increase the share of renewable and excess energy in the energy mix of the DH networks, and thus to ease the access to financial supports (investment subsidies, adapted debt funding, tax incentives…).

However, it is important to note that the status of biogas may vary according to national regulations, and may be considered as a renewable energy in some countries, and may not in others. Even in the same country, the use of imported biogas in a DH network may allow to access to tax incentives but may not be eligible for investment subsidies. This is the case in France for example, since biogas production facilities are already financially supported by a separated feed-in tariff mechanism.

Yields of gas boiler

The yield represents the proportion of energy recovered (secondary energy) from the input energy (primary energy). For a boiler, it reflects the efficiency of the combustion process. The yield of a new gas boiler is ca. **90%.**

A gas boiler can be used on a wide operating temperatures range, and thus can generate steam as well as low temperature water. It is therefore very flexible and **compatible with high to low temperature DHC networks**.

Plant management integration

According to the purity of biogas and its content in methane, the biogas may be used in a dedicated boiler, or, as it is usually the case since biogas is often imported as biomethane, directed to a boiler used for both gas and certified biogas.

Biogas can also be used to feed a CHP unit, the heat generated being used in the DH network and the electricity being sold via feed-in tariffs or other mechanisms.

Biogas for CHP

Exactly like gas, biogas can be used to produce Combined Heat and Power. The exact same principle applies: thermal energy is recovered from the exhaust gases and cooling circuits of gas engines or turbines, or from the expanded steam in steam turbines. The mechanical energy is converted into electricity by means of an alternator.

The use of primary energy is thus considerably improved, resulting in a high overall efficiency of more than 80% when good heat recovery can be achieved (like with DH).

Different techniques are available depending on the targeted uses:

- Gas engines (Stirling or internal combustion)
- Gas Turbine
- Steam turbine
- Organic Rankine Cycle (ORC)

Case study of Querfurt (DE): Biogas production from local agriculture (Annex 6)

The case study of Querfurt illustrates how a DH network can be modernised and decarbonised while maximising local value creation. It also shows the **synergies' between DH and agriculture through local biogas production**.

The retained solution resulted from a **complete benchmarking of potential projects based on economic, environmental, and social welfare criteria.** It includes the construction of a new biogas plant and pipeline connecting the DH plant, and the establishment of a new DH company, that can also provide other energy services.

The biogas plant uses local agricultural waste and feeds with raw biogas a **500 kW CHP unit through a 2.5 km pipeline**. One of the key success factors consisted in securing the feedstocks for biogas supply and the offtake by the DH system through a long-term contract between the biogas plant and the DH operator.

An additional 9.7 MW gas boiler ensures the rest of the DH supply and peak loads. The current production mix consist of **30% biogas** and 70% natural gas, and further decarbonisation is expected, especially in a national context of growing CO_2 taxes for fossil heating in Germany.

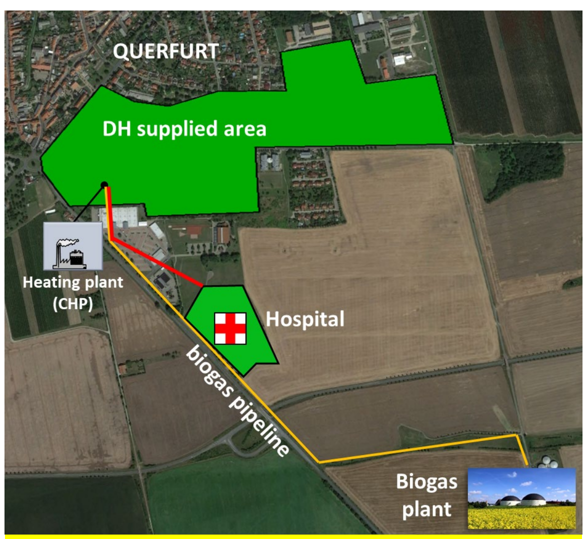


Figure 85: Querfurt DH supplied area and production plants (source: Tilia)

C.1.1.3.3 **Operational constraints and requirements**

Emissions limit values of gas boiler

The flue gases of a boiler contain dangerous pollutants. Abatements technologies are always present in the installation and must meet with the European requirements limiting emissions. The emission limit values are set by the EU Directive 2010/75/EU on industrial emission and EU Directive 2015/2193 on medium combustion plants. These directives are transposed in each national legislation setting their own limit values.

The European values are presented in the following table.

Table 29: Emission limit values set by the EU Directive 2015/2193 on medium combustion plants

Type of installations concerned	Rated thermal input (in MW)	Emission limit values on NOx (in mg/Nm^3)	Emission limit values on Dust (in mg/Nm^3)	Emission limit values on Sox (in mg/Nm^3)
New plants from 20/12/2018	***1 to 50***	200 mg/Nm^3	-	100 mg/Nm^3
Existing plants from 01/01/2025	***5 to 50***	250 mg/Nm^3	-	170 mg/Nm^3
Existing plants from 01/01/2030	***1 to 5***	250 mg/Nm^3	-	200 mg/Nm^3

Controls of pollutant emissions (flow rates and concentrations of the different pollutants) are regulated by national authorities according to a frequency that usually varies in function of the installed capacity.

Impact of return temperature

If the network return temperature is low (less than 55°C), the gas boiler yield can be increased thanks to flue gases condensation [163]. Indeed, a condenser placed at the exhaust of flue gases allows the water still present in the gases to condensate if the return temperature is below the dew point. By condensing the water content of flue gases, heat is released. It enables to preheat the water and reduce losses in the flue gases, hence increasing the yield.

Maintenance of gas boiler

A gas boiler is controlled by a range of alarms and error codes monitoring constantly the operation and informing for the maintenance [164]. The temperature and pressure are controlled continuously. For the maintenance, several points need to be secured regularly: water treatment, pumps, burner combustion, blockage of the venting system, leaks or vibrations. An annual maintenance is done to clean all the parts of the boiler. A maintenance planning is set to ensure good maintenance. National regulations set the frequency and scope of theses controls according to the installed capacity.

Downtime of gas boiler

The planned downtime of a gas boiler is ca. one week per year. The forced downtime due to failure is estimated at 1 to 2% of the annual operation time [165].

Feedback on the technology

Biogas production has a significant potential that is still underexploited in most countries. The major difficulty for operators is to secure the resource, as it is a heterogeneous source of inputs, and to finance their projects. In addition, the development phase usually lasts more than 3 years to be operational due to various administrative procedures. Social acceptability also slow projects with concerns about olfactory, noise and sanitary nuisances. A high number of actors is required as the resource and production may imply local municipalities, farmers, industries, gas network and DH operators.

Biogas production therefore requires a complex project management, but it has the great advantage to be rooted in a local scale and to develop positive externalities when properly operated (decrease in the use of mineral fertilizers, preservation of biodiversity, local employment, valorisation of the gas distribution assets…). As it enters the energy transition strategy of most countries today, biogas production tends to benefit from stronger financial support, which shall foster its development in the short to medium term, and foster its use in DH networks through gas boilers or CHP units.

C.1.1.4 Solar thermal

C.1.1.4.1 **Key technical and operational factors**

The following table aims at setting a general presentation of the key parameters of **solar thermal facilities**. Each value is an **average of the values encountered in the scope of solar thermal production for district heating and cooling**.

Table 30: Overview of key technical parameters for solar thermal energy

Key parameter	Definition	Value
Installed capacity	Maximum power achievable under ideal conditions	350 kW up to 110 MW
Yield	Proportion of energy recovered (secondary energy) from the input energy (primary energy)	35% [166]
Required floor space	Surface occupied by the installation[79] per unit of power	ca. 5 250 m²/MW
Operating time	Percentage of operating time for which solar thermal can be valorised over a year	20 to 50% [167]
Downtime	Period of time for which the facility does not produce due to maintenance or regulation	Very limited and plannable during non-operating hours
Greenhouse gas emissions	Emission of CO_2 in milligram per normal cubic meter	0 mg/Nm³
Atmospheric pollutant emissions	Emission of major pollutants in milligram per normal cubic meter	0 mg/Nm³

C.1.1.4.2 **Technical conditions**

Key principles and technologies

The sun is a powerful source of energy. Solar irradiation is present everywhere in Europe and sufficient to be captured by solar collectors to heat water. Global horizontal irradiation at the surface in Europe ranges from 1000 and 1800 kWh/m² (see Figure 86). It includes direct and diffuse solar irradiation that can be absorbed by collector technologies.

[79] excluding storage facilities

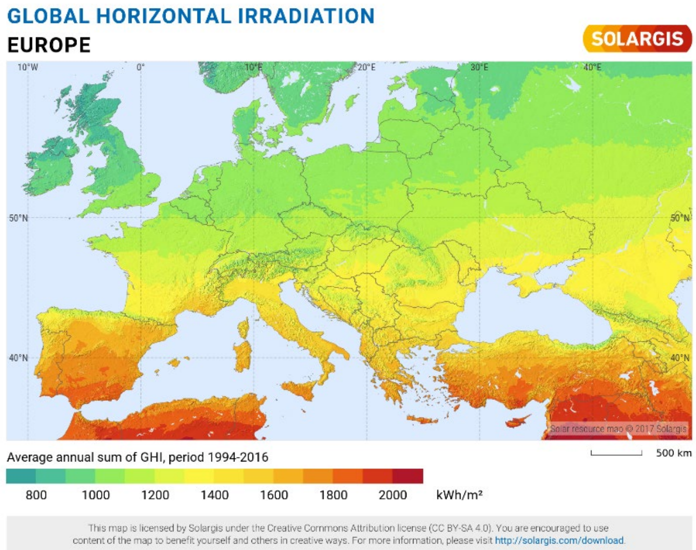


Figure 86: Global horizontal irradiation map of Europe (Source: Solaris 2019)

Three types of collectors are used to capture heat from solar energy:

- **Flat plate collector** (see Figure 87) is composed of an absorber material thermally stable (polymers, aluminium, steel or copper) in which flows a heat transfer fluid. The heat transfer fluid is usually glycoled water, used to decrease freezing temperature. The collector is contained in an insulated box with a glazing enabling greenhouse effect. The heat transfer fluid captures heat from the solar rays in the absorber and transmits this heat to the DH system or a storage facility. To limit heat losses and thus reach high temperatures, the simple glazing can be replaced by a double glazing. Absorber and glazing materials are treated to avoid reflexion and emission of solar rays in order to prioritize the absorption process. The temperatures generated by this technology are usually between 50 and 80 °C. They can **directly feed Domestic Hot Water needs or may be coupled to heat pumps in order to feed heating needs** as well.

- **Evacuated tube collector** (see Figure 88) is a collector composed of a series of glass tubes. The tubes operate under a pressure below 10^{-2} to 10^{-6} bar to get rid of heat losses between air molecules. An absorber plate with the heat transfer fluid is placed into the tubes. It can generate heat at temperatures between 50 and 110°C. Several techniques exist to increase even more the performances of the vacuum tube technology:
  - The fluid can transfer its heat through a heat exchanger. It avoids weakening the connection of evacuated tubes.
  - The fluid in the tube can be condensed and then evaporated with solar heat. This cycle enables to benefit from the phase transformation energy.

- The tube can have a double glazing with vacuum between glass layers. It reinforces insulation.
- Mirror reflectors can be placed in the bottom part of the tube. It enables to benefit from the total surface of the tube and not only from the direct emissions at the top of the tube. It is called Compound Parabolic Collector (CPC).

Both technologies are mature and widely spread in Europe now.

- **Concentrated solar power (CSP)** is using optical reflectors (mirrors) which aim to concentrate the solar rays towards a small section receiver containing the heat transfer fluid. The receiver can thus generate heat at very high temperature, between 250 and 1 000 °C. Several geometries of reflectors exist (parabolic trough, parabolic dish, Fresnel or heliostat field). In the reflector, the fluid can be molten salt (or synthetic or mineral oils) which has a great heat capacity and can be easily stored. CSP technology is mostly used to produce electricity.

CSP technology requires direct irradiation, which is limited in Europe, and especially in the northern part. Therefore, CSP is rarely used in Europe, where diffused irradiation is mostly exploited through flat plate or evacuated tube collectors [167]. This report will not detail further this technology.

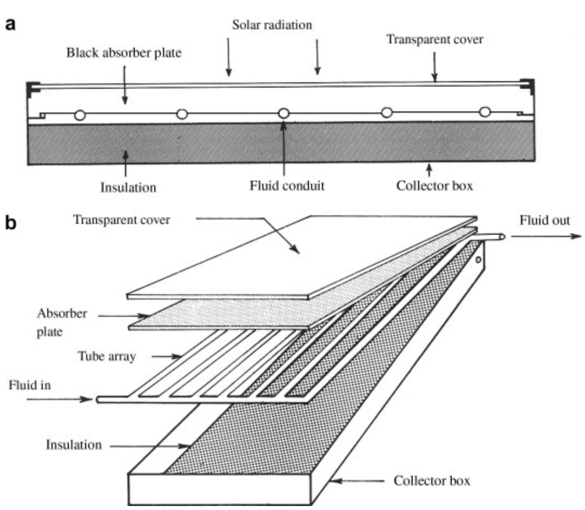


Figure 87: Flate plate collector (Source: A. Sözen, T. Menlik, S. Ünvar, 2008)

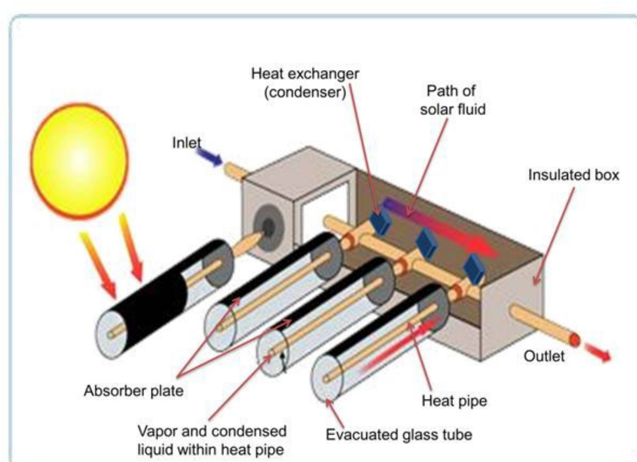


Figure 88: Evacuated tube collector (Source: solar365)

Facility overview

The solar facility is composed of a series of collectors, a thermal storage and the connection to the DHC network. Heat pumps can be used to reach higher levels of temperature.

Solar collectors are either **ground-mounted** or installed on **roof-tops** [167]. Solar DHC production is usually ground-mounted on a field, as roofs availability or compatibility can be limited (use for other applications, structure issues, aesthetic constraints…). However, land access is also a sensitive issue and solar collectors are usually installed on lands where nothing else could be built (e.g. close to railways).

Flat plate and evacuated tube collectors require large area and both can be installed ground-mounted or on rooftops. The area is equivalent for the two types of collectors. The installation of 1 MW requires ca. 1500 m² of collector area. Ground mounted, the collectors need to be separated from each other. The land used is 3 to 4 m² per meter of collector, hence the average required space is about 5 250 m²/MW.

Design and applications

Solar thermal application can adapt to every size of DH system, from districts or villages to large cities.

Flat plate and evacuated tube collectors can be used in zones of low irradiance. Azimuth and tilt are essential parameters, the idea being to capture maximum solar radiation at a perpendicular slope. A tilt above 40° (from horizontal) could maximise the production in winter and limit it in summer, because the sun is higher in the sky in summer [167]. Optimum design must be assessed in accordance with the corresponding needs for heat and/or cold.

The installation can be centralized or distributed (see Figure 89). In a **centralized installation**, solar collectors are placed in the central plant and the heat is transferred to the DHC system (the use of heat pumps might be required to reach the appropriate temperature levels of the system). Whereas in a **distributed system**, solar collectors are placed all over the DH system, usually on the roof of the connected buildings [168]. The heat is consumed locally (for Domestic Hot Water and possibly for heating and cooling as well) and the excess can be injected in the DHC system according to operating temperature levels.

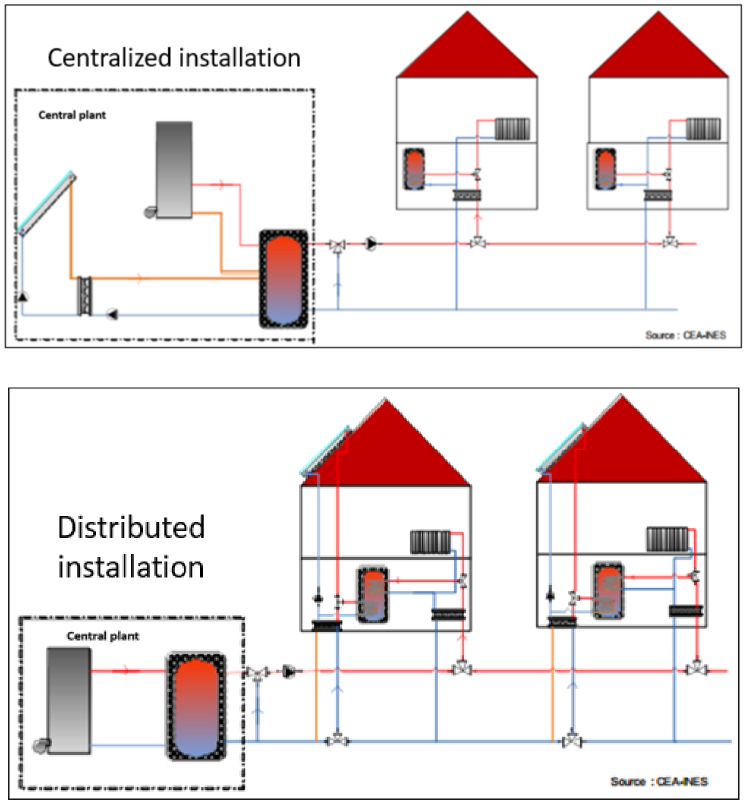


Figure 89: Centralized and distributed solar installations (Source: CEA & INES)

Yields

Solar thermal installations can produce around **400 kWh/m²/year in Europe**, corresponding to a yield of **35%** [166]. Temperature is a key parameter. The lower the supply and return temperatures are, the better the performances (see Figure 90).

Different technologies of collector imply different yields. The more efforts are done to decrease thermal losses, the better is the yield. Indeed, evacuated tube collectors have a higher yield than flat plate collectors (see Figure 90) because vacuum reduces air heat losses in the collector. CPC evacuated tubes are even more efficient because they enable to use more exchange surface than a simple evacuated tube.

The yield also depends on the irradiation that can be captured. At low irradiation, evacuated tube collectors are more efficient because they capture direct, diffuse and reflected radiations. To maximize the yield, the collectors must be placed south facing with no shading with a tilt angle between 40 and 60° [167].

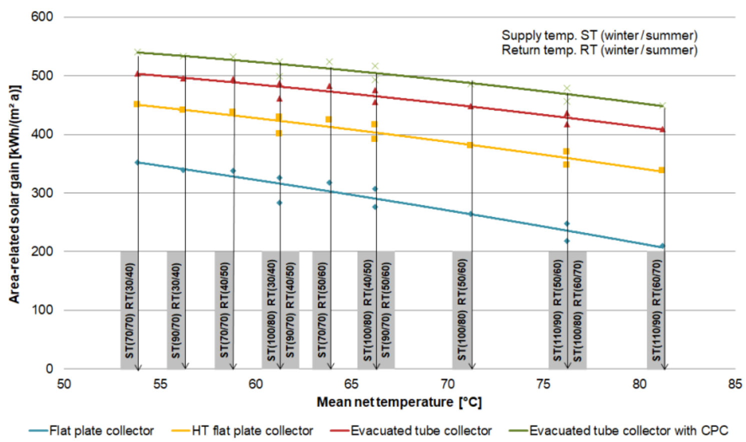


Figure 90: Specific solar heat yield per collector area versus DH network temperatures and collector types in South Germany (Source: Solites)

Plant management integration

The solar fraction is the solar coverage of the DHC annual needs. This solar fraction can reach around 20% in the main DHC systems with solar thermal production. It can even be improved up to 50% by a buffer storage or a seasonal storage [169]. The solar production is designed to cover all the needs in summer.

Solar thermal technologies are flexible and can be combined with other technologies, as centralized or decentralized production units. As the fuel (solar irradiation) is free, production from solar thermal is used as basis (i.e. prioritized over other production units) or stored if storage capacity is available. They are modular and can adapt to the size of the network, as long as land or roof access is provided.

Synergies with thermal storage

Most solar energy can only be captured during the day at relatively high temperature and solar irradiance. There are times when the production does not match with the demand. Therefore, a storage is essential to increase the solar coverage of the network. It can be a **short-term storage with a daily period** enabling to use at night the energy stored during the day. It can also be a **seasonal storage with an annual period**, enabling to use in winter the energy stored during summer when solar irradiance is at its maximum but there is low heat demand [167].

Short term storage facilities are **thermal tanks**. They are cylindrical, made of steel and filled with water. The inside water is stratified and outlets at different heights can provide different levels of temperatures. This technology is used in DH using all kind of energy supply (see biomass section C.1.1.1.2). It helps to smooth out peak loads.

Seasonal storage uses large storage (see Figure 91). Different geometries of **pit storage** exist. They are made by mounting a insulated liner in a buried pit. Thermal energy can also be stored by transferring its heat into the ground through **borehole or aquifer geothermal facilities** (the so called BTES and ATES as described in Figure 91).

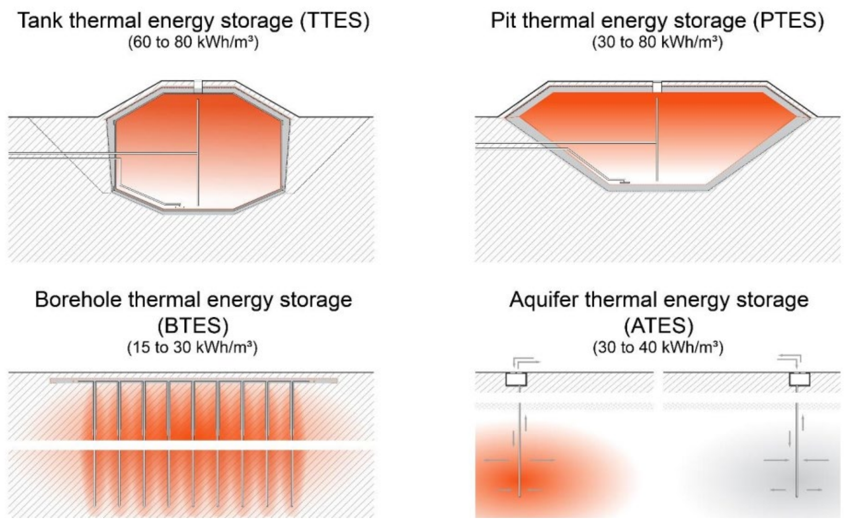
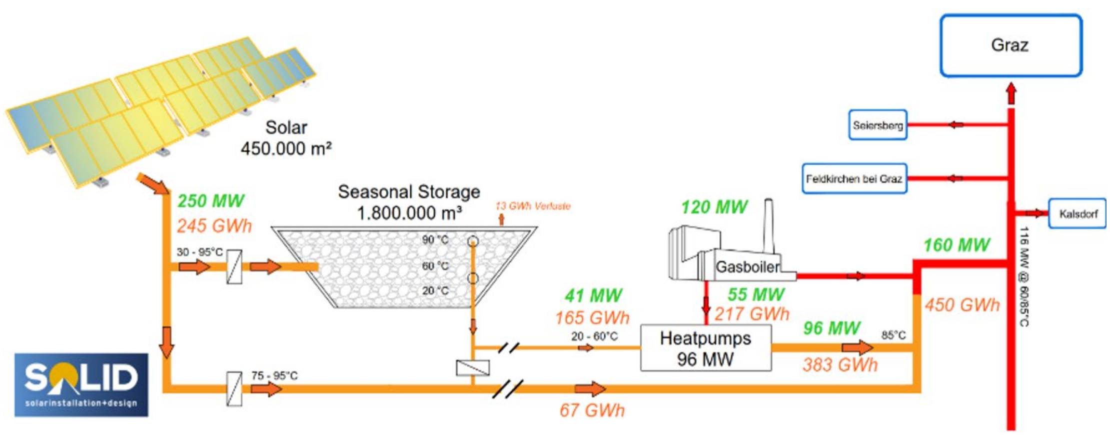


Figure 91: Overview of available underground thermal energy storage concepts (Source: Solites)

Case study of Graz DH (AT): "Big solar" project (Annex 6)

The "Big Solar Graz" project is remarkable as it would be the world's largest thermo-solar collector. A detailed feasibility study has been carried out and highlighted the potential for a 450,000 m^2 collector field area for a total of **250 MW**, coupled with **1,800,000 m^3 seasonal storage** and **96 MW absorption heat pump** capacity. With this project, up to **25% of the heat demand in Graz could be supplied by solar energy**. In the long term, this project is designed to be competitive with gas.



A recent study also highlighted the **impact of reducing the return and supply temperatures** of the DH network. A reduction of 10°C in the supply and return temperature would **increase the solar yield by 13%** (total yield of the system including the planned storage facilities) and therefore increase the overall integration of solar energy in the DH production mix.

Synergies with cooling

Solar thermal collectors can be used for cooling in DC networks and benefits from a particularly interesting synergy since solar power is usually coincident with cooling needs. Cooling from solar power can be achieved through 2 major principles [170]:

- **Absorption cooling** (see Figure 92): The heat captured by the solar thermal collector is used in the generator to evaporate the ammoniac of a water-ammoniac solution. The pure ammonia vapor is then condensed in the condenser, releasing heat to a cooling tower. The liquid ammonia then passes through an expansion valve to lose its pressure. As it contacts with the outer surface of water tubes of the evaporator, it starts boiling as a result of taking heat from the returning water line from the consumer, i.e. it exchanges its cold to the DC network (the evaporator being here the thermal exchanger with the network). Finally, the vapor ammonia condenses again in the absorber, releasing heat to a cooling tower, and mixes with the remaining water of the generator. The solution is then pumped towards the generator for a new cycle.
- **Adsorption cooling** (see Figure 93): It is a two-step process, very similar to the absorption cooling, except that the working fluid (refrigerant or adsorbate) molecules adsorb onto the surface of a solid instead of dissolving into a fluid. The adsorbate could be gaseous state ammonia, water, methanol… while the adsorbent is a solid, such as silicone gel, activated carbon, zeolite… (unlike in the absorption cooling where the absorbent is usually liquid). In the desorption step, solar thermal collectors bring heat to the adsorber. The adsorbate is evaporated (desorption) and goes towards the condenser where it is condensed, releasing heat to a cooler. In the adsorption step, the adsorbate evaporates at the contact of the outer surface of water tubes of the evaporator (acting again as the thermal exchanger with the network). The evaporator transmits cold to the DC network during evaporation. The adsorbate condenses back in the adsorber (adsorption) and the system is then ready to a new adsorption step. An adsorption cooling system is actually composed of two adsorbers and two exchangers (see Figure 93) allowing the two steps to work simultaneously and produce cold continuously.

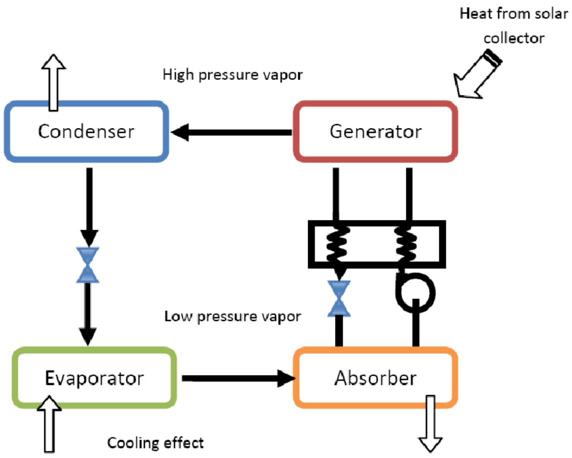


Figure 92: The basic principle of the absorption cooling system (Source: H. Boyer 2007)

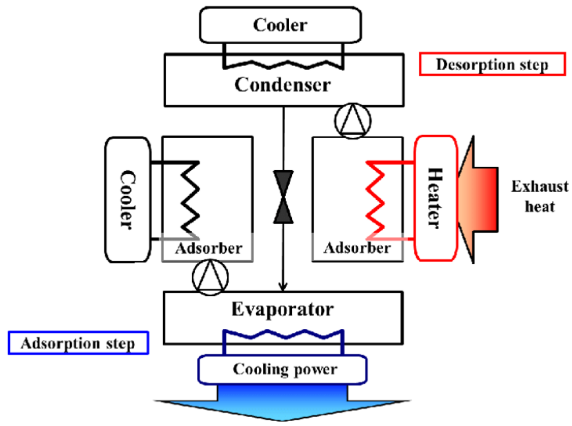


Figure 93: Adsorption cooling principle (Source: Zeng et al. 2017)

C.1.1.4.3 **Operational constraints and requirements**

Resource assessment

A resource assessment is done before any project to determine the availability of solar thermal resource. Its aim is to **assess solar radiation conditions at site**. Indeed, clouds absorb ca. 20% of the direct radiation and knowing the variable climatologic conditions is essential to evaluate the performances of a project. Ground stations with measurement technologies exist but **satellite data** are still the most used. In a second phase, an on-site **measurement campaign** is done to collect more precise data.

The resource assessment of a solar thermal project consists in 4 steps [171]:

- **Prospection**: A site benchmarking is done. Global data are used to create a screening map of potential sites. The aim is to select the best site for the project.
- **Prefeasibility study**: A first preliminary study is carried out with rough data to evaluate the global performances of the project.
- **Feasibility study**: This study uses more precise data on hourly time-steps. This step includes design and technical optimization of the project.
- **Due diligence**: Long term performances are evaluated on the lifetime of the project.

Permitting

Ground-mounted installations are subject to heavy permitting process granted by local public authorities. Given the tension on land access for farming, the main prospects that are valorised for solar panel installations are "degraded" lands such as industrial wastelands, abandoned airports, roads or railways, former quarries, former landfills, or former polluted sites.

Rooftop installations are subject to building licence granted by local public authorities as well. Different kind of conditions are required: roof structure compatibility, mounting structure certifications, safety (during construction and during operation), architectural constraints…

For both ground-mounted and rooftop installations, **permitting is a long process that needs to be anticipated and addressed seriously**. A complete assessment of environmental impact is usually required from a certain level of installed capacity.

Maintenance and downtime

Solar collectors need very few maintenance operations. A **periodic cleaning** is recommended to avoid dirt accumulation. During the maintenance, the fluid pressure, insulation, risk of leaks, flow rate and settings are checked. **The pump is replaced each 10 years and the heat transfer fluid each 5 years.**

If an evacuated tube is defective, the coating at the base of the tube changes colour due to air penetration. The tube must then be replaced.

Downtime is therefore very limited and major maintenance operations can usually be planned when solar irradiation is the lowest.

The lifetime of solar installations is 25 to 30 years.

Feedback on the technology

Using solar thermal energy in DH application presents numerous advantages. It enables to benefit from a local resource widely spread across Europe. This resource is renewable, produces no CO_2 emission, and is free and therefore not exposed to fuel price fluctuations. Despite its relatively high investment cost per kWh produced and its permitting constraints, solar thermal energy is growing in Europe.

It is a simple but robust technology, with limited maintenance operation, and which benefits from proven records. In many places, using solar energy limits the use of local biomass fuel, that can be subject to sourcing pressure. When space is available, it can significantly cover heating and cooling needs with thermal storage combination.

The advantage brought by the modularity of this technology and its centralized or decentralized mode can be key in some projects with specific constraints (district development spread over time, multiple roofs or lands available at various locations…).

C.1.1.5 Ambient energy

Ambient energy is the heat recovered from ambient air, sewage water or natural streams or lakes. It can be a source for DHC systems when recovered with a heat exchanger and raised in temperature by a heat pump.

C.1.1.5.1 **Key technical and operational factors**

The following table aims at setting a general presentation of the key parameters of ambient energy recovery (as defined in next section). Each value is an **average of the values encountered in the scope of ambient energy use for district heating and cooling**.

Table 31: Overview of key technical parameters for ambient energy

Key parameter	Definition	Value
Installed capacity	Maximum power achievable at optimized conditions	100 kW – 50 MW [172]
Yield and COP (Coefficient Of Performance)	Yield: Proportion of energy recovered (primary energy) from the input energy (primary energy) COP: Ratio of heat provided over the electricity needed for heat pumps	Heat exchanger: 80% [173] Heat pump: 3,5 – 4,5 [174] [175]
Required floor space	Surface occupied by the facilities (for heat pump only)	12 m²/MW
Downtime	Period of time for which the facility does not produce due to maintenance or failure	ca. 1 week per year
Greenhouse gas emissions	Emission of CO_2 in milligram per normal cubic meter	0 mg/Nm³
Atmospheric pollutant emissions	Emission of major pollutants in milligram per normal cubic meter	0 mg/Nm³

C.1.1.5.2 **Technical conditions**

Presentation of the different solutions

DHC production can benefit from ambient energy, i.e. as defined in the EU Directive 2018/2001 on the promotion of the use of energy from renewable sources **"'ambient energy' means naturally occurring thermal energy and energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water*"*. Heat at low temperature is collected by a heat exchanger and usually directed to a heat pump.**

Sewage water recovery includes rainwater and returns of Domestic Hot Water (DHW) from washing machines, dishwasher, bath tubs, showers, etc. The heat can be recovered at different locations of the sewage network (see Figure 94) [176]:

- **At the foot of the building** for buildings rejecting large amounts of waste water. Hospitals, industries or public buildings are potential sources.
- **In the pipe of the sewer**, which is the most common because it gathers a more important flow rate.
- **After the treatment plant** before the reinjection of the water. The advantage is that the purified water does not damage the installation, facilitating the maintenance. There might be competition on this resource however as the wastewater treatment plant (WWTP) may want to recover the calories from its effluents for its own heat demand.

If the waste water is recovered far from the building, flow rate is higher due to the gathering of pipelines and the resource is less dependent from water consumptions. However, the temperature is lower because of heat losses in the pipes, which matters since the loss of only 1 or 2 degrees for low temperature resources is significant.

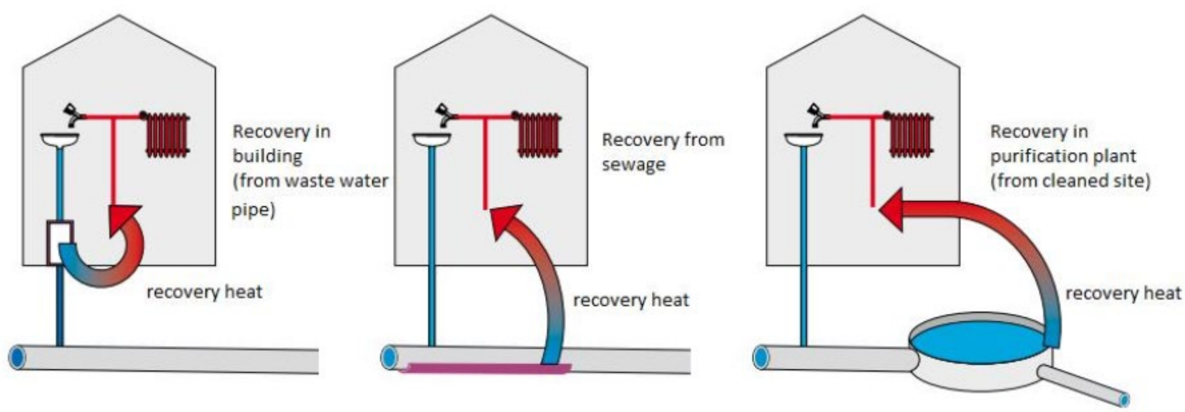


Figure 94: Location for energy recovery system (Source: SwissEnergy 2005)

Two types of heat exchangers technology can be used to recover heat from sewage water, both of them use water as a fluid (or glycoled water to decrease the freezing temperature) [172]:

- **In-sewer heat exchangers** are installed on the bottom of the pipe over a 50 to 200 m length. Several models are adapted to this application, an overview of different models is provided in annex 6. Their application is usually restricted to new project since it is very difficult to install these exchangers on existing sewers.
- In the case of a **sewer-external heat exchanger**, waste water is by-passed from the sewer, and filtered when it is located upstream of a WWTP. It exchanges with a basic plate exchanger and then pumped back to the sewer (see Figure 96). This technology is more flexible and facilitate the access for maintenance and operation.

Water from natural streams or lakes can also be used for this application with the same principle as a sewer-external installation (see Figure 97). Water is pumped from depth where the temperature is constant over the year (e.g. 70 m deep in the Lake Genova in Switzerland). Temperature usually varies between 6 and 10°C [177].

Once heat is recovered from ambient energy at low temperature by the exchanger, it is directed to a heat pump to increase its temperature level or to generate cooling. As the heat input can vary over time with water consumptions and rainfalls, storage facilities are sometimes associated to this type of installation (when the installed capacity is significant and designed for peak load) [178].

As the calories recovery from ambient air is rather dedicated to heating and cooling solutions for individual housing, this technology will not be addressed in this study.

Facility overview

The facility of sewage water heat recovery is, first, composed of a heat exchanger that can be in-sewer (see Figure 95) or sewer-external (see Figure 96). For sewer-external exchangers, an additional sewage screening station is set to recover sewage water and operate filtration when necessary (i.e. when located upstream of a WWTP). In both cases the exchanger is connected to a heat pump in the heating plant (or machinery room). In the case of a sewer-external exchanger, the exchanger is located in the heating plant [179]. The plant can also host a thermal storage and a CHP unit. The heat is brought to the DH system and the sewage water returns to the WWTP.

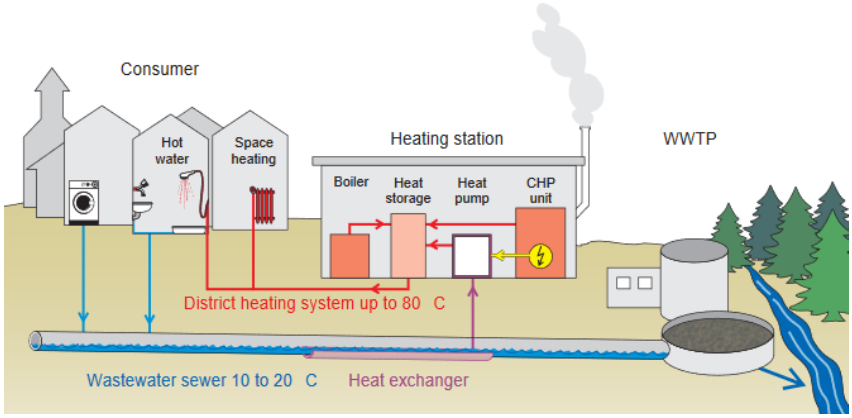


Figure 95: Facility overview for an in-sewer heat exchanger (Source: SwissEnergy 2005)

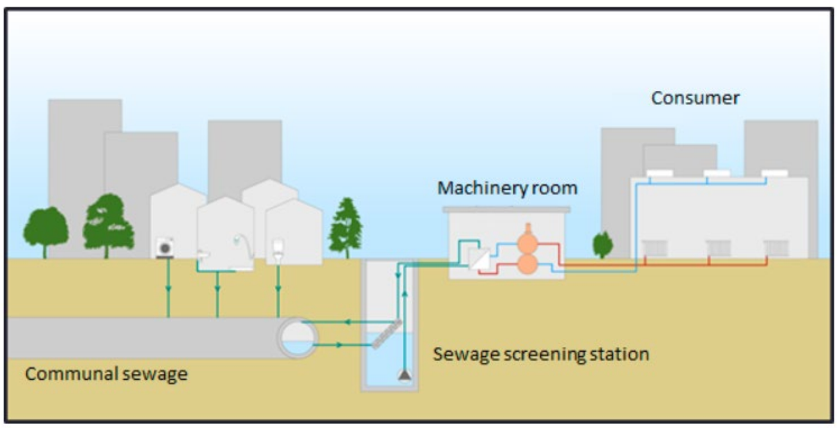


Figure 96: Facility overview for a sewer-external heat exchanger (Source: M. Aprile et al. 2019)

The facility for natural streams or lake water heat recovery is similar to a sewage facility with a sewer-external heat exchanger (see Figure 97). The major difference is that the source is farther from the heat exchanger and the heat pump. Therefore, large pipelines need to be installed.

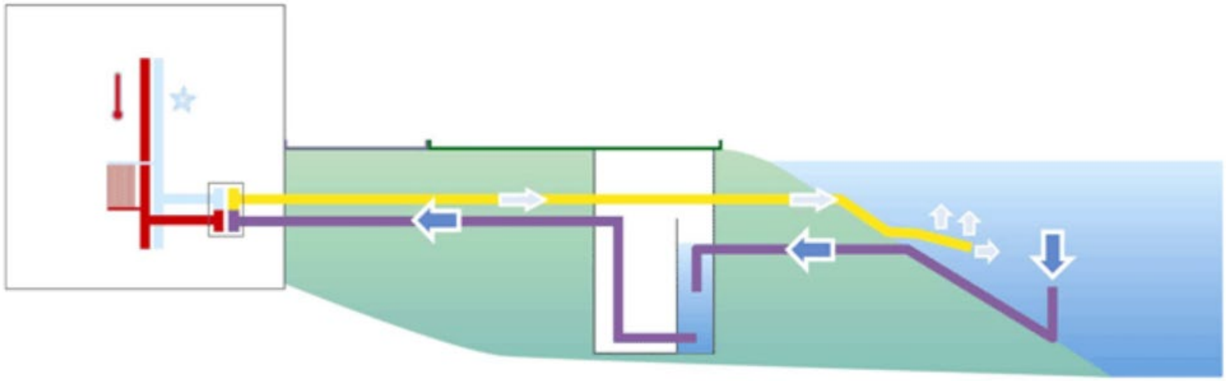


Figure 97: Facility overview for a heat recovery from lake water [177]

As already stated, the distance of the heat source is crucial for such projects and the economic conditions usually require that the source of calories (from sewage water, natural streams or lakes) is not located further than ca. 2 km from the heating station.

Different designs of heat pumps and applications

The principle of a compression heat pump is to capture ambient energy heat at relatively low temperature, raise its temperature by a compression process, and transfer it at high temperature to a DH network. A more detailed description of heat pumps and their design is provided in the Geothermal section in paragraph C.1.1.2.2. In the case of ambient energy, the heat is captured at an average temperature of 10-15°C (slightly lower in the case of natural streams and lakes). Heat pumps can be installed in a cascading technique enabling to provide a supply temperature up to 70°C, **particularly adapted to low to medium temperature DH networks** [176].

Heat pumps used for ambient energy recovery have usually a capacity between 100 kW to 1 MW to be economically viable [173] [180].

However, in the case of large installations where ambient energy is used as a peak load heating source, heat pumps can have a capacity of 20 MW up to 50 MW, raising water to ca. 90°C [172]. It is the case for example in Sweden with large heat pumps operating on WWTP.

Yields and Coefficient of Performance

The yield of an exchanger is the ratio of the amount of heat recovered over the amount of heat present in the source. The type of exchanger used in ambient energy recovery have a yield of 80% to 90% [173]. Their efficiency is very sensitive to maintenance and filtration process.

The COP of heat pumps directly depends on the resource temperature and the supply temperature for DH (see Figure 78 in the Geothermal section). In the case of ambient energy, the COP of heat pumps is between 3,5 and 4,5 [174] [175].

Plant management integration

Ambient energy with a heat pump is generally used as a base energy because it provides heat at low temperature. **A complementary energy is needed to cover peak demands**. It is commonly a natural gas or biomass boiler.

- Either the heat pump operates at its maximum load and is stopped when the demand is too high, the boiler providing all the heat. This can be the case when the complementary boiler is a biomass boiler, which is less flexible and require a minimum load for start-up [172].
- Or, the complementary boiler operates with the heat pump and the heat needs are covered with both energies. In this case, the supply temperature of the heat pump is usually lowered in order to increase the COP of the heat pump [172].

Synergies with cooling

Ambient water can be used as cooling for DC or DHC systems through different technologies. The most common applications are **free cooling** (or direct cooling) and **refrigerating machine** (reversed heat pump). These two technologies are detailed in the Geothermal section in paragraph C.1.1.2.2. Instead of transferring heat of the network to the underground through a geothermal loop, it is transferred to ambient water (sewage waters or natural waters).

If the resource is not cold enough in summer, cooling can also be done by **absorption** and **adsorption** technologies. Both principles are explained in the Solar thermal section in paragraph C.1.1.4.2.

Case study of Bordeaux DHC (FR): Heat recovery on wastewater (Annex 6)

One of the solutions chosen to **supply heating and cooling to the new 162 ha district *Bassins à flot*** in Bordeaux is to recover the heat from the local urban Wastewater Treatment Plant (WWTP).

The DHC network is based on a a **mid-temperature loop** (8 km network) transporting water heated all year long between 12 and 25°C thanks to heat exchangers located at the central unit. The water comes back at around 7°C in winter and 30°C in summer.

The mid-temperature loop supplies **40 substations** located in every building connected. These substations comprise **decentralised heat-pumps (8,4 MW in total) and gas boilers (6,6 MW)**, connected to the loop by means of heat exchangers, to produce water for heating (45°C), domestic hot water (63°C) and cooling (7°C) as needed. The Coefficient Of Performance (COP) of the heat pumps is around 3,5 to 4 all year.

The integration of such a low temperature resource is possible and particularly interesting (both technically and economically) for new urban districts made of new buildings with low temperature regimes for heating. This innovative solution of mid-temperature loop with decentralised heat-pumps enables to **mutualize the production of both heating and cooling** in a very efficient way.

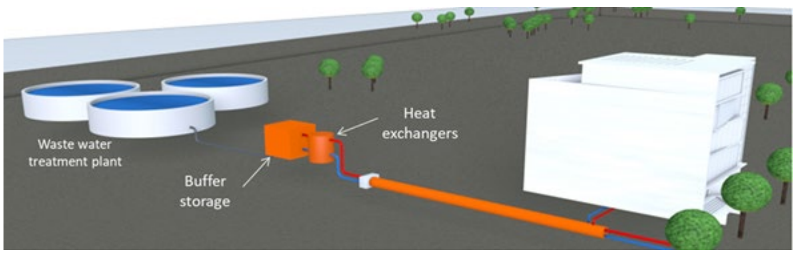


Figure 98: Heat recovery from a waste water treatment plant for the production of heating and cooling on Bordeaux DHC (source: EDB)

C.1.1.5.3 **Operational constraints and requirements**

Resource assessment and availability

Before designing an installation, a resource assessment is done to evaluate the availability and anticipate the performances. The first step is to build a map gathering information about sewage pipes, diameters, water consumptions and heat demands. This map helps **to determine the best location for the installation**. As the resource is highly dependent on water consumptions and rain falls, a long-term analysis of the consumptions needs to be done. Buildings with high and constant consumptions are preferred (e.g. hospitals, industries, public buildings) [172] [176].

Then, a feasibility study shall be carried out, **temperature and flow rate variation are measured**. It is an essential issue as it can affect significatively the performances. Usually these parameters are relatively constant. Waste water temperature varies between 10 and 20 °C during the year, ensuring an average temperature of 15°C. The temperature should not fall below 10°C. The minimum flow rate acceptable is usually about 15 L/s, or 10 L/s if the heat demand is low. An optimal flow rate would be ca.50 L/s. This measured flow rate is the dry weather flow. It represents the average flow in the sewage pipe for a day following 7 days without rain after 7 days during which the rain has not exceed 25mm (as the sewage networks collecting rainwater sees its flow rate increased and its temperature dropped) [172].

It is usually necessary to have early and concerted discussions with local authorities and/or WWTP to obtain permission to use the sewage network system.

The same consideration applies for natural streams and lakes. In addition, study on environmental risks has to be carried out to ensure the protection of the resource [177].

Impact of return temperatures

The WWTP operator may not consent to the installation if the return temperature of waste water is less than 12°C. Indeed, it could degrade the process of biological water treatment (nitrification) which is temperature dependent and which is a very sensitive subject for obvious sanitary reasons.

In the case of recovery from natural streams or lakes, the water protection authority can refuse the installation if it causes a too important variation of temperature in the resource. For example, the Swiss authority impose a limit of 3°C variation in the water sources and 1,5°C if the waters host sensitive species. In the lake of Genova where such an installation was built, a variation of at most 1°C was measured and no significant effect on the lake was found [177].

Maintenance

Sewage water is a non-purified water and contains micro-organism that degrade the heat exchanger. Indeed, **waste accumulate on the surface of the heat exchanger creating a 1 mm thick biofilm causing fouling and clogging**. This biofilm can build-up quickly (a few weeks) and degrade the performances of the heat exchanger by a factor up to 2. Therefore, two methods are used to compensate [172]:

- A **regular cleaning** of the heat exchanger, at least once a year. It can be done automatically or by high pressure or flushing, or chemically using chlorine. However, the film formation shall be closely monitored.
- The other solution is to **oversize the surface** of the heat exchanger to compensate its degradation. A factor of 1,5 is usually taken.

Sewer-external heat exchanger are easier to maintain as the sewage water is filtered before entering the exchanger and as their access is much easier. It is also the case for installation located after the treatment plant. Maintenance must be anticipated when selecting a in-sewer heat exchanger. Indeed, large pipes with an important volume and a height of more than 2 meters enable an easy access to maintain the heat exchanger. If it is well maintained, the heat exchanger has a lifetime of ca. 30 years.

Heat pump maintenance is described in the Geothermal section in paragraph C.1.1.2.3.

Downtime

There is no significant restriction of operating time concerning waste water recovery and ambient energy use for DH. Few maintenance operations are needed. The maintenance of the heat pump lasts ca. 4 days per year. The annual downtime is estimated at ca. 1 week [180].

Feedback on the technology

Heat pumps are a growing market. They represent an efficient way of capturing low temperature heat from ambient sources and are capable of raising the temperature and provide enough heat or cold for DHC systems. The technology is mature and reliable. It can integrate various types of energies and apply to a large range of solutions.

Ambient energy for DH is a good way to valorise heat or cold and to optimise environmental performances. The major problems arising from these technologies are the requirements in terms of proximity of such resources with the DHC networks and the uncertainties related to their instability due to seasonal variations and water consumptions.

C.1.1.6 Renewable electricity

Renewable electricity can be used in DHC systems through thermo-electric equipment, enabling the sector coupling of the heating and electricity systems. The driver of this scheme is to integrate intermittent renewable electricity (photovoltaic and wind energies) to produce heat when there is a surplus in the electricity grid, therefore contributing to grid stability. The technologies used to do so are mainly electric boilers and heat pumps.

C.1.1.6.1 **Key technical and operational factors**

The following table aims at setting a general presentation of the key parameters of **electric boilers and high-capacity heat pumps**. Each value is an **average of the values encountered in the scope of renewable electricity used in district heating and cooling** through electric boilers and large heat pumps.

Table 32: Overview of key technical parameters for renewable electricity

Key parameter	Definition	Value
Installed capacity	Maximum power achievable under ideal conditions	Electric boiler: 1 - 90 MW [181] Heat pump: 0.5 – 50 MW [182]
Yield and COP (Coefficient Of Performance)	Yield: Proportion of energy recovered (primary energy) from the input energy (primary energy) COP: Ratio of heat provided over the electricity needed for heat pumps	Electric boilers yield: 99% [183] Heat pumps COP: 3 [182]
Required floor space[80]	Surface occupied by the facilities	Electric boilers: 50 to 100 m² [184] Heat pumps: 12 m²/MW
Operating time	Percentage of operating time for which renewable electricity can be valorised over a year	6% [184]
Downtime	Period of time for which the facility does not produce due to maintenance	ca. 1 week per year [184]
Greenhouse gas emissions related to heat production	Emission of CO_2 in milligram per normal cubic meter	0 mg/Nm³
Atmospheric pollutant emissions related to heat production	Emission of major pollutants in milligram per normal cubic meter	0 mg/Nm³

[80] Including pipes and heat exchanger

C.1.1.6.2 **Technical conditions**

Key facts regarding renewable electricity and its use for heat and cold production

The use of renewable electricity in DHC systems enables **flexibility** in the production and **interconnection with the electricity network**. Renewable energies like solar photovoltaic and wind energies are intermittent, and their related peak production can go significantly beyond the energy demand in some countries. DHC systems can support their integration and provide balancing services to the electricity grid by using thermo-electric equipment, which can also be coupled with thermal storage.

This intermittent electricity production can be used for district heating and cooling through electric boilers or heat pumps. In markets where DHC networks are contributing to balance renewables' intermittence, electric boilers are mainly used to stabilise the grids, while heat pumps are rather a base energy production. Heat pumps are more efficient but usually present lower capacity. The two technologies are therefore complementary.

There are two types of electric boiler technologies, which can be combined with a thermal storage [181] [185] [183]:

- **Electrode boilers** use electrodes to heat water. The capacity varies with the depth of the electrodes depending on water level. The common capacities vary between 5 MW and 50 MW but the largest installations have a capacity of 90 MW. The heat is then transferred to the DHC network by an exchanger.
- **Electric flow heaters** use heating elements with electrical resistance directly dipped into the flowing water. The capacity is modulated depending on the number of heating elements. It varies between 100 kW and 10 MW. It is generally used in smaller applications (1 or 2 MW).

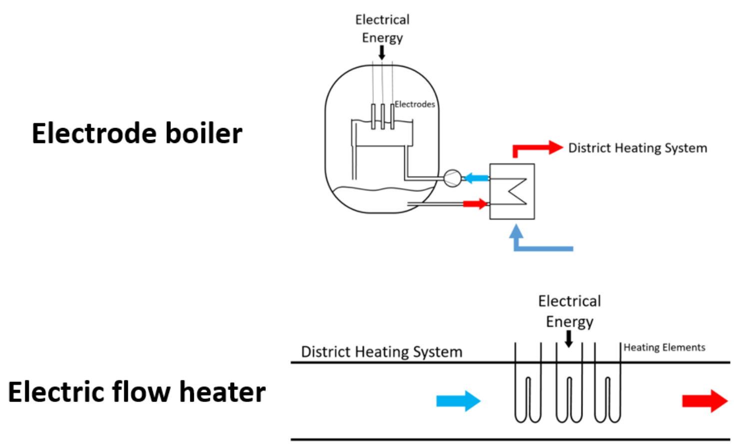


Figure 99: Types of electric boilers (Source: AGFW)

As far as heat pumps are concerned, **compression heat pumps** are the most common. A first exchanger captures heat from an ambient temperature source of energy (ambient air or water, geothermal or solar heat, waste heat). Then, electricity is used to power the compressor, heating the fluid to high temperature. This heat is finally delivered to the DH system through a second exchanger. This technology can also be used to produce cold. More details are provided in the Geothermal section in paragraph C.1.1.2.

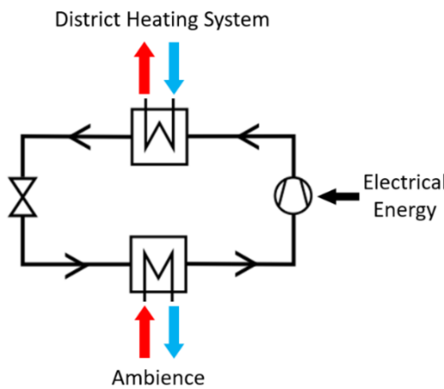


Figure 100: Compression heat pump (Source: AGFW)

In countries where the RES penetration is high, electric boiler technologies are more developed (e.g. Denmark and Germany). There is a potential for large heat pumps in countries such as France, Germany and Italy due to a valuable geothermal heat potential. Sweden has already largely deployed large heat pumps and electric boilers to use renewable electricity because of a surplus of hydropower and nuclear electricity.

Origin of the renewable electricity and use

Even though some renewable electricity can be produced on site on largest projects (usually limited to a few MW of solar photovoltaic panels), the main share of renewable electricity that is used in electric boilers and heat pumps is **bought on electricity markets or imported from the Transmission electricity grid to balance the grid.**

A flow heater electric boiler needs to be connected at 400 V or 690 V (low voltage), while an electrode boiler needs to be connected at 10-15kV (medium to high voltage). The minimum load accepted is 2%, so a constant current is needed [186].

The required floor space is in the range of 20 to 40 m² for an electric boiler with a height of 5 to 6.5 m [184]**. For the total installation, about 50 to 100 m² are required**, including pipes and heat exchanger. An electric boiler of 10 MW is ca. 14.4 m^3. For heat pump, the required floor space is about 12 m²/MW.

Furthermore, if the production plant has a CHP unit, a connection to the electricity grid already exists. If the capacity of the substation is sufficient to integrate the additional capacity from an electric boiler or heat pump, this will enable to reduce connection costs.

Supply of renewable electricity and electricity market

Renewable electricity can either be bought on electricity markets or be a means to balance the electricity grid when there is a surplus due to electricity production from intermittent sources of energy.

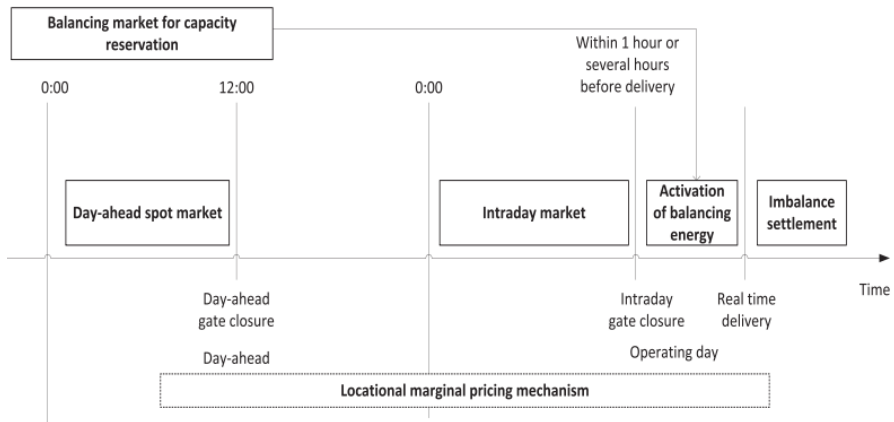


Figure 101: Renewable electricity purchase from electricity markets [187]

Renewable electricity is **purchased on the different spot markets** [187]:

- Day-ahead market: the electricity is purchased for the following day.
- Intraday market: the electricity is purchased for the same day up to 45 minutes from the deliveries.

Currently, renewable electricity for DHC networks is not purchased on the long-term markets. However, as some technologies can bring reliability, it can represent a valuable opportunity and could be a long-term strategy [188].

The purchase of renewable electricity is clearly driven by its cost. **DHC operators use electric boiler and heat pump when electricity prices are low or even negative** (see section 3.6.3.1 below). Renewable electricity price can be subject to feed-in tariffs and carbon tax reduction [187]. It is sometimes bought with guarantees of origin that enable to access to RES financial supports (investment subsidies, adapted debt funding, tax incentives…). In the majority of European countries, the guarantee of origin is a reliable proof that electricity is produced by renewable energies. In Sweden, where there is no such guarantee, the electricity is mainly produced by RES. It is then sufficient to use electricity in this purpose. In Denmark, the electricity is used in electric boilers mainly when the price is negative. A negative price means that there is a surplus, thus ensuring a renewable energy source (for Denmark mainly wind energy).

Finally, renewable electricity for DHC systems can also be purchased through **contracts with Transmission System Operators (TSO) on the balancing market.** The TSO adjusts the electricity grid in real time and can have reserve requirements. If there is a lack of electricity capacity, CHP installations can export electricity in the grid. If there is a surplus of electricity, DHC can act as downregulating party and use this surplus to produce heat with electric boilers or heat pumps. In this balancing market, the response time needs to be less than 15 minutes. Electric boilers and heat pumps have a fast response time and thus are a good solution for balancing the electricity grid [189]. **This flexibility brought by the DHC system provides an additional source of revenue for DHC operators under these contracts,** as the TSO remunerates the DHC operator to be available for balancing its grid. Usually, the tariff structuration is composed of a fixed part and a variable part, the latter being paid in function of the quantity of electricity that has been injected or withdrawn for balancing purposes.

Yields of electric boiler and heat pump

The yield of electric boilers is more than 99%. All the electricity is converted because water has an electrical resistance and it produces heat directly to the water. However, additional losses come upstream during electricity production and downstream during heat distribution [183].

The temperature of supply water is generally 180°C with a return temperature at 70°C. An electric boiler can heat water up to 260°C (for industrial use). Like gas boilers, these boilers are thus **compatible with high to low temperature DHC networks**.

The COP of large heat pumps is usually between 1.7 to 3.8. These heat pumps are usually implemented in DHC systems with supply temperature averaging 85°C and return temperature averaging 45°C [182].

Plant management integration

Electric boilers have a 30 second response time allowing fast response to an intermittent surplus [183]. **Heat pump start-up lasts a few minutes with a low COP**, it is thus used for a more stable surplus electricity source rather than a temporary source.

Electric boilers installed as **peak load units** in district heating systems operate ca. 500 hours per year at full load [184].

C.1.1.6.3 **Operational constraints and requirements**

Impact of market prices on electric boiler / heat pump operation

Electricity price represents a significant part of the operation costs of electric boilers and heat pumps. It becomes interesting to use renewable electricity in DHC if **they are the cheapest solution when power prices are low** (often due to a surplus of electricity, as mentioned above).

The figure below illustrates the choice of the cheapest solution when electricity price varies (prices are given in Danish Krones (1 DKK = 0.13 €) as the figures represent a Danish case) [190]. When there is a surplus electricity, the electricity price is negative and electric boilers or heat pumps are the cheapest solutions. When there is no surplus electricity, these applications come into competition with other energy sources and may no longer be the most cost-efficient. When electricity prices are high, CHP selling electricity on spot markets (i.e. not bound by any feed-in tariff mechanism) can be very interesting. This perspective is sometimes targeted and used in order to extend the lifetime of a CHP plant once its feed-in contract has come to its end.

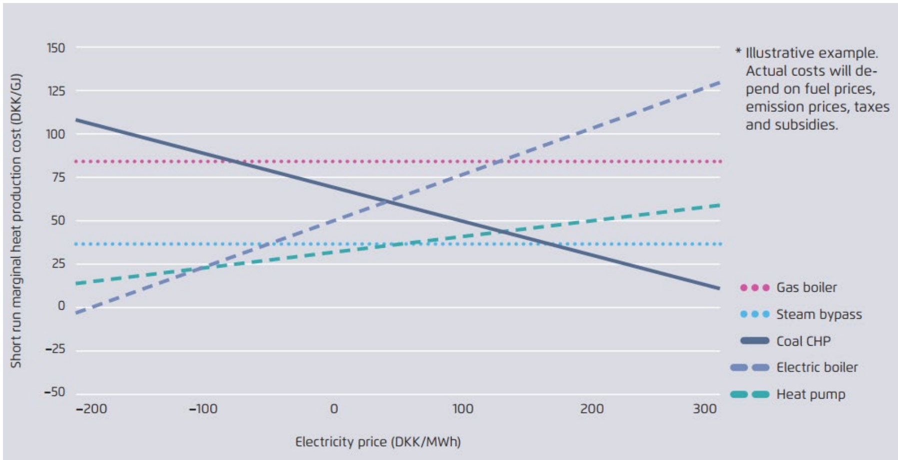


Figure 102: Short run marginal heat production cost for different units depending on the electricity price* [190]

Maintenance of electric boiler and heat pump

An electric boiler is **easy to maintain**. It is a reliable technology with no complex components and no fuel feeding systems. There is no wear (erosion of metallic components) on electrodes. The lifetime of an electric boiler is 20 years.

Maintenance consists of **daily cleaning** of water level control and filters [191]. The valves are checked and the boiler is blown down to avoid accumulations. The **electrical circuits need to be checked monthly** during shut down.

Once a year, the water is drained and all the boiler is cleaned and checked. The **annual maintenance** includes electrodes, nozzles, pressure gauges, circulating pump, etc.

Heat pump maintenance is described in the geothermal section in paragraph C.1.1.2.3.

Downtime of electric boiler and heat pump

The annual maintenance implies up to a week of shut down. The downtime is usually limited to 2 days per year for electric boilers and 4 days per year for heat pumps. As electric boilers are used as peak load units with limited operating hours, this is usually not interfering with operations. The estimated forced downtime is below 1% of annual operation time [184].

Feedback on the technology

Sector coupling of the heating/cooling and electricity systems is based on mature technology involving the use of thermo-electric equipment like heat pumps, electric boilers and CHP. It is significantly developed today in some countries in Northern Europe like Denmark, where renewable electricity covered 75% of the demand in 2019.

The integration of heating and power sectors through renewable electricity provides clear advantages: improvement of the environmental performances of the DHC network, efficient management of intermittency from wind and solar power, electricity grid balancing options, opportunities for optimisation of grids design… Given the last technological and environmental improvements of heat pumps and the new constraints met on electricity grids with the development of renewable electrical energies, sector coupling is expected to develop significantly in Europe, where DHC networks will have a key role to play as multi-energies modular exchangers.

Case study of Greater Copenhagen (DK): integrating intermittent renewable electricity through large heat pumps, electric boilers, thermal storage and CHP (Annex 6)

Denmark is one of the EU countries with longest experience in sector integration, and has been **valuing synergies between the heating and electricity sectors since the 1980s**.

While those synergies started with the deployment of CHP plants and DH networks, today DHC systems have become key enablers to integrate intermittent renewable electricity (more than 50% of the total production in Denmark, mainly wind) through **large heat pumps and electric boilers coupled with thermal storage**, which are complementary to CHP plants. The combination of these technologies allows providing **balancing services** to the power grid, constituting a new source of revenues for DHC operators.

The interconnected DHC system of Greater Copenhagen perfectly illustrates this Danish approach. For instance, electric boilers are being used to avoid wind curtailment and to down-regulate the power system, and DHC control rooms can **take into account electricity price signals to optimise the production**, as illustrated in the figures below. DHC networks can thus produce heat or cold through thermo-electrical equipment when electricity prices are low, usually due to a high share of intermittent renewables on the power grid, and produce electricity through the CHP plants when electricity prices are high or the grid needs up-regulation, using stored thermal energy for H&C. The recent **reduction of electricity taxes for comfort heating and cooling** will facilitate further synergies between the heating and electricity sectors.

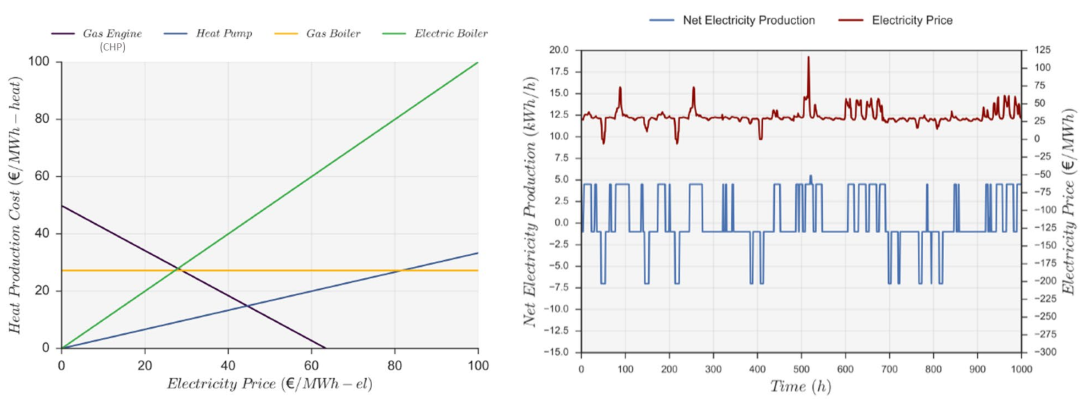


Figure 103: System response on fluctuating electricity prices (source: Ramboll)

C.1.2 Waste heat or cold sources

C.1.2.1 Main sources of waste heat and cold

C.1.2.1.1 **Definition and classification of the main sources of waste heat and cold in Europe**

As defined in the EU Directive 2018/2001 on the promotion of the use of energy from renewable sources "'waste heat and cold' means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible".

Waste heat sources can be classified into conventional sources and unconventional sources [192] [172]. Conventional sources are sources that can generate high temperatures. They come from:

- **Power generation** installations, such as nuclear, coal or gas power plants, electrical substations, etc. Heat losses during power generation can be extracted with a heat exchanger or directed to a CHP unit. Gas expansion in turbo expanders before distribution from the gas grid also reject waste heat that can be recovered.
- **Industrial production** sites, such as steel, chemical, food, refineries, or paper large industries [193]. Waste heat from industry processes at high temperature is largely available. It is though often used for internal needs.
- **Waste-to-energy**, i.e. heat recovery from waste incineration. This type of waste heat will not be analysed in this study as it does not enter the definition of waste heat from the EU Directive 2018/2001 on the promotion of the use of energy from renewable sources (waste-to-energy is considered under the scope of the Waste Directive of the European Commission).

Unconventional sources have a lower temperature (<50°C). They can come from:

- **Tertiary buildings**, such as hospitals, supermarkets, schools, offices, and public buildings. These buildings have large cooling installations that reject excess heat during the cooling process.
- **Data centres** cooling systems. Data centres have an important cooling demand due to the heat rejected by IT equipment and servers.
- **Underground railway**, subway stations and transportation tunnels ventilation system. The air heated by the vehicles is extracted by ventilation. It is not mentioned in the EU Directive 2018/2001 but will be covered in this section.
- **Sewage water** heat recovery. This type of waste heat is defined as ambient energy by the EU Directive 2018/2001. It is thus analysed in details in the Ambient Energy section C.1.1.4.

Waste heat is recovered using a heat exchanger and can be directed to a heat pump to raise the temperature if necessary. A thermal storage can be used to increase flexibility. The heat, or cold, can then be used to supply a DHC network.

Waste cold can be recovered from Liquefied Natural Gas (LNG) regasification process in LNG terminals. It can supply a DC system. In addition, cooling can also be made from waste heat (or other sources of heat) through absorption and adsorption technologies.

The potential of waste heat sources is well distributed over Europe. European projects such as ReUseHeat [192], Stratego [194] or Heat Roadmap Europe [195] have studied the potential of each sources. The results are presented in the following figures (Figure 104 for conventional sources, Figure 105 for tertiary sector, Figure 106 for data centres and Figure 107 for metro stations).

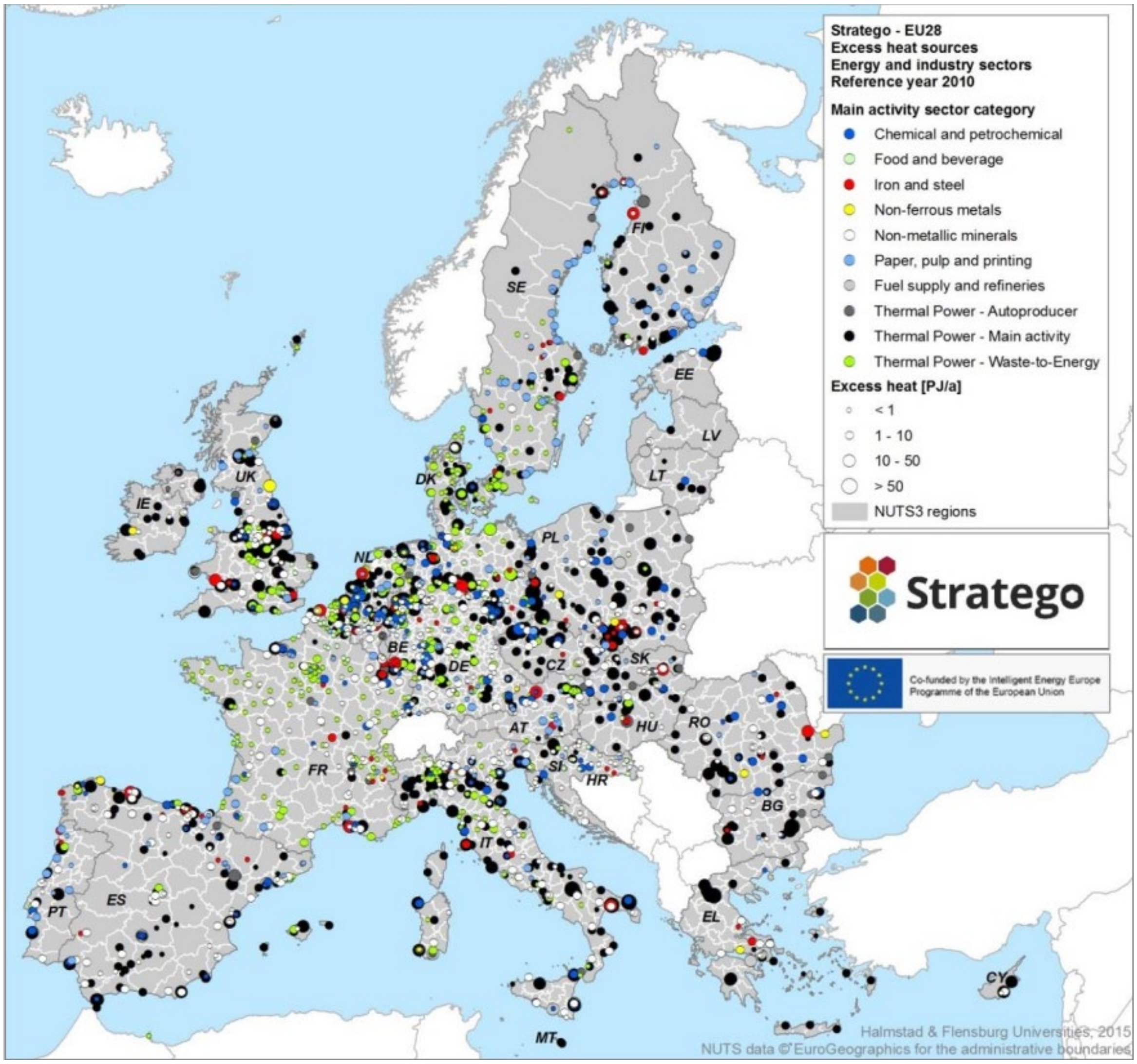


Figure 104: Excess heat facilities by main activity sectors and assessed annual excess heat [194]

MS	QH (inside) COP 2.5 [PJ]	QH (inside) COP 3.5 [PJ]
AT	3.1	2.6
BE	9.2	7.7
BG	6.5	5.5
CY	0	0
CZ	1.9	1.6
DE	29.4	24.7
DK	2.1	1.8
EE	1.6	1.4
EL	-	-
ES	65.9	55.4
FI	2.4	2.0
FR	55.7	46.8
HR	2.8	2.4
HU	4.5	3.8
IE	0.5	0.4
IT	76.6	64.3
LT	0.4	0.4
LU	0.1	0.1
LV	0.3	0.2
MT	0	0
NL	2.6	2.2
PL	8.8	7.4
PT	5.3	4.5
RO	8.7	7.3
SE	6.0	5.0
SI	1.8	1.5
SK	0.8	0.6
UK	26.8	22.5
EU28	**323.9**	**272.1**

Figure 105: Service sector accessible excess heat inside urban district heating areas at practical COP of 2.5 and 3.5 [192]

MS	Data centres (2km) [n]	QH COP 2.5 [PJ]	QH COP 3.5 [PJ]
AT	16	7.9	6.7
BE	29	10.1	8.5
BG	19	3.7	3.1
CY	0	0.0	0.0
CZ	22	7.0	5.9
DE	187	65.1	54.6
DK	28	4.1	3.4
EE	10	1.0	0.8
EL	1	0.5	0.4
ES	36	19.4	16.3
FI	17	10.4	8.8
FR	124	50.9	42.8
HR	4	1.7	1.4
HU	8	5.1	4.3
IE	21	3.3	2.8
IT	39	22.7	19.1
LT	9	1.1	0.9
LU	7	0.4	0.3
LV	17	0.9	0.7
MT	0	0.0	0.0
NL	62	9.2	7.7
PL	29	17.0	14.2
PT	13	3.2	2.7
RO	47	5.8	4.9
SE	45	14.8	12.4
SI	7	1.8	1.5
SK	11	2.7	2.3
UK	189	30.9	25.9
EU28	**997**	**300.6**	**252.5**

Figure 106: Number of EU28 data centres and accessible excess heat within 2 kilometers of urban district heating areas at practical COP of 2.5 and 3.5 [192]

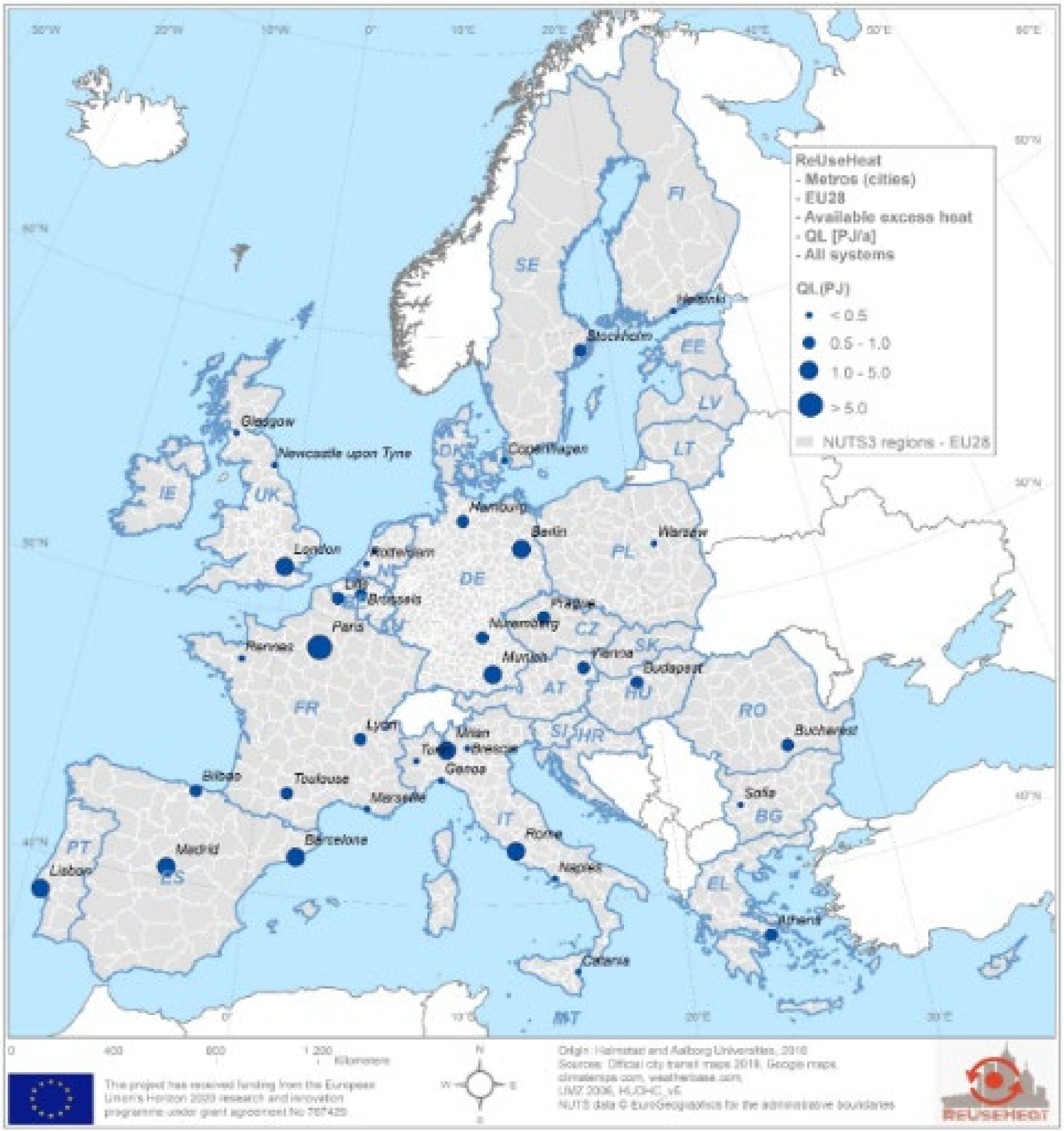


Figure 107: Available excess heat in 37 EU28 cities with metro systems in operation [192]

C.1.2.1.2 **Key technical and operational factors**

The following table aims at setting a general presentation of the key parameters of **waste heat and cold recovery**. Each value is an **average of the values encountered in the scope of waste heat and cold use for district heating and cooling**.

Table 33: Overview of key technical parameters for waste heat

Key parameter	Definition	Power generation	Industrial production	Tertiary buildings	Data centers	Transportation networks	LNG waste cold
Installed capacity	Maximum thermal power achievable at optimized conditions	20MW – 500 MW [196]	1MW – 30MW or more [196]	1MW – 3MW [196]	1MW - 25MW [196]	300kW – 2MW [192]	Up to 30MW [197]
Operating tempera-tures	Temperatures of recovery of the sources	60°C - 600°C depending on the expansion stage of the turbine where heat is recovered [198] [199]	From below 30°C up to 500°C depending on the type of process [200]	30°C – 40°C [192]	Air-to-water exchanger: 25°C - 35°C Liquid-to-water exchanger: 50°C - 60°C [192]	5°C - 35°C depending on the season [192]	Ca. -10°C [201]
Operating time	Percentage of operating time for which waste heat can be recovered / year	Ca. 35% [202]	Depends on the industrial activity	Depends on the building cooling demand	100% [192]	100% [192]	Constant during summer
Proximity with DHC networks	Qualitative assessment of the geographical proximity usually found with DHC networks	Usually inappropriate	Appropriate in some cases	Appropriate	Appropriate in some cases	Appropriate	Appropriate in some cases

C.1.2.1.3 **Technical characteristics**

Range of typical installed capacity

Conventional waste heat sources and data centres can generate high thermal capacities due to the great amount of waste heat. Recovery in industrial production sites can reach up to 30 MW or more (usually with a fluctuating availability as discussed below however). For data centres case studies indicate installed capacities between 1 MW and 25 MW [196]. Power plants have a capacity from 80 MW up to 500 MW [198].

Other waste heat sources offer a limited thermal capacity, rarely exceeding 5 MW. In tertiary buildings the capacity is up to 3MW [196]. Waste heat recovery in underground transports varies with seasons. In summer the capacity can be up to 2 MW while in winter it drops to 400 kW or less [192]. The average European capacity is set between 300 and 500 kW per station [196].

Waste cold from LNG regasification can provide up to 30 MW [197].

Operating temperatures and use

Power generation and industrial production plants enable to supply DHC with **high temperature fluid up to 200°C usually** [198]. In function of the DHC network characteristics and needs, this fluid can be delivered directly through a heat exchanger, remaining in vapor phase or converted to liquid phase through heat losses. The fluid can also be used upstream in a CHP plant with steam turbine to finally deliver steam at lower temperature and lower pressure.

The other sources of waste heat deliver heat at **low temperature, below 40°C typically**. It is then recovered by a heat exchanger coupled with a heat pump. The heat pump enables to reach a supply temperature up to 70°C, **optimal for a district heating at low temperature and/or for DHW** [196]. Heat pumps can be installed in a cascading technique to reach a high enough temperature. More details about heat pumps can be found in the Geothermal section C.1.1.2.2.

Waste cold DC can deliver cold at ca. 5°C [201].

Fluid type, temperature and quality

Power plants generate electricity from heat through gas engines, gas turbines or steam turbines (either gas-fired, coal-fired, nuclear, or heated with the exhaust gas of a gas turbine in a combined cycle). The conversion factor between heat and electricity is about 33%. Thus, two third of the heat is wasted in the process and rejected in the atmosphere or cooling water. A CHP plant is a power plant that uses direct exhaust gases of these power generation technologies to supply heat and generate extra electricity. In addition, waste heat can also be recovered from the condenser of a steam turbine.

In the case of a nuclear power plant, heat can be extracted in the nuclear reactor or in the different expansion stages of the turbine. The fluid is hot steam at a temperature between 60 and 140°C depending on the part of the process where heat is recovered [198]. Indeed, if excess heat is recovered from a high-pressure turbine, the temperature can be up to

140°C, while if it is recovered from a low-pressure turbine or the condenser, the temperature does not exceed 100°C. In the case of a gas, coal or combined cycle power plant, the exhaust heat is between 300°C and 600°C [203] [199]. After the condenser, the temperature decreases and a heat pump is necessary. In the case of a combustion engine plant, the exhaust flue gases are extracted at 400°C [199].

At these temperatures, the heat transfer fluid is steam. According to the technologies, some filtering facilities may be required upstream of the heat exchanger to preserve the integrity of the exchanger from potential or mechanical damages or corrosion issues for example.

Case study of Aranda del Duero (ES): Waste heat from a CHP unit supplying a lo industry (Annex 6)

The **first project of waste heat recovery for DH in Spain** was commissioned in 2019 in Aranda del Duero (Castilla y León). The waste heat is recovered from a CHP unit supplying a tyre manufacturer, and provided **70%** of the total DH supply in 2020, the rest being produced from biomass. Both technologies are highly complementary.

The DH grid is being developed by a private promoter in an urbanised environment, aiming at achieving a **city-scale fuel switch from gas and oil to sustainable DH** in 5 years, **while reducing by 10% the heating bill** of the connected buildings.

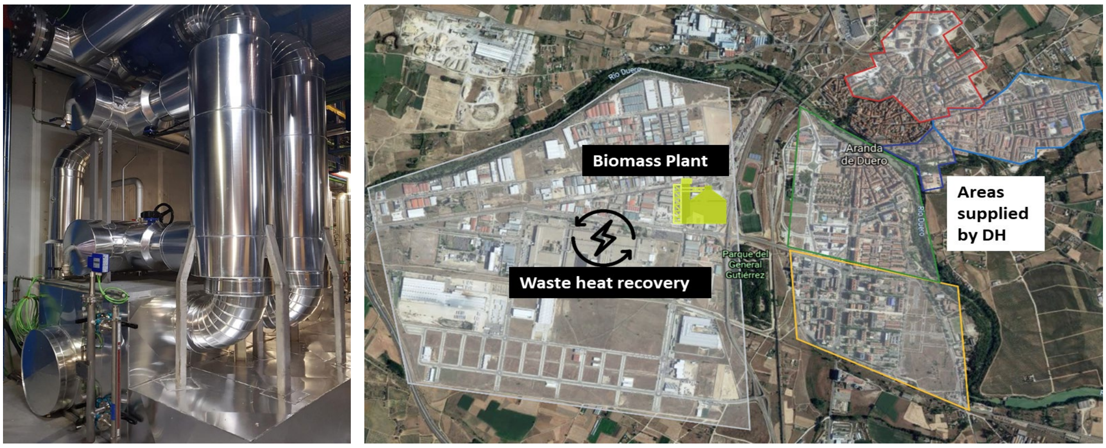


Figure 108: Map and waste heat exchanger of the DH network in Aranda del Duero

The development of the new DH grid has enabled to recover **15 to 40 GWh/y of waste heat that was previously untapped**. Waste heat is recovered from a 33 MWe / 75.5 MWth CCGT CHP unit in form of steam. Up to 15 ton/h of steam at 4.5 bar are recovered through a heat exchanger of 90% efficiency. A 4,000 m^3 **thermal storage** tank will allow to further optimise the production and to increase the use of waste heat, as this tank can store around 100 MWh of energy.

Electricity distribution systems can also be an additional source of waste heat, with low operating temperature though. Indeed, these systems generate large heat losses due to the electric current passing through a conductor (Joule effect) [204]. Cables and transformers are thus waste heat sources as they need to be cooled down. The cooling process is based on a forced circulation of oil through the transformer and uses an oil-to-water heat exchanger. The temperature of oil is 62 to 70°C and enables to recover water at 30 to 42°C [204].

In industrial production sites, waste heat is recovered from different types of processes at different temperatures (see Table 34):

Table 34: Waste heat recovery in industrial processes [200]

Process	Fluid	Temperature
Cleaning	Waste water	Below 30°C
Cooling	Refrigerating water	30°C – 90°C
Purge	Water	100°C – 130°C
Ambient	Ambient air	Below 30°C
Drying	Drying air	30°C – 60°C
Condensation	Condensed air and vapor	60°C – 130°C
Natural cooling and defected insulation	Moist air	30°C – 500°C
Combustion processes (furnaces, boilers)	Fume	130°C – 500°C
Radiative heat transfers in combustion processes (furnaces, boilers)	Air	130°C – 500°C

Two type of industries are distinguished: industries at low to medium temperature processes (up to 100°C water) such as food, paper or chemical industries, and heavy industries at high temperature (130°C to 500°C, usually steam) such as metal, glass or cement industries [200].

Case study of Plock DH (PL): Heat recovery from industrial production (Annex 6)

With a CO_2 content close to zero, **Plock DH network is supplied at almost 100% by the industrial waste heat from the local oil refinery,** which is also the industrial symbol of the city's renewal after the substantial losses resulting from the Second World War.

This solution was found to be the most efficient one to ensure **the complete decarbonisation** as well as **the most competitive prices on the long-term** for the modernization of this network built before 1960 and previously entirely supplied by fossil fuels.

The refinery operates a **CHP mainly fuelled by natural gas** for its own industrial processes, while waste heat is recovered and sold to the DH operator. The tariff and contractual clauses are discussed and agreed by the two parties, within the frame set by the national regulator ERO.

Despite the relatively high seasonal variance of the waste heat, the refinery is able to cover the vast majority of the DH demand. The **geographical proximity** between the DH system and this large industrial player with excess heat was also key in order to limit the connection cost and the transmission heat losses.

Figure 109: PKN Orlen local oil refinery (photo from PKN Orlen SA.)

In tertiary buildings, waste heat is recovered from the cooling unit through the liquid-to-water exchanger of a refrigerating machine. The liquid can be water or another refrigerant fluid. The temperature recovered is in average 30°C to 40°C but varies with the cooling needs during the day or between seasons [192].

Case study of Greater Copenhagen (DK): Waste heat from a vegetable market, enabled by district cooling (Annex 6)

Since 2016, Copenhagen Markets (selling fruits, vegetables and flowers) are supplied by **district cooling** from Høje Taastrup Fjernvarme, one of the 20 DHC distribution companies composing the interconnected DHC system of Greater Copenhagen, supplying 7 200 consumers that also own the DH company.

These markets have a high cooling demand, which was previously met through individual and less efficient cooling systems that were replaced with a centralized 2 MW DC unit (heat pumps and a chiller) that benefits from **economies of scale and synergies with DH**, reducing energy consumption by 10-15%, and presenting an overall **COP of 5.3**.

District cooling is delivered to the markets at **−8 ◦C**, using an extra chiller, and **returns at 16 °C.** This return flow from DC is a source of **waste heat**, which is **recovered through a heat pump to supply hot water** to the DH consumers, representing 2.5% of the total production of DH. The overall system benefits from co-producing cooling and heating.

Figure 110: Copenhagen Markets, supplied by district cooling and providing waste heat to the DHC system (source: Høje Taastrup Fjernvarme)

In data centres, the cooling needs are constant due to the heat generated by IT servers (see Figure 111). Waste heat is recovered from the cooling unit through an air-to-water or liquid-to-water exchanger. The temperature that can be recovered is in average 25 to 35°C. In the case of a liquid-to-water technology, a refrigerant fluid circuit cools directly within the servers, instead of using ambient air. The transfer is thus more efficient and can recover 50°C to 60°C [192].

	Component	Proportion of total heat	Temperature
For standard server	Microprocessors	30%	85 °C
	DC/DC conversion	10%	50 °C
	I/O processor	3%	40 °C
	AC/DC conversion	25%	55 °C
	Memory chips	11%	70 °C
	Fans	9%	30 °C
	Disk drives	6%	45 °C
	Motherboard	3%	40 °C
For high performance cluster (HPC)	Microprocessors	63%	85 °C
	DC/DC conversion	13%	115 °C
	I/O processor	10%	100 °C
	Memory chips	14%	40 °C

Figure 111: Distribution of heat and temperatures within IT servers [192]

Case study of Odense (DK): Waste heat from a large data centre (Annex 6)

The project to recover waste heat from the Facebook data centre in Odense (Denmark) is game changing, as it had never been done before at such a large scale. The waste heat recovered is mainly replacing the production of a coal-fired CHP plant, and once fully operational is expected to provide 10-15% of the total DH supply. It emerged in two phases:

- A **first phase with 24 MW heat pumps** on the data centre's servers, firstly tested in 2019 and commissioned in 2020;
- A **second phase with 20 MW** more on other servers, also commissioned in 2020.

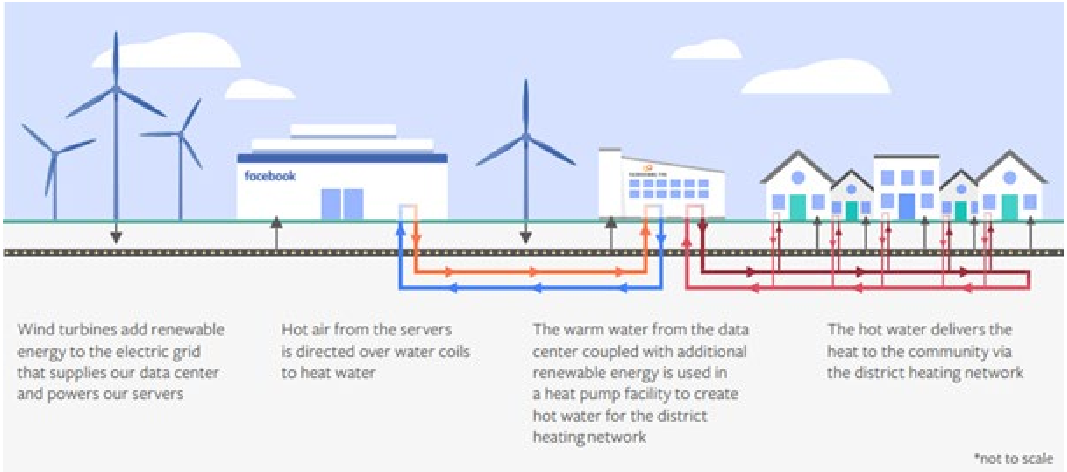


Figure 112: Heat recovery from a large data centre in Odense (source: Facebook)

Ammonia heat pumps were chosen to recover the heat produced by the air-cooled servers. The air heated by the servers is directed over water coils that recover the heat. This warm water recovered at **40°C** is then delivered to the heat pump station where the temperature is raised to 70°C and delivered to the DH grid through another water circuit. The system has a **COP of 5.**

In **underground transportation networks**, waste heat is recovered from the ventilation system through an air-to-water or liquid-to-water exchanger. Excess heat come from different sources generated by the transport systems (see Figure 113). The temperature of sources varies between 5 and 35°C [192]. It changes with the ambient air temperature and the traffic, i.e. during the day and between seasons. In winter the typical temperature recovered is 15°C, and 27°C in summer.

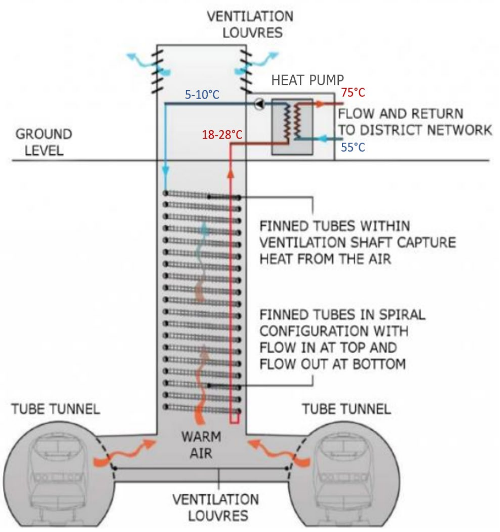
Heat source	**%**
Breaking losses	38
Mechanical losses	22
Drive losses	16
Train auxiliaries	13
Tunnel systems	4
Tunnel systems	4
Station systems and passengers	4
Train passengers	3

Figure 113: Shares of heat sources in underground systems [196]

Case study of Islington (UK): Valuing waste heat from an underground train network (Annex 6)

Islington DHC network is the **first operation in the world valuing waste heat from an underground train network** and using it to supply heating, DHW and cooling to social housing, schools and leisure centres. The system is based on a **1 MW air-to-water heat pump** (COP of 4.2) that captures warm exhausted air produced by trains and machinery in London Underground network. The extracting fan in the ventilation shaft was accordingly upgraded to **optimise heat extraction**.

In addition, **the fan in the ventilation shaft has the potential to be reversed in the summer to provide cooling to the London Underground network,** helping to make journeys more comfortable.



To accommodate the integration of this waste heat in the network, the supply temperature was reduced from around 90°C to 75°C. The return temperature fluctuates around 55°C.

In this case, **the waste heat is supplied for free by Transport for London** (which will receive cooling for free in the summer), making this project virtuous in terms of CO_2 content but also competitive in terms of heat price for the end-users.

Waste cold can be recovered from LNG regasification. The process consists in vaporizing the LNG from -190°C (temperature for transport) to 4°C (temperature to be distributed in the gas network) [197]. During vaporization, cold is rejected. It can be recovered by an exchanger using glycoled water (to avoid freezing). The recovered temperature is about -10°C [201] (see Figure 114).

This kind of project is still very rare today since the technology involves high-capacity titanium heat exchangers (due to the very low operating temperatures) which are very expensive and require to secure a significant volume of cooling sales on the long-term. In addition, potential cooling demand is usually not located close to LNG terminals, which further deteriorates the economic feasibility of these projects.

To date, only one project of this kind has been studied in Europe (for Barcelona DHC network). However, it is currently aborted as the cooling demand identified initially did not develop as expected.

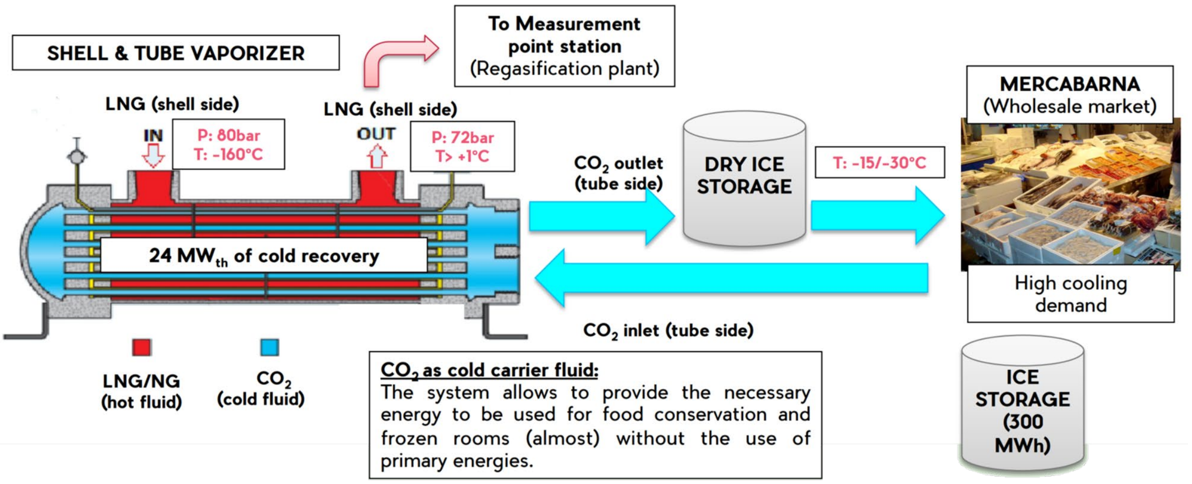


Figure 114: Technical scheme for waste cold recovery from LNG plants (Source: Aiguasol)

Production profiles and possible storage requirements

The operating time of a nuclear CHP is ca. 3000 hours per year [202]. Combined cycle CHP usually operate only in winter because heat demands in summer are low and the minimum load is not reached (see Figure 115). Gas engine CHP plants offer better flexibility. In summer some engines are shut down to meet with a reduced demand, thus ensuring a continuous production (see Figure 116) [199]. A storage facility can optimize the operating time of the CHP unit. A complementary boiler is used to satisfy peak demands.

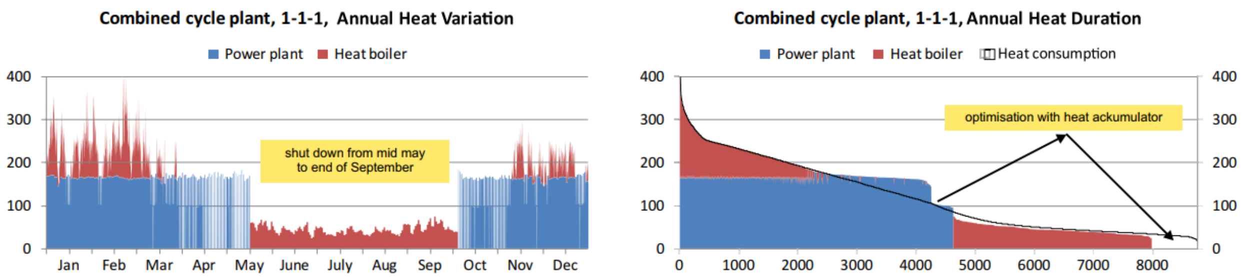


Figure 115: Load profile of a combined cycle CHP plant [199]

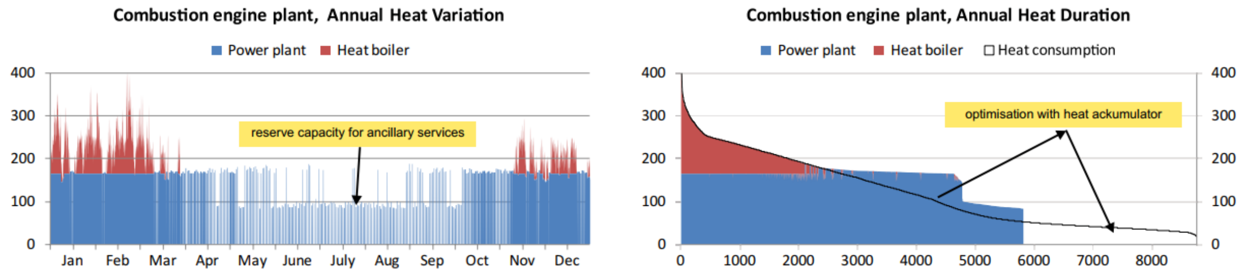


Figure 116: Load profile of a combustion engine CHP plant [199]

For industrial waste heat recovery, heat production profile varies with the activity of the industrial site. Tertiary building waste heat is recovered from the refrigerating machine exhaust heat. Therefore, waste heat production profile follows the cooling demand profile of the building, i.e. a constant low demand in winter and an important demand in summer (see Figure 117).

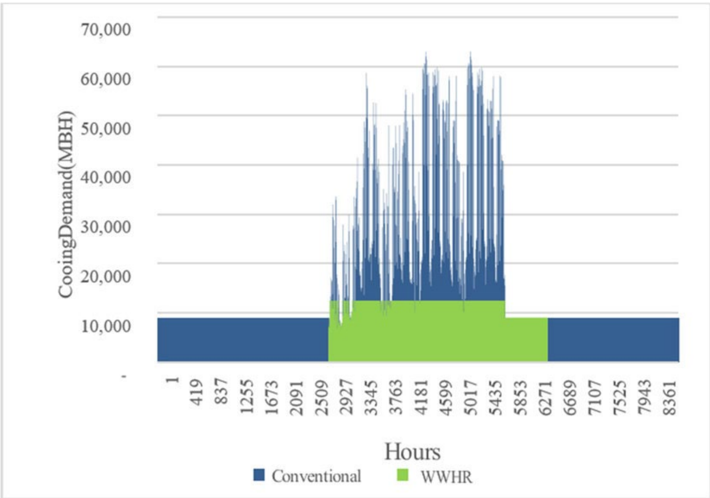


Figure 117: Annual hospital cooling demand and waste water heat recovery supply (Source: Sohail 2019)

Waste heat annual load from electrical substations, underground transportation systems and data centers is considered constant. Data centers production forms a uniform profile as the servers are constantly operating [192] [205] (see Figure 118).

Waste cold can supply DC during the summer months. It can cover ca. 50% of the demand in some cases (see Figure 118) [201].

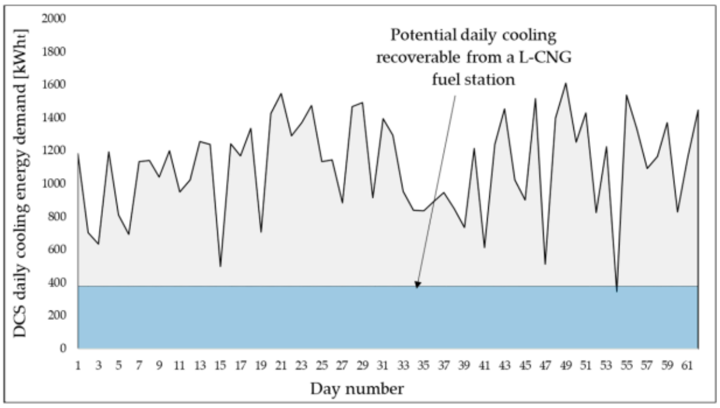


Figure 118: District daily cooling energy demand for July and August [201]

Storage is essential in waste heat utilisation for DHC. Indeed, waste heat loads are variable and might not match with DHC demands. This can cause reduction of potential by 30% or more. With a storage facility, this reduction can only 10% [206]. Storage can be **thermal tanks** for a short-term flexibility or **seasonal storage** to have a flexibility over a year of production. Thermal tanks are described in detail in the Biomass section in paragraph C.1.1.1.2, and seasonal storage in the Solar thermal section in paragraph C.1.1.4.2. Another way to increase flexibility is to use load shifting and postpone the production, but this is usually much more difficult to implement than thermal storage [207].

Specific regulations with regards to performance and safety

In most cases, there is no regulation for waste heat supply in DHC networks because the supply is regulated through bi-lateral contracts between the producer and the supplier [196] (see discussions in section B.3.2).

However, in some cases, **specific safety regulations** must be applied. In underground transportation networks standards are important to ensure the safety of installations [208]. In the case of recovered heat from electrical installations and transformers a bypass for the DH is made to avoid overheating and ensure safety when handling low and high voltages [172]. In the case of nuclear power plant, there are requirements on radiation safety. A separate circuit is made in the reactor at high pressure so that there is no connection with the power generation loop and DH network [198]. Radioactivity is monitored constantly and other nuclear plant requirements apply. When starting the project an environmental impact assessment is done.

The DH supply water temperature can be regulated if it provides DHW. Indeed, at low temperature (between 25°C and 45°C), a bacterium called legionella grows [196]. This bacterium is dangerous for human health but can be killed at temperatures over 50°C. Therefore, some countries regulate the temperature of DHW installations (see Figure 119). This applies to any DHC system regardless of the heat production sources.

Country	DHW temperature at the tap (°C)	DHW production temperature
Belgium	≥55	≥60
Denmark	≥50*	≥60
Finland	≥55	≥60-65
France	≤50	≥60
Germany (large systems)	≥45	≥60
Italy	45-48	≥60
The Netherlands	-	≥60
Spain	≥50	≥55
Sweden	≥50	≥60 (in tank)
United Kingdom**	≥50 (45)	≥60 (50)

* The requirement of the DHW is 50 °C but 45 °C at maximum flow.
** There is no regulatory requirement to achieve a specific temperature. The figures cited are 'custom and practice' for commercial systems with hot water recirculation. (Real world domestic systems are more like 45C and 50C)' [16]

Figure 119: Overview of temperature requirements in some EU countries [196]

Downtime

The maintenance of the installation is principally the cleaning of the heat exchanger and the maintenance of the heat pump. There is a risk of fouling for the exchangers, especially if the fluid is moist or condensed air. Heat pump maintenance is described in the Geothermal section in paragraph C.1.1.2.3.

The downtime of waste heat installations corresponds to the downtime of the activity. Businesses can stop during the night, the weekend, or winter. Some examples are described here:

- For industrial waste heat, there is no generation of waste heat when the processes are interrupted.
- Data centres ensure a continuous activity but have a downtime of few minutes to few hours each 5 years [209].
- Nuclear power plants have a planned downtime when changing the reactor fuel. It may not affect the DH system because the reactors are not changed simultaneously and therefore other reactors act as a backup source [202].

Long term availability

Waste heat recovery present instabilities that can affect the DHC system on the long term. The availability is one of the major risk concerning waste heat recovery [208]. It is especially true for industrial waste heat. Indeed, **if the processes, use or capacity change, or if an improvement is made towards energy efficiency, the amount of waste heat available may decrease**. Moreover, there is always a non-null **risk for the companies to end or adapt their activity and close their installations**.

Other sources of waste heat are usually more secured or at least framed by a clear contractual period (for power generation for example). Discussions on short and long-term contracts between heat supplier and DHC operator are detailed in section B.3.2.

C.1.2.2 Technical and operational requirements for the integration of waste heat and cold in DHC systems

C.1.2.2.1 Technical conditions and design of the connection to DHC network

The principle of waste heat integration to DHC networks is based on the recovery of heat that would normally be dissipated and wasted. The connection between a DHC system and waste heat supplier is discussed and designed by both parties (see section B.3.2). A feasibility study to assess the resource availability and the technical issues is done. It requires a planning including multiple actors. A contract is made between the producer of waste heat and the DH supplier. **There are no standardized contracts**. Therefore, the redaction of a contract can be a long process with negotiations. The risk is to omit important clauses [208].

Industry sites may have to modify the space to integrate the recovery units and heat exchangers when applicable. For some facilities like data centers for example, it can be too constraining to connect as it may affect their operations that run continuously. Connection is always preferred to be at the construction stage or during renovation [209]. For power plants the connection can imply heavy modifications in the turbines [210].

In power plants, the DH system is either connected directly to the generation of heat through a heat exchanger (nuclear reactor in a nuclear plant for example), or is connected to a CHP unit (see Figure 120 and Figure 121) [198]. In each stage of the expansion in a turbine, heat is produced and can be transferred to the DH network by a heat exchanger. Waste heat can also be recovered from the condenser. If the temperature of the recovered source is low (low-pressure turbine or condenser), a heat pump can be necessary. However, despite their huge heat recovery potential, power generation plants can rarely transfer their excess heat to DHC systems since they are usually located too far from urban areas. Examples of such projects in Europe involve distance of about 30 km at most between the power plant and the DHC network in order to maintain favorable economic conditions, although it is possible to transport heat over distances up to 100 km with pre-insulated pipes buried in trenches [198].

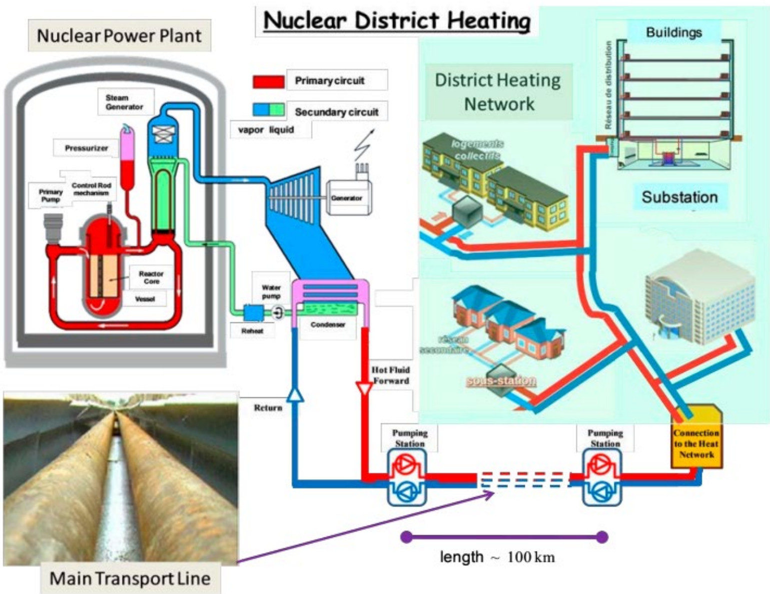


Figure 120: Principle of nuclear cogeneration for district heating [198]

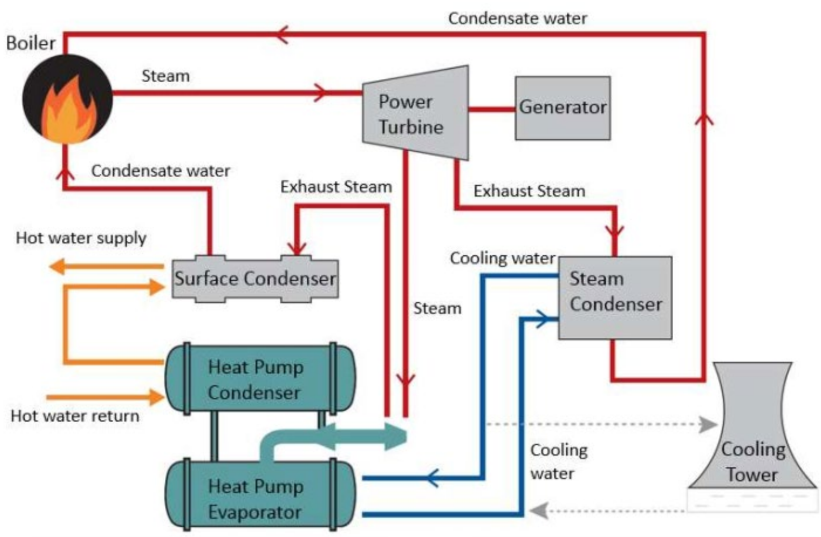


Figure 121: Coal fired CHP Exhaust Steam Heat Recovery for District Heating (Source: International District Heating Association 2018)

Four different types of connection are possible for **industrial processes heat recovery** [211]:

- **Drying air exchangers** (see Figure 122) to recover drying heat.
- **Economizers** on boiler or furnaces to recover heat from the flue gases (see Figure 123). Boiler flue gases can still contain up to 20% of primary energy and furnace flue gases up to 60%. Moreover, it can include a condenser to benefit from the energy released by the condensation (latent heat) of the water present in the flue gas.
- **Condenser of a refrigerating machine** (see Figure 124). A refrigerating machine is a reversed heat pump. The evaporator transfers cold to the building and heat is rejected in the condenser. Usually this excess heat is wasted and rejected in the outside air through a cooling tower, but it can actually be recovered at the condenser and transferred to a DH system.
- **Other exchangers** water-to-water or air-to-water to recover heat from other processes.

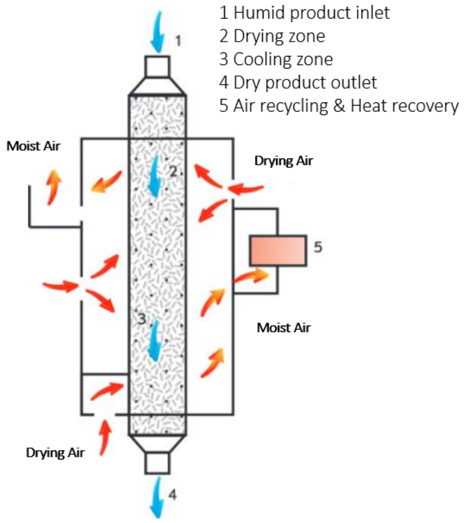


Figure 122: Drying air heat recovery (Source: ADEME 2018)

Tertiary building waste heat recovery is connected to the condenser of the refrigerating machine (see Figure 124).

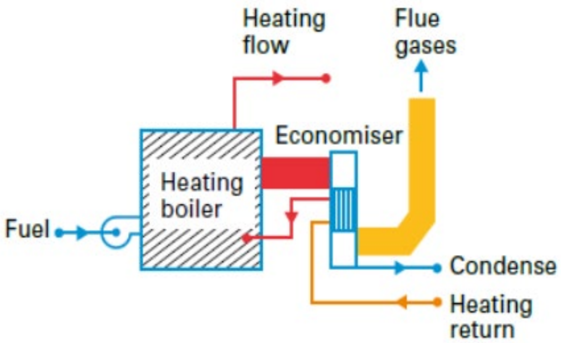


Figure 123: Economizer on a boiler (Source: ADEME 2018)

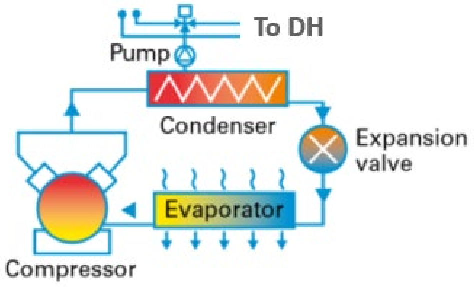
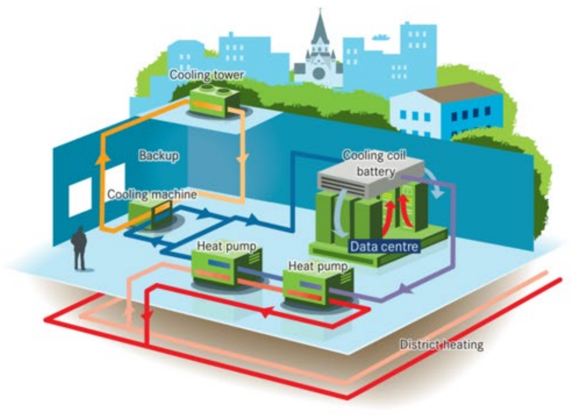


Figure 124: Refrigerating machine heat recovery (Source: ADEME 2018)

The connection of a **data centre** is made using a heat exchanger and heat pumps in a cascading way (see Figure 125). The installation can be connected directly to the cooling circuit or to a cooling machine. In the latter, a cooling tower can be used to reject excess heat not taken by the DHC network.



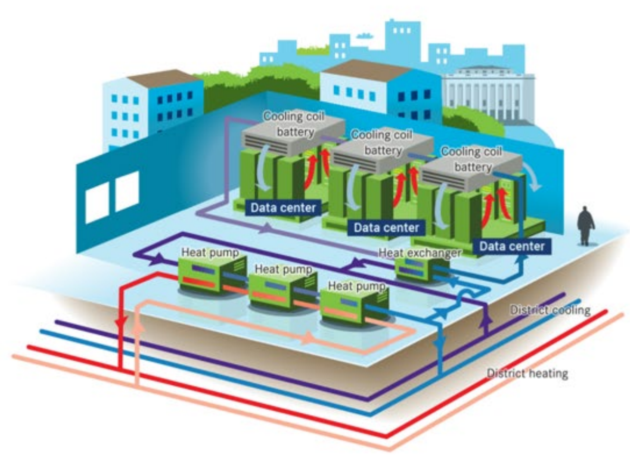


Figure 125: Data centres heat recovery installation [172]

Connection to **underground heat recovery** is made using a large fan system and a heat pump. The installation is reversible and can be used for cooling with fresh air in summer (see Figure 126).

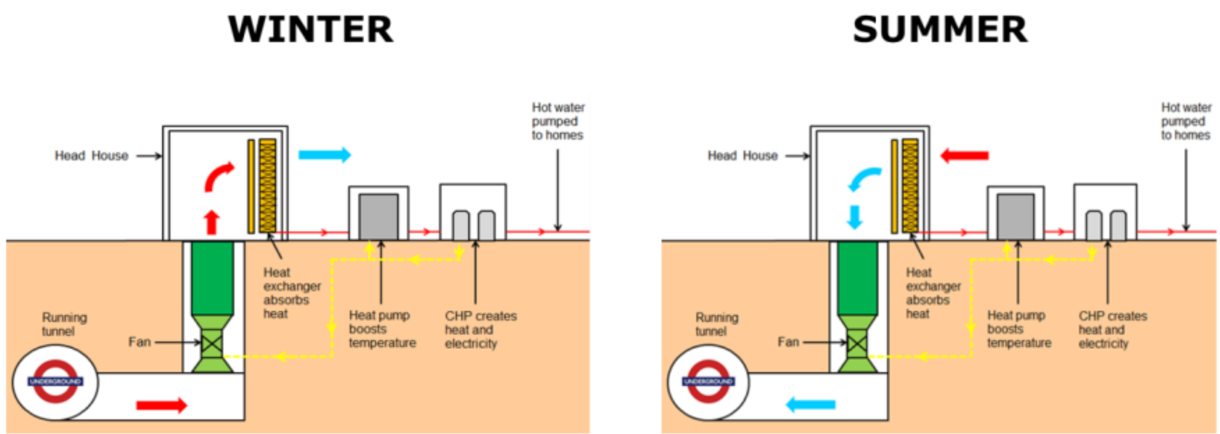


Figure 126: Underground heat recovery installation [196]

Waste cold recovery is possible if the DC system is close enough to connect to a LNG terminal. The connection is made in the LNG vaporizer. The cold is transfer through an exchanger using glycoled water (to avoid freezing) and then transferred to the DC network through another exchanger (see Figure 127).

More technical details on connection, substation and impact on the network are discussed on a general basis in section C.1.3.

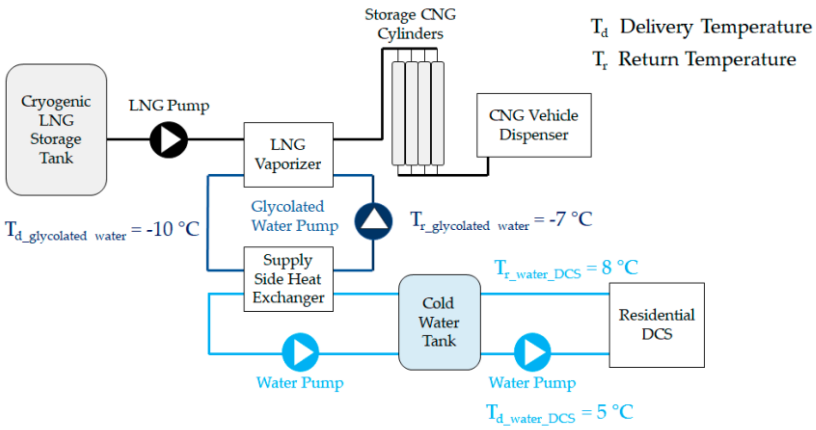


Figure 127: Plant scheme: cooling energy recovery from liquid to compressed natural gas (L–CNG) vaporizer to fulfil a residential district cooling systems (DCS) [201]

C.1.2.2.2 **Operational compatibility and DHC plant management integration**

Waste heat supply **can cover a significant share of DHC production** [192] but is exposed to possible intermittencies according to the waste heat suppliers' activity or to the season. It is **used either directly as a production unit for DHC network or indirectly to preheat the returns of the DHC network** [172]. The latter may not require a heat pump as a low temperature can be sufficient for preheating. To optimize the use of waste heat and increase the number of operating hours, the DHC system can include a separated system for DHW as lower temperature levels apply for it.

In the case of waste heat directed upstream to a CHP plant with steam turbine, the heat load generated downstream of the CHP and available for the DHC network is flexible as the facility can operate at steady full thermal power while varying the electricity output [198]. However, this flexibility has an impact on the business model of the CHP (revenues from electricity sales Vs. revenues from heat sales) and should therefore be considered carefully.

In addition, as low temperature waste heat has often to be directed to heat pumps to increase the operating temperature, the cost structure not only depends on the waste heat tariffs but also on the electricity market prices. Therefore, the profitability of such projects is related to a certain extent to electricity prices, and DHC operators shall assess their exposure during the periods of time when waste heat is available. Thermal storage facilities can help to mitigate this exposure to prices volatility.

As direct source of waste cold is limited to LNG terminals, cooling can also be achieved with waste heat through absorption and adsorption technologies, explained in the Solar thermal section in paragraph C.1.1.4.2. This can be done via low temperature water loop with cooling machines located in decentralised substations for example (see example of Paris Saclay DHC network [30]).

C.1.2.2.3 **Status of waste heat/cold in national policies**

In the majority of European countries there is no legal nor regulatory framework regarding waste heat and no direct incentives [212]. Some countries tax DHC industrial waste heat similar to the fuel used in the industrial plant [208]. Waste heat in DHC is competing with fossil fuels and renewable heat sources that are usually more favoured. Moreover, the different waste heat sources are not always treated equally. For example, sewage water heat recovery is defined as a renewable source in the European Directive and therefore it might be incentivized as a renewable source in some countries.

In some European countries, however, waste heat recovery benefits from incentives. These incentives might be orientated toward the waste heat supply (heat exchanger, adaptation of the processes…) and/or to the development of the DHC network fuelled by this waste heat. A few examples are provided below (Source: own survey with national DHC stakeholders).

Countries where DHC networks supplied with waste heat benefit from the same support than renewable energies:

- In Belgium, DHC projects can apply for investment support (Call Groene Warmte, organized twice a year on average) with the Flemish Energy Agency whether they are supplied by heat based on renewable energy or residual heat.
- Similarly, in Norway, DHC networks fuelled by waste heat (which usually comes from industrial production in Norway) can apply for the same subsidies as the networks fuelled by renewable heat sources.
- In the Netherlands, DHC networks supplied with waste heat benefit from the same support than renewable energies. In addition, the new Heat Law has proposed to require industries to make waste heat available for free.
- In France, a fund is allocated by the agency for environment and energy management (ADEME) for industrial, tertiary and data centers waste heat recovery. This fund is orientated toward the waste heat supplier and comes on top of the fund (also allocated by ADEME) for DHC networks development with high share (65% minimum) of renewable and waste energy sources.
- In Germany, the Heat system 4.0 scheme funds 60% of feasibility studies and 50% of construction for DH systems supplied by at least 50% of RES or excess heat [208]. In the building code however, new buildings are required to cover the heat demand with a minimum of 50% of excess heat (e.g. directly or via DH system), while the minimum is only 15% if it is covered by RES.

Countries where waste heat enters specific support schemes:

- In Czech Republic, there is no subsidy for the generation part but subsidies for network upgrades and reduced VAT both apply (Source: Euro Heat and Power).
- In Italy, waste heat is eligible for Energy Saving Certificates. Furthermore, a specific incentive scheme has been implemented in 2017 for waste heat recovery with Organic Rankine Cycle (ORC) units.
- In Slovenia, waste heat enters the energy efficiency support scheme.
- In Denmark, there is no specific subsidy, but tax invectives are being revised to make waste heat more competitive when compared to fossil fuels.
- In Sweden, a specific fund has been created to subsidise heat or CHP production from municipal waste.
- In Austria, waste heat can benefit from local or federal support scheme.
- In Lithuania, independent heat suppliers can compete in heat tenders organized by the DHC operator (see section B.3.2.4). If two competitors bid at the same price, waste heat is prioritized overheat from fossil fuels.

C.1.3 Connection to DHC systems by third party suppliers

Technical constraints shall be taken into account and constitute an upstream work, regarding several aspects:

- General layout and geographical locations of both DHC operation and third party supplier (TPS) process
- Technical characteristics of both DHC operation and third party supplier process
- Technical adaptations to connect both processes inside plants or on network

The energy exchange point shall be designed and located according to existing technical constraints on both sides (energy transfer fluids, equipment quality and capacity) to achieve the objectives in terms of energy supply and performance.

This section lists and comments these technical requirements and modalities of connection in terms of design, performance and economic impacts.

C.1.3.1 General layout

DHC operations are composed of three main elements:

- Energy plant(s), more or less centralised, depending on the local energy context
- Network, designed to connect plants to buildings
- Local substations, delivery points located inside each connected building

Connection by third party suppliers shall occur at the most convenient location, to maximize heat transfer capacity and ensure proper operation of both DHC and third party supplier facilities. Therefore, the injection point is usually set as upstream as possible, through the energy plants or the network, giving more flexibility for the design, construction and future operation. Different locations can be undertaken considering the point of heat or cold exchange. The most common cases in DHC operations are schematically represented below.

C.1.3.1.1 **Case 1: energy exchange point located in the TPS plant**

The energy exchange point is located inside (or contiguous to) the third party supplier plant, meaning all equipment (exchangers, pipes, valves, monitoring and metering devices) stand inside the TPS perimeter.

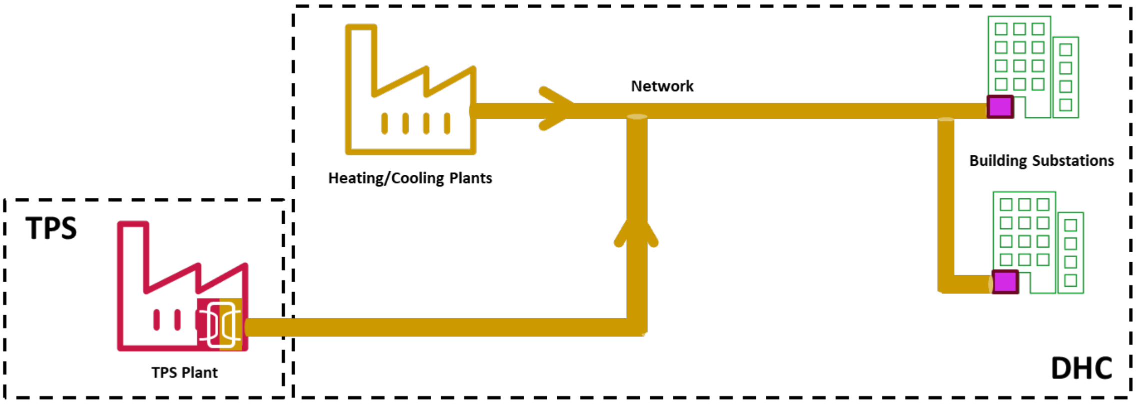


Figure 128: Layout of an energy exchange point located inside the TPS plant (Source: own display)

This configuration occurs when there is obviously enough space in the existing plant and/or when this location does not imply too significant modification works on existing networks, DHC plant and building substations (assessed by cost-benefit analysis). This is often the case for waste heat recovery from industrial production plant or data center e.g.

It also allows to control the connection design between the TPS plant and the DHC network (size, quality, transfer fluid).

C.1.3.1.2 **Case 2: energy exchange point located on the network**

The energy exchange point is located on the network, between the TPS plant and the DHC network perimeter, meaning a dedicated room shall be installed to receive all equipment (exchangers, pipes, valves, monitoring and metering devices).

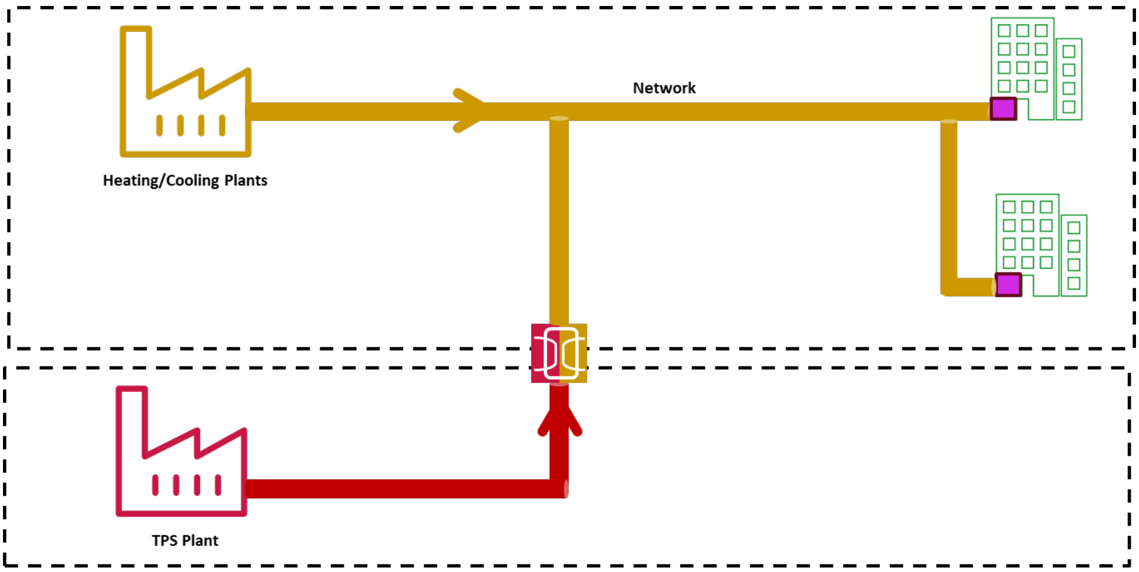


Figure 129: Layout of an energy exchange point located outside/in between TPS and DHC networks (Source: own display)

This configuration occurs when there is no possibility to install equipment inside the TPS plant nor in the DHC plant because of space or technical constraints (hydraulic adaptation for example), but also to optimize the location of the point of energy injection in accordance with the potential DHC clients (between two different DHC operations for example, or to cover a new building area).

C.1.3.1.3 **Case 3: energy exchange point located in the DHC plant**

The energy exchange point is located inside (or contiguous to) the DHC plant, meaning all equipment (exchangers, pipes, valves, monitoring and metering devices) stand inside DHC perimeter.

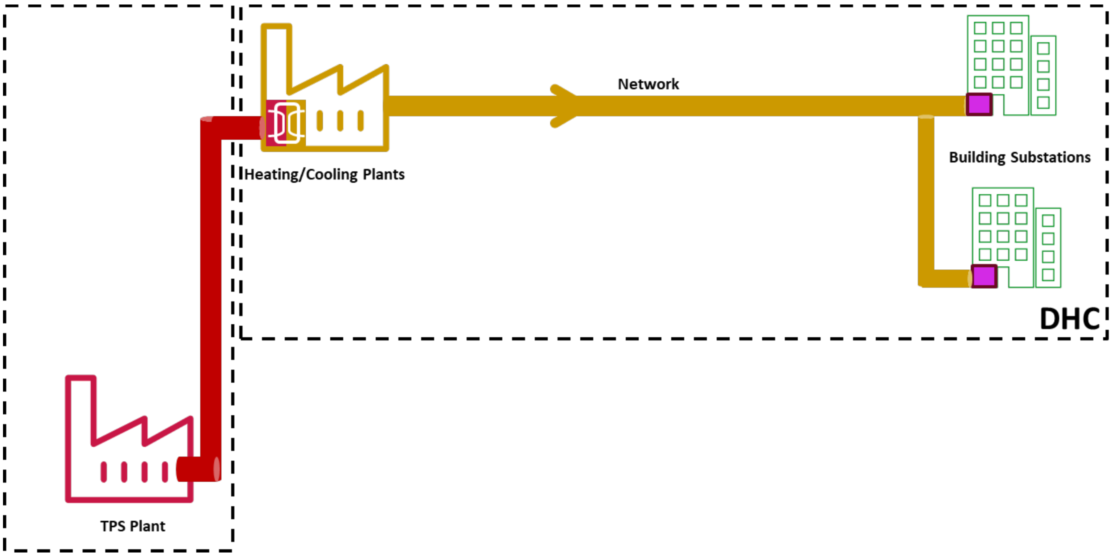


Figure 130: Layout of an energy exchange point located inside the DHC plant (Source: own display)

This configuration occurs when there is obviously enough space in the DHC plant and/or when previous cases 1 and 2 are not possible.

Case study of Helsingborg (SE) and EVITA interconnector: integration of waste heat through the interconnection of neighbouring grids (Annex 6)

The EVITA interconnector case study is an excellent illustration of **the current tendency of Swedish DHC systems to interconnect with their neighbouring grids to improve their economic and environmental performance**. It illustrates a strong cooperation between three public utilities who chose to interconnect their DH networks and, by doing so, enabled an overall optimisation of the networks and a **higher use of waste heat and renewable energy sources.**

The EVITA collaboration is based on the creation of a DN500 district heating pipe of **30 km** between Landskrona and Eslöv, enabling energy transfer in both directions based on daily cost optimization. It also brought additional synergies between the 3 utilities, such as sharing best practices and resources.

This example also epitomizes the benefits of a transparent relationship with industrial third parties supplying waste heat to the grid, which in this case resulted in a collaboration based in **sharing risks and benefits** within a long-term vision.

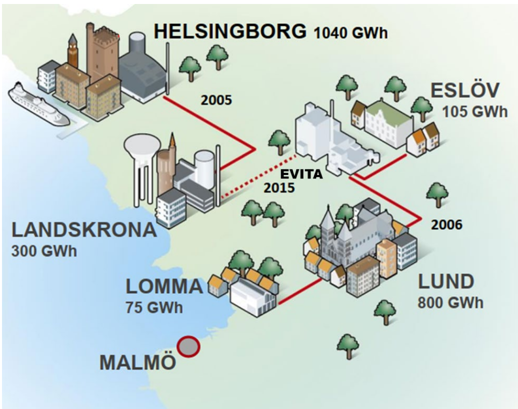


Figure 131: Grid and interconnection scheme of Helsingborg and surrounding cities - Source: Öresundskraft

C.1.3.2 Energy exchange point: general description

The main objective pursued when it comes to connect a TPS to a DHC system is to supply the exact energy quantity at the requested temperature. Represented by an exchanger in the above figure, the energy exchange point can actually take different forms:

1. A heat and/or cold exchanger ensuring the energy transfer and allowing a physical separation between the TPS process and the DHC network which preserves their own technical characteristics (transfer fluid, monitoring system) and global functioning. On the other side, the more delivered power is at stake and the more technical characteristics are different, the more specific the exchanger design will be, impacting its size and cost.

2. A two- or three-way valve regulating the flow in response to energy demand and setpoint temperature. Easier to set-up than exchangers, this solution comes along with inconveniences such as the absence of physical separation between the TPS and DHC systems and their perimeters. It is also limited when it comes to transfer different quality fluids or to reach high ranges of power.

3. A mixing tank which, as its name indicates, creates a mix between transfer fluids from the TPS to the DHC network to obtain the setpoint temperature. This well-known technology is flexible on fluids quality considerations, but presents a lack of efficiency when it comes to temperature regulation. Like the previous solution (two- or three-way valve), this type of equipment implies an absence of physical separation between the TPS and DHC systems.

Whichever technology listed above is chosen, a feasibility study for its implementation shall integrate all technical constraints presented previously, which are detailed in the following subsections.

Considering that the energy exchange point is usually located in a specific area inside the TPS or DHC plant or in a dedicated technical room, it will be designated as the "substation" in the following subsections. The energy exchange point will be represented by an exchanger system which is the most representative equipment for such analysis.

C.1.3.3 Design of the substation

The design of the substation, regardless of the chosen technology for the energy exchange point, depends on both TPS and DHC technical characteristics, such as:

- Setpoint temperature and related parameters
- Transfer fluid characteristics
- Performance objectives

These characteristics influence design choices such as energy exchange point technology listed above, but also related components such as delivery pumps, pressure loading, monitoring regulation and metering devices.

C.1.3.3.1 **Technical characteristics**

- Transfer fluid characteristics

As previously exposed, transfer fluid characteristics have a major influence on TPS connection to a DHC operation and on its technical modalities. Considering heating and cooling energy transfer, 4 types can be distinguished:

1. Steam: water is in a gaseous state at high pressure and high temperature

It is a common situation to have a TPS steam process (recovery energy from industrial facilities or from power generation), while DHC networks are nowadays mainly superheated or hot water systems. In this case, the heat exchanger and its related components shall support high temperature and high pressure conditions, and allow water phase change and transfer to the DHC system. It requires the use of resistant material and involve very specific and regulated technical specifications, in order to limit, among other issues, corrosion caused by condensation.

2. Superheated water: liquid water is at a temperature over 100°C without phase change (due to operating pressures above atmospheric pressure)

Situation and equipment design are relatively similar to the steam case discussed above, with less restrictions in terms of regulation.

3. Hot water: water is at a temperature below 100°C.

In this case, the heat exchanger and its related components shall work under low temperature and low pressure conditions.

4. Cooling water: water is at a temperature below 10°C.

Situation and equipment design are relatively similar to hot water case.

- Setpoint temperature and related parameters

Energy transfer principles applied to DHC systems are based on a power exchange between a delivery point (the DHC system here) and a production unit (the TPS here), power being a combination of temperature and flow rate:

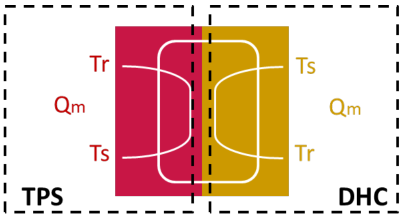


Figure 132: Exchange parameters between TPS and DHC systems (Source: own display)

$$P = C_p * \mathrm{Qm} * (\mathrm{Ts} - \mathrm{Tr})$$

P : power exchanged between the TPS and the DHC operator, strictly identical modulo the exchange system efficiency

Ts : supply temperature on each side of the exchange system:

- Setpoint temperature defined by the DHC operator on his side of the exchange point considering his own system characteristics.

- Production temperature on the TPS side depending on the process which shall be equal (modulo exchange point efficiency) or superior to the setpoint temperature defined by DHC operator. A key issue is therefore for the TPS to provide energy with the expected temperature set by the DHC operator.

Tr : return temperature on each side of the exchange system:

- Return temperature on the DHC operator side results from DHC system functioning (building heating/cooling systems combined to the network efficiency). It shall be equal (modulo exchange point efficiency) or inferior to a setpoint temperature defined by the TPS. In the same way it has been discussed for different technologies in section C.1, minimizing the return temperature from the connected buildings is therefore a key issue for the DHC operator in order to maximize energy exchange.

- Return temperature on the TPS side results from DHC return temperature modulo exchanger efficiency ("pinch"). As per the formula above, it shall respect a minimum gap with supply temperature to satisfy the expected power to transfer.

Cp: heat capacity of the fluid on each side of the exchange system

Once the energy exchange capacity has been decided considering both power demand (on the DHC side) and supply (on the TPS side), expected DHC supply and return temperature will be requested to design the exchanger (or any alternative solutions as discussed in section C.1.3.2), impacting the number of plates or tubes and the global size.

- Performance objectives

In the case of energy transfer, performance objectives are obviously to have the best exchange efficiency, meaning to minimize losses at the exchange point. This will impact technical parameters such as exchange temperatures and resulting flow rate. The following elements shall be defined regarding expected performance objectives:

- Exchanger pinch
- Plate/tube thickness
- Exchange surface
- Pressure loss

These elements require a special attention when there is not enough flexibility between the TPS capacity (available power or temperature) and the DHC demand (energy supply from the DHC operator and temperature). This would apply to low temperature TPS systems using energy recovered from data centres or geothermal energy for example. In these cases, the exchange parameters listed above shall be chosen with great caution, namely a minimum exchange pinch, a maximum plate/tube thickness, large exchange surfaces and appropriate pressure losses.

C.1.3.3.2 **Substation design process**

- Exchanger technologies

In sequence, design process takes place as follows:

1. The evaluation of transfer fluid characteristics conducts to a certain type of exchanger.
2. Setpoint temperature and related parameters as well as performance objectives conduct to designing the number of plates/tubes and the exchanger size.

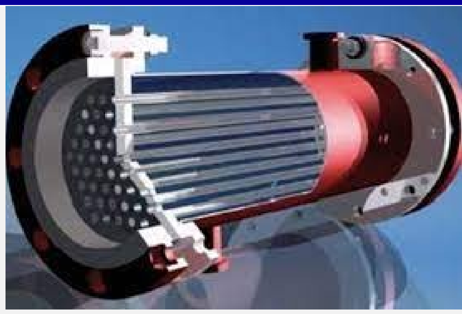
Transfer fluid	Exchanger type	
Steam Superheated water	Tubular exchanger: T°C > 100°C Nominal pressure >25 bar Pinch >10°C	 Source : Info-chimie
Hot and cooling water	Plate exchanger T°C < 100°C Nominal pressure <25 bar 1°C < Pinch <10°C	 Source: Alfa Laval

Table 35: Characteristics of different exchanger technologies

- Related components

Besides the exchanger, delivery pumps and pressure loading are important items to consider:

- Delivery pump design depends on the nominal flow rate resulting from the exchanger parameters listed above and on the network design regarding pressure losses generated by its length and layout.
- Pressure loading is designed to maintain a constant pressure in the network by compensating temperature and flow rates variation.

Monitoring regulation shall also be designed to guarantee the expected setpoint temperature and is subject to close discussions between the TPS and the DHC operator to potentially adapt existing monitoring regulation systems on both sides.

Metering, at last, can be mechanical or ultrasonic type, but it shall be designed by considering transfer fluid characteristics and flow rates range, like for control valves.

C.1.3.3.3 **Investment costs**

Considering the technical constraints which were previously exposed, investment costs mainly depend on the following aspects:

- Operation context and general supply layout which will be chosen as exposed in section C.1.3.1, meaning:
  - Creation or not of a technical building implying civil works;
  - Adaptation of existing equipment (hydraulic, electrical and regulation);
  - Implementation and specific design of structural equipment such as delivery pumps.
- Technical characteristics such as transfer fluid characteristics and performance objectives which have influence on:
  - Exchange point technology choice, valve being the less expensive and exchanger being the most expensive technology;
  - Equipment material choice (steel quality, pressure resistance) and design to supply the required capacity.

Besides these technical considerations, based on each operation specificity, investment costs will also depend on each country local context, as such investments depend on both equipment furniture and labour:

- Material costs are a major indicator of investment costs, steel specifically which had a 20 to 30% increase from 2020 to 2021.
- Labour, which can represent 20 to 50% of the investment costs, will vary from a country to another as illustrated in the graphic below.

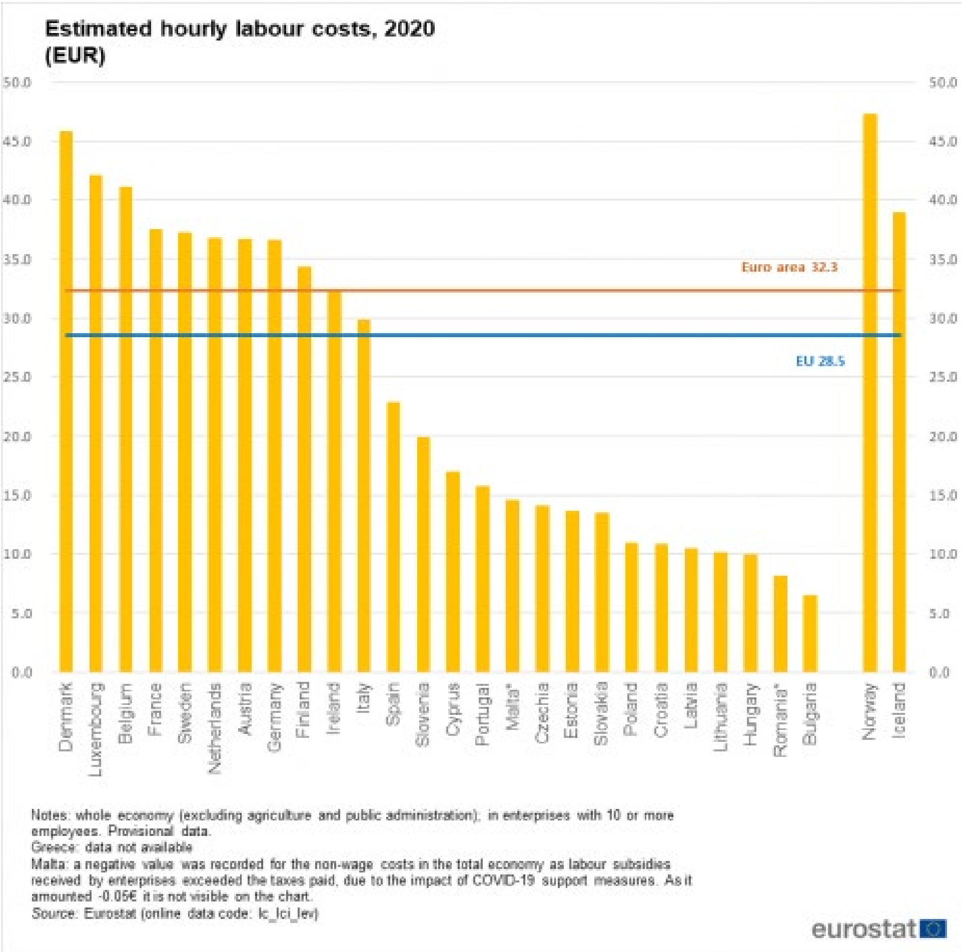


Figure 133: Estimated hourly labour costs across Europe in 2020 (Source: Eurostat)

Therefore, estimation of investment costs considering all exposed variables is not so obvious. Such task shall be the object of a specific feasibility and conception study in order to evaluate both energy benefits and investment/operational costs.

At this stage, the following examples shall illustrate the scales of investment costs at stake in DHC projects (Source: own operational experience):

- Hot water substation (with exchanger technology) in an existing plant with same fluid quality on both sides (DHC and TPS) for a 1 to 2 MW supply capacity: about 100 k€;

- Overheated water substation (with valve technology) in an existing plant with different fluid quality between TPS and DHC for a 5 to 10 MW supply capacity: about 500 to 1 000 k€;

- Steam substation (with exchanger technology) in a dedicated building with phase change between TPS and DHC for a 5 to 10 MW supply capacity: above1 000 k€.

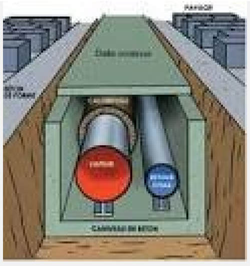
C.1.3.4 Design of the network

Design of the network follows the same logic than for substation, depending on both TPS and DHC technical characteristics listed previously, but also on the general layout.

C.1.3.4.1 **Influence of technical characteristics**

- Transfer fluid characteristics

The main pipes technologies are presented below in function of different transfer fluid characteristics:

Transfer fluid	Pipes type	
Steam	Stainless steel pipes in a gutter (steam and condensate) T°C > 100°C Nominal pressure >25 bar	 Source: CPCU
Superheated water	Stainless steel pipes in a gutter T°C > 100°C Nominal pressure >25 bar	 Source: ETCM - Tuyauterie
Hot water Low temperature water Cooling water	Pre-insulated steel pipes T°C < 100°C Nominal pressure <25 bar	 Source: DHC News

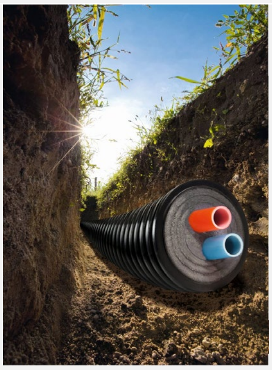
	Composite material pipes T°C < 100°C Nominal pressure <25 bar	 Source: SMT-Bondstrand
	High Density Polyethylene pipes T<70°C Nominal pressure <16 bar	 Source: Willems-lucy

Table 36: Characteristics of different pipe technologies

Each technology has its own physical specificities such as material quality, sustainability to water and chemical treatments… These specificities impact laying modalities (rigid or flexible pipes, welding processes) and pipe nominal diameter.

- Setpoint temperature and related parameters

Network pipes design is based on fluid mechanics principles. This implies to consider nominal flow rate values (resulting from the temperature differences between supply and return, which vary continually all year long) and pipes physical specificities in order to calculate the nominal diameters and pression losses over the different sections of the network. An example of synoptic built for network design is provided in Annex 7.

As discussed above, the design of the network will have a significant impact on the technical choices made for the design of substations and their equipment.

When it comes to implement a new energy source to an existing system, especially when it implies renewables and/or systems with different hydraulic characteristics, static hydraulic modelling (calculated on a few functioning point) is not sufficient to anticipate the long-term performances at different functioning points. Dynamic hydraulic modelling is thus required to prevent from misassumptions with a complete approach (flow rates, temperature gradients, pressure losses) and will provide the best guaranties to a successful project achievement.

- Performance objectives

In the case of energy distribution, performance objectives are again to have the best efficiency, meaning to minimize distribution energy losses. Therefore, the quality and sustainability of insulation materials are major issues when it comes to select the network pipes technology.

Depending on the transfer fluid characteristics and the pipes technology, these losses may represent 2% (for cooling and low temperature water) to 20% (for superheated water) of the distributed energy. In the specific case of steam, condensate recovery rate has a strong impact on these losses.

C.1.3.4.2 **Investment costs**

Considering the technical constraints which were previously exposed, investment costs related to network mainly depend on the following aspects:

- Operation context and general supply layout which will be chosen as exposed in section C.1.3.1, meaning:
    - Location of both TPS and DHC connection point;
    - Characteristics of the network implementation field (length, altimetry, urban or rural environment, obstacles, …).
- Technical characteristics such as transfer fluid characteristics and performance objectives which have influence on:
    - Pipes technology choice;
    - Equipment material choice and design to supply the required capacity.

Besides these technical considerations, based on each operation specificity, investment costs will also depend on each country local context, as such investments depend on both equipment furniture and labour in the same way as for substations.

Yet, network investment costs can be estimated more easily than substations as it relies mostly on the combination of 3 items:

- Pipes furniture, depending on network length and pipes design;
- Pipes laying, depending on chosen technology and labour qualification;
- Trenching work operation, depending on the implementation field.

At this stage, the following examples shall illustrate the scales of investment costs at stake in DHC projects:

- Hot water network in a rural environment: 500 to 1000 €/lm (linear meter);
- Hot water network in an urban environment: 800 to 1500 €/lm (linear meter);

- Overheated water network in an urban environment: 1500 to 3000 €/lm (linear meter);
- Steam network: 2500 to 3500 €/lm (linear meter);
- Cooling water in an urban environment: 1000 to 2000 €/lm (linear meter).

In any case, network costs depend a lot on the local context, urban and rural specificities, inhabitant density, circulation flow and existing infrastructure. For major European capital cities for example, work organization, scheduling of civil work for trenches and competition of use with other underground networks (water, electricity, gas, telecoms…) can request specific works that will potentially generate significant overhead.

In any case, a specific feasibility and conception study prevents from misestimation one way or another, when it comes to evaluate the economical balance of such project.

C.1.3.5 Connection impact on the TPS and DHC plant

C.1.3.5.1 **Connection impact on existing DHC network**

TPS connection on existing DHC operation can have a major impact on its design and performance:

1. The energy source location of the TPS implies to evaluate the point of energy exchange point and to adapt equipment on both sides, considering hydraulic constraints previously detailed (power, temperature and flow-rate)
2. Depending on TPS supply parameters on one side and DHC design limits on the other side, specific adaptations can be required such as:
   a) Network reinforcement meaning replacing existing pipes for bigger ones;
   b) Network extension to reach the suitable energy exchange point and to maximise supply energy potential;
   c) Delivery pumps replacement;
3. The integration of any new and/or renewable energy sources leads the DHC operator to assess the impact on its overall performance through the following factors:
   a) Temperature regulation and related parameters;
   b) Energy mix, especially in the case of base load sources in competition (as discussed in section B.3.2.2.2)

These technical constraints can be restricted on case 1 or case 3 general layouts.

C.1.3.5.2 **Connection impact on both parties process**

Considering the energy exchange point to be an exchanger with a strict separation between the TPS et DHC systems, the main parameter to take into account, besides design issues, is the setpoint temperature.

Therefore, both TPS and DHC processes shall be adapted to satisfy this technical parameter and related ones, listed in previous subsection. In particular:

- On the TPS process side, regulatory bodies shall be tested and adapted to provide energy with the expected setpoint temperature. This may imply process optimization or capacity reinforcement in some cases.
- On the DHC side, centralized technical management system shall be adapted to integrate the TPS energy source to the global management of the network.

Finally, both parties shall respect technical prescriptions on shared equipment (like the exchanger for example in some cases) and on their own performances, to guarantee well-functioning parameters, especially water treatment and exchange temperatures.

C.2 Case studies analysis of European best practices

Many European cities and communities are already benefitting from a low-carbon district heating and cooling supply. To illustrate how the renewable and waste heat and cold technologies described in Section C.1 are currently being used by some of the most efficient DHC systems in Europe, ten case studies were analysed in detail, covering different geographies as well as different national and local contexts.

The selected DHC networks not only are efficient in the sense of Article 2 (41) of the EED, but they also comply with the key indicators identified by the JRC on its report *Efficient DHC systems in the EU: case studies analysis, replicable key success factors and potential policy implications* [30][81], namely:

- Economically viable (robust business model)
- Affordable heating and cooling prices for consumers
- Stable and resilient supply
- High standards of service to customers
- Mid-to-long term adaptability/flexibility of the service
- Low-CO2 emissions and limited global environmental footprint

The methodology used for the case studies analysis is explained in Annex 6.

C.2.1 Presentation of case studies

Given the local nature of the heating and cooling markets, one of the essential tasks for **policy makers, municipalities, DHC operators or urban planners willing to foster H&C decarbonisation through DHC** is to understand the main learnings from best-performers, as at least some of their success factors will be replicable in other local contexts.

The 10 case studies analysed in detailed in Annex 6 aim at feeding with **concrete and operational examples** the public and scientific debate on H&C decarbonisation, while contributing to a better **awareness on efficient DHC** and the key role it can play in the energy transition. The figures and tables below aim at allowing the readers to identify the most interesting case studies depending on different aspects (e.g., location, governance, size, DH or DCH, type of energy sources and technologies used, key success factors, etc.).

Figure 134 shows the location of the DHC networks studied and the main features of their governance model (in terms of risk sharing), even if each local situation is different (details available on Annex 6).

[81] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104437/study%20on%20efficient%20dhc%20systems%20in%20the%20eu%20-dec2016_final%20-%20public%20report6.pdf

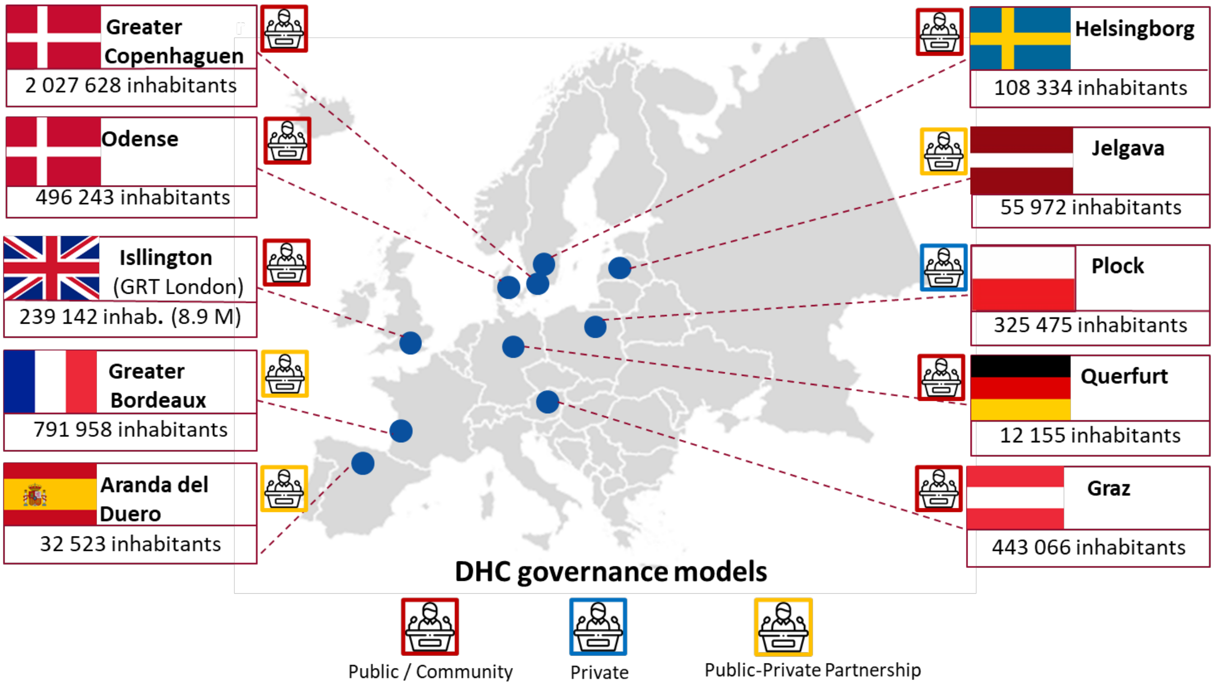


Figure 134: Map of case studies analysed and their governance models

Most of the analysed DHC networks combine the use of renewable and waste heat/cold sources, proving the complementarity of these. As depicted by the Figure above, each of the different technologies of renewable and waste heat/cold addressed in this report (Section C.1) is illustrated by at least one of the selected case studies.

Figure 135 presents a **summary of the energy sources used by the analysed DHC networks**, indicating the % of RES and waste heat/cold sources used, as well as how they comply with the EED's definition of efficient DHC network, out of the 4 possibilities:

(i) district heating systems using at least 50% renewable energy (indicated as "RES");

(ii) 50% waste heat ("Waste");

(iii) 75% cogenerated heat; or

(iv) 50% of a combination of such energy and heat ("Mix").

The DH grids of Querfurt, Islington and Graz, still below 50% RES, illustrate the on-going transition process towards a decarbonised production mix, Querfurt being also in transition towards an efficient DH system according to the EED.

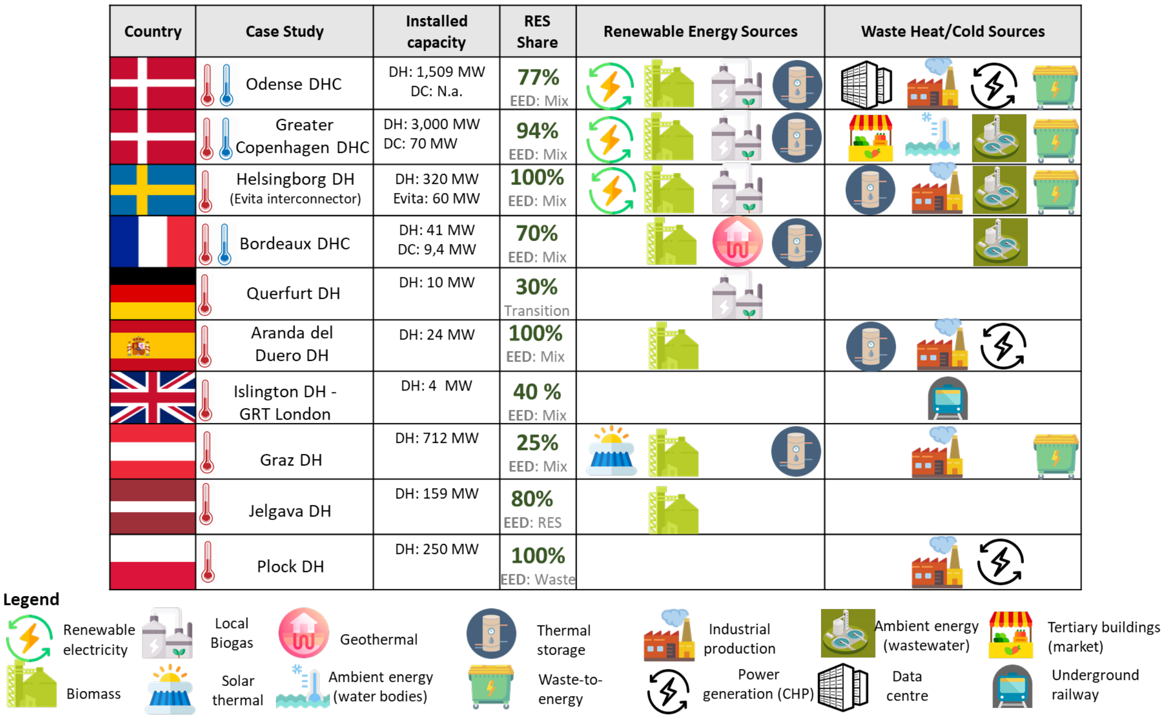


Figure 135: Summary table of case studies and their energy sources

C.2.2 Conclusion of case study analyses and key enablers for sustainable DHC deployment

The analysed case studies **detailed in** Annex 6 **provide a wide picture of EU best practices in sustainable DHC, addressing the historical developments of those networks, key actors, technologies and energy sources in place and foreseen, governance, business models and tariff strategies, to ultimately identify key success factors (KSF) for the integration of RES and waste heat and cold sources.**

While each local situation is unique, a cross case study analysis of the KSF allowed to identify **8 pillars for a successful decarbonisation through efficient DHC systems** (the columns in the table below).

Amongst these 8 pillars, half appeared as critical for the successful decarbonisation of all the networks studied. This suggests that the **support of the municipality**, a **suitable and robust business model**, strategic (long-term) **technical choices for DHC supply** and the implementation of **collaborative and innovative approaches** are essential success factors for any sustainable DHC project, mainly addressed at local and regional levels:

- **Municipalities** had a key role in all the analysed cases, directly owning and operating the DHC networks and therefore completely steering their developments, or influencing these through urban policies and support schemes, connecting their public buildings, valuing synergies between urban infrastructure and with neighbouring communities, and generally supporting sustainable DHC as a powerful tool to achieve their local climate targets.
- **DHC operators** in the studied networks managed to integrate in their **business models** the investments and actions needed to progressively improve the networks' efficiencies and decarbonise their production, ensuring appropriate risk sharing and economic viability (for example through cost-reflective and

incentive tariffs) ultimately supporting the competitiveness of DHC against alternative H&C solutions.

- Adequate **technical choices** are at the core of those initiatives (complementary and diversified energy mix, maximising the use of local energy sources, increasing flexibility…).
- The trend towards production decentralisation and higher climate awareness amongst all type of local actors (businesses, organisations, citizens…) resulted in successful **innovative and collaborative approaches** for deep H&C decarbonisation.

The rest of the KSF has also contributed to the decarbonisation goal of most of the networks studied:

- Among the ones with highest impact, one could highlight the **national policy and regulatory frameworks**. Indeed, these usually have a very strong influence on the decarbonisation of H&C markets, as proved by some of the EU best-performers in H&C decarbonisation (Sweden, Latvia, Denmark), which are also countries with high DHC market shares. While some cities managed to develop sustainable DHC systems despite a low-supportive national framework, all agree on the potential acceleration effect on H&C decarbonisation of addressing this policy issue.
- The **DHC-building nexus** is also a key technical enabler for decarbonisation through DHC. Mainstreaming **low-temperature heat emitters** and **comprehensive heat planning** resulted in high systemic efficiencies in some of the analysed grids.
- Finally, different **governance models for the DHC operators** (public, private, PPP) have proved effective and efficient across the case studies and, where existing, **consumer empowerment** measures also led to higher energy efficiency at building and system levels.

<table>
<tr><th rowspan="2">Case studies analysed</th><th colspan="8">Key Success Factors for H&C decarbonisation through DHC</th></tr>
<tr><th>National policies and support schemes</th><th>Municipality support</th><th>DHC operator's governance</th><th>Business model</th><th>Strategic technical choices for DHC supply</th><th>DHC – buildings nexus</th><th>Collaboration and innovation</th><th>Consumer empowerment</th></tr>
<tr><td>Odense

(DK)</td>
<td rowspan="2">• Coherent package of DHC policies and support schemes implemented since the 1980s (mandatory heat planning, environmental taxes…).

• Transparency on heat decision-making. Comprehensive methodology developed for local heat planning applied all across the country.

• Generalized deployment of low-temperature heat emitters in buildings required by the Building Code since the 1990s.

• Voluntary national benchmark of DH prices encouraging performance and price reductions.</td>
<td rowspan="2">• Municipalities are responsible for heat planning and own the DH operators.

• This facilitates cooperation between neighbouring communities (including interconnection of DHC networks).

• Municipalities as key facilitators to value DH synergies with other urban infrastructure (electricity, wastewater, waste, data centres) and with local companies (e.g., waste heat recovery from local industries).</td>
<td rowspan="2">• National "non-for-profit principle" in DH empowers cities and communities, reinforcing the local energy governance (municipal or consumer ownership).</td>
<td>• Renovation and modernisation strategy in place for several decades, constantly seeking cost-effective improvements.

• Priority given to operational performance to ensure price competitiveness and quality of service.

• Long-term vision supported by a mid-term strategy and action plans to become fossil-free while keeping prices low.</td>
<td>• Diversified production mix, integrating decentralised low-carbon energy sources and complementary technologies, such as heat pumps, electric boilers coupled with storage and CHP.

• Heat pump projects enabling to accelerate coal phase out.

• One of the world's biggest operations of waste heat recovery from data centres.</td>
<td>• Low-temperature heat emitters (60/40 C) enhance the system's energy efficiency and enable the integration of low-temperature waste energy sources (data centre, wastewater).</td>
<td>• The waste heat recovery from a large data centre required collaboration with the private owner of the data centre and technological and organisational innovation.</td>
<td rowspan="2">• Consumers are direct or indirect owners of the DHC networks and are well informed about their own consumption and strategic DHC decisions.

• Benefits are transferred to consumers via tariff reductions.

• Through their tariff and by making consumption data available to all clients, DH operators foster energy-saving behaviours. Thanks to incentive and cost-reflective tariffs and free of charge advise from the DHC operators, consumers are encouraged to reduce their return temperature and to consume less when production costs are higher, becoming front-line actors of the system's efficiency.</td></tr>
<tr><td>Greater Copenhagen

(DK)</td>
<td>• Price competitiveness and stabilisation at the core of the DHC utilities' strategies.

• The model allows to share risks, costs and profits between utilities, municipalities and consumers.</td>
<td>• Integrated system approach (interconnection of networks, coordination of their heat and electricity production through a heat dispatch unit…).</td>
<td>• DH deployment pushed heat emitters' temperatures down from optimal regimes for oil boilers (90/70°C) to optimal levels for DH (60/40).</td>
<td>• A long history of highly innovative and collaborative culture, resulting in one of the most efficient and decarbonised large DHC systems in the world.</td></tr>
</table>

Case studies analysed	Key Success Factors for H&C decarbonisation through DHC							
	National policies and support schemes	**Municipality support**	**DHC operator's governance**	**Business model**	**Strategic technical choices for DHC supply**	**DHC – buildings nexus**	**Collaboration and innovation**	**Consumer empowerment**
Helsingborg / Evita interconnector (SE)	• A **national context favouring sustainable investments in heating**, through a series of policies put in place since the 1990s (e.g., environmental taxes, building code…).	• The **municipal ownership** of Helsingborg's DH operator has influenced the **progressive decarbonisation** of the grid (from 100% oil to 100% RES and waste heat in about 25 years), in line with the **city's Climate and Energy Plan.**		• Cooperation between DH operators to create the Evita interconnector based on **sharing risks, costs and profits** instead of negotiating a fixed price for exported or imported energy between them. • Interconnector's operational rules formalised in a **long-term collaboration agreement.**	• The **interconnection of the 3 neighbouring DH grids** enables a higher uptake of waste heat. • It has also enhanced the capacity of the 3 utilities to **stabilize their prices and remain competitive** in the heating market.		• The Evita collaboration was built on **transparency and cooperation between 3 municipal utilities**, to reach the common goal of improving overall security of supply at minimum cost. • Thanks to this collaboration, the 3 utilities also **share best practices and resources** (e.g., O&M workers), and have put in place **joint procurement** procedures enabling to obtain better prices using less internal resources.	
Bordeaux (FR)	• **Reduced VAT** for sustainable DHC. • **Investment subsidies** (15% CAPEX). • **Building regulation:** CO_2 requirements for new buildings.	• Bordeaux Metropolis as **initiator and facilitator** of the eco-district and its sustainable DHC supply.	• While the DHC system is operated as a private network, **the Metropolis is a shareholder of the project company** and thus is involved in its governance.	• A **private scheme** allowing to introduce more innovative and flexible approaches to compensate the commercial development risk.	• Integration of **cheap or free RES** (excess heat from the WWTP and geothermal energy). • Combined **heat and cold** production through **heat pumps** located in substations supplied by a **mid-temperature loop.**	• Technical match between **local low-temperature energy sources** and new **buildings' temperature regimes.** • **Modular design** to accommodate the new urban district development (planned over 14 years).	• Technical support from DHC operator to **real estate developers** at a very early stage to ensure an **efficient design** of their building and equipment. • **Synergies with other urban infrastructures**, namely wastewater facilities (waste heat recovery).	• **Advice of the DHC operator to the end-users** (e.g., fine-tuning of the contracted capacity).

Case studies analysed	Key Success Factors for H&C decarbonisation through DHC							
	National policies and support schemes	**Municipality support**	**DHC operator's governance**	**Business model**	**Strategic technical choices for DHC supply**	**DHC – buildings nexus**	**Collaboration and innovation**	**Consumer empowerment**
Querfurt (DE)	• The national **support schemes for renewable heating** (biogas CHP feed-in-tariff, CO_2 taxes, subsidies…) made the decarbonisation financially viable.	• **Creation of a new municipal DH company,** bringing a new lever to the municipality to implement its energy strategy: higher revenues, possibility to offer new services, creation of local employment…		• A fruitful **public-private collaboration**, in this case through a **performance-based** service contract. • A pragmatic, long-term and inclusive approach, putting **price competitiveness** and **local value creation** at the core of the strategy. • A **balanced share of profits** between the DH operator and the community (agriculture cooperative, consumers).	• A complete benchmarking of potential projects and solutions based on **economic, environmental, and social welfare criteria** established with the municipality (owner of the DH grid). • A biogas supply profiting from the proximity of **agricultural facilities** to the DH system.		• **Continuous improvement culture**: decarbonising as long as it is economically viable. • 50% joint venture created between the municipal housing association and the **local agriculture cooperative** feeding the new biogas plant.	
Aranda del Duero (ES)		• Political support from the **city** and the **Region,** crucial to develop the new DH grid.	• **PPP** at regional level, with **private majority.** • Private SPV for the DH network allows **high flexibility and reactivity** in a very competitive market, with very limited public support to renewable H&C.	• A **private sponsor willing to take the development risk** and to mobilise funding. • **The tariff guarantees price competitiveness** against fossil alternatives (min. 10% discount). • The DH operator offers to maintain existing fossil boilers as an entry strategy for **DH in an urbanised environment.**	• Conception of a new DH system using **100% RES** (local biomass at a first stage, produced by the mother company of the project's sponsor). • Integration of **industrial waste heat** and **thermal storage.**	• **City-scale fuel switch** of apartment buildings with oil or gas central heating. • Combination of **energy refurbishment** and connection to DH. • Possibility to use previous fossil boilers as back up for DH.	• Highly **innovative business model,** being replicated in other Spanish cities. • **First industrial waste heat recovery** operation in the Spanish DHC sector.	

Case studies analysed	Key Success Factors for H&C decarbonisation through DHC							
	National policies and support schemes	**Municipality support**	**DHC operator's governance**	**Business model**	**Strategic technical choices for DHC supply**	**DHC – buildings nexus**	**Collaboration and innovation**	**Consumer empowerment**
Islington - Greater London (UK)	• Obtaining **national and EU investment grants** to make the business case for waste heat recovery financially viable.	• The elaboration of a **local climate strategy** identifying DHC as a key tool to reach climate targets. • The **public ownership** of the DHC network and the dedication of its teams was key to **facilitate the coordination with the multiple stakeholders** (operators of the different infrastructures…) and partners (Transport for London, Greater London Authority…), and to **secure customers** in a country with little national support and where DHC suffers from a relatively bad reputation.		• The **integrated approach** and diversity of the offer. The London Borough of Islington also supplies **electricity** (as well as **cooling** in the near future) to its customers and/or partners. • A successful integration of **environmental performance and social criteria** (adapted tariff structure built for social housing, tariff discount for council tenants…).	• Identification and integration of a **large waste heat source (London Underground).**		• The project is a **first-of-its-kind** to recover **waste heat from the underground train network.** Several studies are currently ongoing to implement this solution in other places in London and other European cities. • **Efficient and open cooperation** with Transport for London to integrate technical and operational constraints.	
Graz (AT)	• **Financial support** schemes (investment subsidies).	• The DH network is used as a **municipal tool to improve air quality and decarbonise the city**. • The Municipality, through its **municipal utility** Energie Graz, played a central role in decarbonising the DH grid, **coordinating** its efforts **with other public actors** (for the design of the DH network or for the financial support schemes e.g.) as well as **private actors** involved in the development of the DH network and its heat supply.		• A **long-term planning** to organize a **realistic and efficient phasing-out of fossil supply.**	• The **assessment of all possible local opportunities**, leading to a pipeline of low-carbon projects: solar, biomass, excess heat from different sources (industry, wastewater treatment plant, power to heat…).		• A **working group led by the municipality and involving the core stakeholders** as well as relevant **experts** proved to be an excellent tool to foster communication, common understanding and new initiatives.	

Case studies analysed	Key Success Factors for H&C decarbonisation through DHC							
	National policies and support schemes	Municipality support	DHC operator's governance	Business model	Strategic technical choices for DHC supply	DHC – buildings nexus	Collaboration and innovation	Consumer empowerment
Jelgava (LV)	• The significant **EU and national support schemes** to foster the development of biomass CHP, resulting in 70% CO_2 emissions reduction over 10 years.	• The **historical commitment of the Municipality to the DH system**. It has been developed for more than 60 years and is at the hearth of the **city's energy strategy**, supplying about 85% of the city's total heat consumption.	• The **operational experience and financial capacity of the private operator** were key to handle the modernization of the network and ensure a successful implementation of the different technical solutions deployed.	• A **PPP model** (30-year concession) enabling an intensive and fruitful cooperation between the municipality and the private DH operator.	• **Major modernisation and renovation programme** undertaken by the concessionaire, while ensuring a proper **service continuity.** • Integration of local and renewable energy sources to secure **competitive and stable prices.**		• **Culture of innovation**. The innovative approach and multi-fields (including circular economy to diversify the biomass resource) experience of the operator were key to ensure continuous improvement of the DH system.	
Plock (PL)	• **Financial support** schemes.	• **Political willingness** at local level to commit to the energy transition and **air quality improvement.**		• A **stable price enabled through the use of industrial waste heat** (competitive advantage with respect to alternative coal and gas solutions).	• The **geographical proximity** between the DH system and large industrial players having **important amounts of excess heat.**		• The **historical relationship** that binds the industrial plant (refinery) and the Municipality facilitates their collaboration.	

Conclusion

The study provides a detailed vision, for all **EU Member States as well as the UK, Norway, Iceland and Ukraine**, of DHC markets (Block A), regulatory framework of DHC systems and urban regulations affecting its use in buildings and industries (Block B) as well as the various technical possibilities to further integrate renewable and waste heat and cold sources in local energy systems (Block C).

By doing so, it tackles the existing DHC market data gap, contributing to an **enhanced knowledge of European DHC markets**, **needed to develop efficient and effective policies contributing to achieving the H&C decarbonisation targets** set by the European Green Deal.

The key messages of each block are summarised below, followed by a set of policy recommendations for H&C decarbonisation through sustainable DHC.

Block A: Detailed market overview of DHC

DHC supply share, technology, and heat supply mix

Section A.1 provides an **overview of the final DH consumption** in the residential, service, and industrial sectors. Furthermore, it defines the installed capacities of the different **heat supply technologies**, the cogeneration shares and the **fuels** used for heat production. The results have been compiled in an Excel file as well as a dynamic web application which can be accessed on the following website: https://irees.de/2021/10/18/district-heating-and-cooling-trend-interactive-report/.

In 2018 the total DH final energy consumption in the **EU-27** was ca. **445 TWh**, representing, for the residential and services sectors, **12% of the final energy consumption for space heating and hot water**. **Around 52%** of the heat was supplied to the **residential sector**, followed by the **service sector** with a share of **28%** and the **industrial** sector with **14%**. The highest shares of DH supply from the total space heating and hot water consumption **in the residential sector** are observed in the **Scandinavian** (Sweden 50.2%, Denmark 46%, and Finland 33.4%) **and Baltic countries** (Lithuania 40.1%, Estonia 39.2%, and Latvia 35.7%). In the **commercial and public services,** apart from the Scandinavia and Baltic countries, significant shares of DH can be observed in **Austria** (38.1%), **Slovakia** (53.9%), **Slovenia** (35.8%), and **Ukraine** (49.9%). As for the **industrial sector**, due to the missing statistical data of **heat consumption by type of use**, it is not possible to separate the share of space heating and hot water consumption from the total heat consumption (heat being also used for industrial processes). DH shares **above 5% of the total heat consumption** in the **industrial sector** can be observed in Denmark (5.2%), Estonia (7.3%), Latvia (9%), Poland (5.1%), Slovakia (13%), and Czech Republic (7.3%).

The observed total installed **heat generation capacity in 2018** in the EU-27 was around **353 GW$_{th}$**. Most of the heat capacity is covered by **heat-only boilers** with an estimated **216 GW$_{th}$** and **cogeneration** plants with a total installed thermal capacity of **142 GW$_{th}$**. Other heat supply technologies such as **geothermal** (**1.83 GW$_{th}$**), **solar thermal** (**1.29 GW$_{th}$**[82]), **heat pumps** (**2.17 GW$_{th}$**) and industrial **excess heat** (**0.9 GW$_{th}$**) still cover a small share of the total installed DH capacities[83].

[82] Installed capacities for solar thermal plants only as indicative values for statistical reasons
[83] these numbers do not exactly sum up since different data sources have to be compiled to provide the complete panorama

In 2018, **around 63%** of the heat supplied in the EU-27 came from **cogeneration** plants, with shares above 50% in most of the Member States. **Natural gas** accounts for ca. **30%** of the DH fuel mix and is the major source of heat in many countries, followed by **biomass, biofuels and renewable waste** with a total share of ca. **27%**. The share of renewable waste used as a DH fuel in the EU-27 is ca. 4.5%, where significant shares can be found in Norway (13%), Germany (9%), France (9%) and Sweden (8%). In total, **two-thirds** of the DH supply are **generated with fossil fuels** in the EU-27 Member States. **Coal and peat**, as a third most used source of heat with a share of **26.7%** in the EU-27, have a high share in Greece (100%), Poland (73%), Czech Republic (59%), , Slovenia (49%), Germany (27%), and Slovakia (26%) The **remaining fuel mix** in the EU-27 consists of **non-renewable waste** (7.2%), **fuel oil** (2.4%), **industrial excess heat** (1.7%), **heat pumps incl. electricity** (1.2%), **geothermal heat** (0.7%), **solar thermal** (0.1%) and **other fuels** (2.9%).

The **DC** installed capacity in the EU27 in 2018 was around **7.8 GW_{th}** with a space cooling consumption of almost **3.1 TWh**. The DC consumption is not divided per sectors as **most of the sales are in the service sector** (shopping centres, hospitals, trade fairs, office buildings, etc.) with a very small part and site-specific share of residential buildings (mostly new ones) as the connection of existing residential buildings, unlike DH networks, is not feasible due to the absence of cooling distribution systems within these buildings.

DHC historical developments, size, and type of networks

Section A.2 focuses on the **current structure of DHC networks in Europe** regarding characteristics such as trench length, customers supplied, historical developments, installed heat supply system, and thermal condition of the supplied building stock.

Historically, the **first mention** of a hot water distribution network dates back to the **14th century** in **Chaudes-Aigues** in **France,** which is the earliest example for a DH system. The first modern DH network in Europe can be traced back to the end of the **19th century** in Hamburg (Germany) in 1893, followed by Budapest (Hungary) in 1899, and the DH network in the Copenhagen area of Fredriksberg (Denmark) in 1903, where the first waste incinerator supplied heat to a DH network. In the beginning of the 20th century, several projects in Europe were developed in Russia, Poland, the UK, the Netherlands, Czechoslovakia, France, Iceland, and Switzerland. However, **a dynamic development of DH systems** started in Europe **only after World War II**. Another **major event** that led to a **rapid growth** and deployment of DH networks throughout Europe, especially in Denmark and Sweden, was the **oil crisis in the 1970's**. At the **end of the 1980's** and the **beginning of 1990's**, the political changes that took place in Eastern Europe and the USSR had **a negative influence** on DH consumption in **most of the countries**. Due to the shift from planned to market-based economy and the privatization of state-own DH networks, the prices of delivered district heat increased significantly, leading to many disconnections that resulted in decreased heat densities and thus higher distribution costs for DH.

In 2018, the **largest DH market** in terms of **trench length** was Denmark with more than 30,000 km trench length, followed by Germany with 28,629 km, Sweden with 24,000 km and Poland with 21,085 km. **In terms of supplied citizens**, Iceland has the highest share with 90% of the citizens supplied and served by DH networks, followed by Denmark with 65%, Ukraine with 58% and Estonia with 51%. Iceland also has the **highest DH length density** (6.16 km/1,000 residents) followed by Denmark (5.3 km/1,000 residents), Finland (2.74 km/1,000 residents) and Sweden with 2.35 km/1.000 residents. The **EU-27 average** in 2018 was **0.38 km/1,000 residents**.

Apart from the lower supply temperatures, the use of renewable energy is a key characteristic of **fourth generation district heating (4GDH)** systems. However, the data on heat supply cannot provide insights of the type of networks that use these renewable energy sources and **their exact classification** whether they belong to *Third* or *Fourth* generation. The most utilized renewable energy sources in Europe are **biomass and renewable municipal waste** which **implies** that the development of **4GDH** is at a **very early stage**.

In addition to economic considerations, a **barrier** for implementing 4GDH networks with higher share of renewable technologies such as heat pumps and solar thermal is the **poor energy performance of the existing building stock** connected to DH. A superficial analysis of the current building stock specific heat consumption on an aggregated residential and non-residential level and its suitability for 4GHD supply shows that in many countries the **weighted average specific heat consumption is above the suitable 4GDH threshold of 50 to 150 kWh/m²*a** depending on the country's climate and the observed average heating degree days for the period between 1990-2020. By focusing on a **targeted stepwise renovation combined with deep renovations where necessary**, the goal of reducing the existing DH supply temperatures could be reached much faster. To do so, an active **collaboration** between **municipalities** and **DH utilities** via e.g., municipal heat planning process, is necessary. Even if existing buildings perform major renovation to reduce energy losses and low-temperature DH is theoretically feasible, **additional adjustments** at the **housing substations** and hydraulic adjustments of the internal heat distribution systems might be necessary.

Structure of the district energy sector and main suppliers

The study provides an overview of the **DHC market structure and main suppliers** in each of the analysed countries, as well as regional aggregated figures. Transparency levels on DHC markets' structure and actors vary significantly across Europe, and Section A.3.1 therefore contributes to **enhancing the DHC market data gap**, notably regarding the size of the cities supplied by DHC, ownership of the DHC networks, DHC market opening to international suppliers and market concentration.

In the majority of the analysed countries, **DH systems are distributed all across the country**, from small cities to metropolis, while **DC systems are mostly located in a few larger cities,** with higher cooling demand. In terms of number of networks, around half of the analysed countries have **DH networks mainly owned and operated by public entities**, the rest being private, public-private (PPP) or, to a much lesser extent, consumer-owned (mainly in Denmark). For DC systems, private ownership is more frequent than public, compared to DH.

Numerous DHC suppliers have been identified and listed for each analysed country. The majority of them are local suppliers specific to each country, but international players are present in most European countries. **The DHC market of more than half of the analysed countries is mainly composed of a few big suppliers** (local or international), i.e., a few suppliers control a clear majority of the market (at least 70%).

Regulatory framework

Section A.3.2 gives an overview of the overall regulatory framework of DHC systems as well as the relevant supervising authorities of all selected countries of this study. The regulation of DHC with respect to ownership, prices, metering, third-party-access as well as consumer grid access varies considerably by country. **Some countries apply very distinct regulations** in dedicated DH laws, while **others rely on laws that regulate general energy and competition issues**. Similarly, the support frameworks also significantly differ and range from **low levels of support to comprehensive funding programs** for infrastructure development and integration of renewables.

In addition to the cross-analysis carried out on the whole geographical perimeter of the study, the annex 1 of this report includes **country factsheets with details on DHC regulation in each country**, such as licence requirements, price regulations, heat metering, grid access for third parties, grid access for consumers, or support programs. Thus, this comprehensive assessment of the existing DHC regulations across Europe provides a sound background to the analysis of the impact and efficiency of regulations tackled in block B.

Customer perception and satisfaction

Section A.3.3 focuses on consumer perception and satisfaction of DHC as well as on consumer protection measures. Consumers' perception and satisfaction is a very important aspect for DHC, as operators often face the challenge that citizens hesitate to connect to a DHC network. While some studies on acceptance issues in the area of heating exist, there is no extensive survey on the perception of DHC on the EU level so far. Therefore an overview, based on a web, document and literature search with a subsequent analysis for each country is provided in this report. Information on the perception and satisfaction of DHC consumers is available for 22 countries, with most literature coming from independent sources, i.e., not from heat suppliers or the respective associations. In Sweden, Denmark, Finland and Norway, the consumers' perception of DHC is overall very good, according to independent sources. Aspects that underline the **positive image** are a **general customer satisfaction** with DHC, the perception of a high **transparency of prices**, **high quality of heat supply without interruptions** and **good customer service**. In contrast, for some countries, like Croatia, Czech Republic, Hungary, Latvia, Lithuania, Romania and Slovakia, several complaints or negative aspects about DHC are recorded. The **most common complaints** are about **high prices**, followed by **billing issues**. Less frequently, **monopoly issues** and **low quality** are mentioned as negative aspects and metering issues are reported only in three countries, i.e., in Czech Republic, Latvia and Lithuania.

In addition, consumer perception and protection in Estonia, Germany and Norway was analysed in more detail. All three countries rely on specific regulations, especially with regard to prices. Thereby, **Estonia relies on strict price regulation**, specifying what cost can be included in the DHC price combined with an ex-ante price control. **Norway uses a more market-oriented approach** with a general **price cap** derived from the electricity price. The **regulation in Germany** is also more market-oriented and **offers the greatest level of freedom** for the DHC supplier. In addition to price regulation, different approaches regarding connection of consumers can be observed in the three countries. While municipalities can decide on **connection obligations in all three countries**, in Norway the mandatory connection does not include a use obligation (i.e., only connection obligation).

At the same time, there are differences in the perception of DHC, even though **in all three countries DHC** seems to have a **rather positive image**. In **Estonia and Norway there are very few customer complaints**, while in **Germany the price regulations are perceived as difficult** to understand. They offer grounds for criticism and questions at billing times, reflected in several consumer complaints per year. In Norway, the price regulation is perceived as transparent and clear, although sometimes minor misunderstandings occur. In summary, it can be concluded that **fair and transparent pricing through appropriate regulation as well as concrete contact points for consumers can make a positive contribution to the perception** of DHC and thus support the further expansion of existing and new DHC networks.

Block B: Overview of the regulatory regimes applied to DHC

Measuring and accounting

In most of the analysed countries, both, metering at the supplier-customer interface as well as individualized metering inside multi-use buildings are regulated. **While many Member States more or less directly apply the requirements of the EED, some Member States go beyond these standards**. In addition, in some countries, it is already mandatory that new meters are remotely readable (e.g., Flanders/Belgium). In other countries DHC utilities must bill their customers more often than just once a year. In Finland for instance, monthly billing (including the provision of monthly consumption data) is quite common.

In most countries **smart meters are not yet widespread in DHC** systems. Ambitious roll outs of smart meters are recorded in some Member States (e.g., Belgium, Denmark, Estonia, Finland, France, Lithuania, Poland). In Lithuania smart meters are mandatory and in Estonia, Lithuania and Flanders, specific regulation of smart meters is in place. In some countries the smart meter roll out is mainly driven by the market (e.g., Denmark, Finland, Poland), allowing DHC companies to improve the overall system performance and make DHC systems more efficient.

In many countries, the statistical office does not (yet) publish **statistics on DHC**[84]. In most cases, only statistics on heat or energy in general are published (at the present time). DHC statistics are mainly based on market data provided by market participants.

Pricing regimes and support schemes

Pricing regimes

The formation of DHC prices differs between countries. The price formation mainly depends on the fundamental principles the sector is regulated upon (profit-orientation vs. non-profit principle) and the specific design of the regulatory framework. **In more than half of the analysed countries, DH prices as well as the mechanism for setting prices is regulated** whereby the depth of regulation is differing substantially. In less than half of the countries DH prices are liberalized. Most of the countries have some form of price control which is carried out ex-ante or ex-post. In some countries price control is mandatory for all DH suppliers while in other countries price control is only on request.

Regarding price regulation, two main concepts can be distinguished:

- **Liberalised DH prices** with ex-post price control on request (e.g., Finland, Germany, Sweden): DH prices are fully liberalized, and prices are defined on the market. To protect customers from excessive prices, competition authorities are entitled to investigate prices in the case of DH suppliers are suspected of misusing their dominant market position by charging disproportionate high prices. Thus, price control is ex-post and on request only when there is a reasonable suspicion of abuse of pricing.

- **Regulated DH prices** with mandatory price control (e.g., Bulgaria, Denmark, Lithuania, Poland, Slovakia, the Netherlands): DH prices are regulated by law. DH

[84] Eurostat just started publishing DHC data: first incomplete data for 2019 are available since September 2021 at https://ec.europa.eu/eurostat/databrowser/view/nrg_dhdc_cpl/default/table?lang=en

prices of all DH suppliers are controlled ex-ante or ex-post by the regulatory authority. Calculating DH prices is based on a regulated methodology.

Member States follow different price model approaches. In countries with liberalised DH prices, prices are formed on the market. In countries with explicit price regulation, a cost-plus method is usually applied.

Targets and support schemes

According to Article 23 of the RED, Member States should annually increase the RES share in the H&C sector by at least 1.1 percentage points (pp) or by 1.3 pp (which becomes 1.5 pp in the amended RED published in July 2021 as part of the Fit for 55 package) if waste heat and cold are considered. This indication becomes a binding baseline in the amended RED. The Article 24 of the RED, on the other hand, asks Member States *inter alia* to ensure the increase of RES and waste heat and cold share in the DHC sector by 1 ppt annually (which becomes 2.1 pp in the amended RED). In this study, we compared these targets to the plans stated by Member States in their integrated national energy and climate plans (NECPs). The results of this comparison indicate that **a considerable number of NECPs are not compliant with the targets of Art. 23 and 24.** In case of Art. 24, this is even true for a majority of member states.

In order to achieve higher RES-DHC, EU-Member States have implemented a diverse set of support schemes. Concerning the support of DHC, the most widely used instruments are financing grants, premium tariffs, low interest loans and tax exemptions. In particular, the **support schemes** include subsidies and financial incentives for (1) DHC grid infrastructure, (2) renewable and efficient DHC generation, (3) research, technology development and demonstration of innovative DHC systems, and (4) connecting end users to DHC networks.

According to the screened support schemes, subsidies and financial incentives targeting DHC grid infrastructure as well as renewable and efficient energy generation are largely available in most EU Member States. On the other hand, subsidies and financial incentives on research and innovation as well as on the connection of end users to DHC networks are less common in the majority of the Member States.

Connection and access to DHC networks

Regulatory framework for third party access and unbundling requirements

DHC systems are natural monopolies. Nevertheless, regulation on **Third Party Access (TPA) is not yet well developed in most of the countries** in the scope of the study. In about half of the analysed countries, TPA is regulated in some form. However, there are significant differences in the regulation depth. In the other half of the countries there is no explicit regulation of TPA.

In the countries with explicit TPA regulation, TPA usually is subject to certain restrictions such as being limited to renewable or waste heat (e.g., Czech Republic, Slovakia). In Estonia, the grid operator must conduct a bidding process if additional generation capacity is needed and more than one producer applies. Where TPA regulation is in place, **third-party access can usually be denied whenever technical or economic reasons prevent it**. These include, for example, the technical parameters of the heat fed into the grid or possible capacity bottlenecks in the grid. Economic restrictions usually relate to the costs of generation. In Lithuania, for example, grid operators must buy heat from third party producers (auctioning). However, this only applies if the heat fed into the grid is cheaper than or offered at the same price level as the offers from competing producers including the grid operator's own production.

The requirement that third-party heat must not result in higher prices is a significant barrier to the installation of new (renewable) generation intended to be connected to replace existing generation. If the grid operator's generation fleet is already depreciated to a large extent, the full costs of the new generation plant (CAPEX+OPEX) are compared with the variable costs of the existing generation plants (OPEX). This cost comparison is usually in favour of existing generation that is often based on fossil fuels.

TPA is often also permitted in countries that do not explicitly regulate it (voluntary TPA). In most countries where TPA is possible in principle (regardless of whether it is regulated or not), third party access is limited to the producer side (producer TPA, single-buyer approach).

DH systems in which TPA is practiced successfully tend to encompass large supply areas involving several thousand customers (e.g., Copenhagen, Stockholm, Vilnius). However, as can be seen from the examples of Copenhagen and Stockholm, this does not depend on national regulatory frameworks but mainly on private/municipal initiatives.

Only three countries seem to apply certain unbundling requirements, namely Latvia, Lithuania, and Romania. **Most Member States**, on the other hand, **consider DH to be an integrated service** in which generation, grid operation and distribution are operated in an integrated manner by one company. Thus, unbundling is not considered necessary. Studies from Finland, Sweden, Germany, or UK imply that **unbundling DH might lead to higher heating prices.**

Incentivisation of renewables and excess heat

The analysis from this study does not show any obvious correlation between the share of renewables or excess/waste heat and the degree of market opening of DH systems. Member States with considerably high shares of renewables or excess/waste heat in their DH sector do not automatically open their DH systems to third parties, nor do they have particularly sophisticated TPA regulation. **Incentives associated with opening the heating networks to third parties seem at least not to be sufficient to significantly increase the connection rate of renewable heat generation or excess/waste heat.** TPA may be a necessary condition, but in any case, it is not a sufficient one.

One possible reason is the fact that existing TPA regulation is often restricted in a sense that the production costs of third-party generation need to be competitive to generation that is already connected to the grid. In addition, TPA only seems to play a major role in large urban grids with several 100,000 connected consumers. However, it is not possible to deduce from previous experience at what minimum size grid opening makes sense. This depends, among other things, on the existing generation fleet and the existing grid typology.

Contractual modalities for third party access

As previously exposed, DHC grid access undergoes different regulation schemes in different countries and can be voluntary or mandatory. However, in any case, technical and financial efficiency of the DHC network shall be sought and strict conditions shall be guaranteed:

- Competitive price for the whole system and end-customers

- Connection conditions – both technical and commercial
- Security of supply

Therefore, regardless of the local context, **the agreement between the DHC operator and the third-party heat supplier shall clearly define the role and responsibilities of each party and allow the contractual parties to balance their respective financial risk exposure**, which can be significant for both. This contractual agreement must be negotiated and carefully framed by a contract addressing:

- **Operational issues**, including contract duration (according to the project set-up on both the DHC operator and the heat supplier sides), suspensive conditions (to mitigate the remaining risks at the time of the contract signature), technical performances at the delivery point (minimum capacity available, temperature levels, operating hours…), possible back-up solutions (in case of heat shortage or maintenance e.g.), metering (monitored data, ownership of the devices, maintenance…), and communication between the two parties (off-taking forecast, reporting of incidents, planning for maintenance…).

- **Financial issues**, including tariff structuration (period-dependant and/or quantity-dependant rates), take-or-pay conditions to cover the fixed costs (definition on an hourly to yearly basis, priority clauses…), penalties (e.g. in case of heat shortage, and integrating the indirect costs associated to it like degraded CO2 quotas or loss of tax incentives), price update (revision indexes, share of the fixed part…), invoicing and revision clause.

- Other issues, such as the scope of services definition (construction, operation and maintenance of the different components of the installation), insurances and responsibility, and termination of the contract.

Additional discussions are provided in section C.1.3 on the **technical requirements to allow the connection to a DHC grid for a third-party heat supplier.** In particular, this section tackles the issue of the adaptation of the network and the design of the substation. It also provides a few economic inputs to help make a first rough estimate of the costs of a TPA project.

Therefore, the various operational topics discussed in this section illustrate the complexity of such contractual agreement between the DHC operator and the heat supplier, and expose the different **conditions that need to be gathered in order to successfully establish TPA.**

Overview of national building regulations, urban planning and other urban regulations affecting the use of district heating and cooling in buildings

Impact of building regulations on DHC systems

The building codes and in particular the **nZEB requirements** have a multiple potential – more or less direct – impact on DHC systems. First, the mutual impacts of DHC and maximum PEC in fulfilling nZEB requirements, second, the mutual impacts of DHC and minimum share of RES in nZEB requirements and third, the correlations between temperature level demand of nZEB and temperature level supply by DHC.

These impacts are triggered by the following factors: (1) **primary energy requirements**, (2) a **minimum share of RES** in nZEBs and (3) the **primary energy factors of DHC systems** to be applied for the calculation of primary energy demand. The rigorous analysis of these factors on Member States level revealed the significant variety of values for these factors. And even more, the **applied methods** also **strongly vary**, e.g., for calculating the primary energy demand or for how to define the renewable energy requirement. Regarding primary energy factors for DHC, to be applied within building codes, we follow the systematic approach developed by Latosov et al. [75] who classified the PEF into the following three categories:

1) Single fixed: PEF is described as a default value that is valid for all DHC networks in the country.

2) Differentiated: The values for PEF are explicitly assigned for each technology according to the energy production technologies and energy carriers used in the DHC system.

3) Independent calculation: The PEF for DHC is calculated independently for each DHC network by using an official, predetermined calculation method.

In our study, we allocated these systems to the different Member States and provided a comparative overview of the values used by the MS in this context.

Impact of urban planning regulations on DHC systems

Urban planning also includes the planning of energy infrastructures usually in line with regional and national spatial planning. **The potentials for decarbonising the H&C sector highly depend on spatial planning issues for optimal interlinking of demand and supply**. Spatial H&C planning considers political framework conditions and feeds into the political discussion. Hereby, policies can be developed to implement conditions that allow energy savings and the development of renewable H&C technologies.

However, it turns out that **explicit national urban policy is taking place in 10 EU Member States only**. In a number of other countries, national policies guide urban development. However, these policies are not brought together in form of NUP.

Successful H&C planning requires close collaboration between local authorities and central governments. The Danish heating supply law for example lays down that city councils, in cooperation with utility companies and other stakeholders, have the responsibility for heat planning in municipal areas. City councils can therefore impose buildings to connect to the public heat supply, which results in strengthening DHC. However, these steps can be taken on a local level because respective national regulations from the government exist (namely Heat Supply Act No. 347 of 2005).

While local authorities can also solely implement a successful heating and cooling planning, e.g. Oradea in Romania, EU and national regulation have also motivated certain municipalities to make a self-commitment for taking climate protection related steps. Our thorough investigation of 13 city case studies[85] with regard to H&C planning and DHC development showed that the approach for developing an efficient DHC system differs significantly from one city to another depending on the context such as climate targets, supply mix of DHC systems, ownership, urban planning and urban regulations. Overall, we conclude that **urban H&C planning requires national commitment via regulations in order to be implemented across a country**.

[85] City case studies are: Vilnius (Lithuania), Tallinn (Estonia), Plovdiv (Bulgaria), Frankfurt (German), Warsaw (Poland), Copenhagen (Denmark), Stockholm (Sweden), Helsinki (Finland), Ljubljana (Slovenia), Graz (Austria), Miskolc (Hungry), Oradea (Romania) and Bolzano (Italy).

Block C: Overview of available technologies enabling the use of renewable and waste energy sources in DHC

Technical and operational requirements

Block C provides technical information and operational feedback on the integration of renewable energy and waste heat/cold sources in DHC. This section of the report thus analyses **the technical conditions required to ensure an optimized and efficient integration of these energies, and how this integration affects the operational characteristics of the DHC system and its connected end-users**. More particularly, the section addresses:

- **6 sources or carriers of renewable energies:** biomass, geothermal, biogas, solar thermal, ambient energy, and renewable electricity

- **Waste energy from 5 different origins:** power generation, industrial production, tertiary buildings, data centres, underground railway

- **The technical conditions for heat suppliers to connect to a DHC**

For each renewable energy and waste energy sources, a **complete overview** of the associated technology has been provided and includes discussions on the type of fuels, the facility overview, the design of the installed capacity, the operating temperatures, the yields, the integration in DHC systems, and the possible synergies with thermal storage, cooling or CHP e.g. In addition, **operational constraints and requirements** (like fuel supply, emission limit values, maintenance and downtime) are discussed, and a **feedback** on the technology is provided as a conclusion for each source. This analysis, which is based on a literature review and benchmarks, is also supported by 10 case studies across Europe (discussed below) in order to provide a true operational feedback on the different topics.

For the particular case of waste heat and cold sources, the status of these energy sources in national policies and how they are accounted for in DHC systems are discussed. If in the majority of European countries there is no legal nor regulatory framework regarding waste energy sources and no direct incentives, some countries have set a dedicated incentives framework. These incentives might be orientated toward the waste energy supply (heat exchanger, adaptation of the processes…) and/or to the development of the DHC network fuelled by this waste energy.

In a nutshell, this comprehensive assessment of the technologies associated to renewable and waste energy sources presents **their respective opportunities and limits**, but also demonstrates **their complementary and their integrability in DHC systems** (according to the different technical characteristics of these systems). It thus underlines **the key role of DHC systems as the backbone for the integration of the various local sources of renewable and waste energies, using mature technology** largely available on the market.

Case studies illustrating sustainable DHC systems

The 10 case studies analysed provide a wide picture of **EU best practices in sustainable DHC**, addressing the historical developments of those networks, key actors, technologies and energy sources in place and foreseen, governance, business models and tariff strategies, to ultimately identify **replicable key success factors** (KSF) for the integration of RES and waste heat and cold sources through DHC. These case studies and KSF can inspire and guide **policy makers, municipalities, DHC operators, urban planners and even citizens willing to foster H&C decarbonisation.**

Indeed, most of the analysed DHC networks combine the use of renewable and waste heat/cold sources, illustrating through concrete, operational examples the complementarity of these and the **powerful leverage of DHC to use local energy sources that otherwise would remain untapped,** while **creating local value** such as energy savings for consumers, CO_2 savings, local jobs and revenues for the municipality.

Eight pillars for a successful decarbonisation through efficient DHC systems have been identified across those case studies (KSF).

- The (i) **support of the municipality**, a (ii) **suitable and robust business model**, (iii) strategic (long-term) **technical choices for DHC supply** and the (iv) implementation of **collaborative and innovative approaches** appear as critical success factors for any sustainable DHC project, and are mainly addressed at local and regional levels. The operational aspects need to be tailor-made for each specific context, needing an **in-depth and holistic planning phase** integrating strategic, technical, economic, financial, legal and organisational aspects of the implementation phase.

- The rest of the identified KSF proved to have a strong influence in several case studies. In particular, (v) supportive **national policies and regulatory frameworks** can play a key role in decarbonising H&C markets, as proved by some of the EU best-performers in H&C decarbonisation (Sweden, Latvia, Denmark), but are still not enough developed in many European countries. The (vi) **DHC-building nexus** is a key technical enabler for decarbonisation through DHC. Mainstreaming **low-temperature heat emitters** and **comprehensive heat planning** results in high systemic efficiencies and should get higher attention in energy transition and renovation wave strategies. Finally, different (vii) **governance models for the DHC operators** (public, private, PPP) have proved effective and efficient across the case studies and, where existing, (viii) **consumer empowerment** measures also led to higher energy efficiency at building and system levels.

Recommendations for decarbonisation through DHC networks

Based on the different analyses performed in this report and on the various case studies carried out in Blocks B and C, the following policy instruments appear as effective **levers to decarbonise Europe's H&C demand through sustainable DHC networks**:

- Integrating quantified sustainable DHC targets in national strategies for H&C decarbonisation;

- Ensuring steady and sufficiently high indirect support schemes, such as CO_2 taxes for fossil fuels, taxes on non-recovered waste heat or reduced VAT for efficient systems e.g.;

- Providing (direct) financial support for decarbonisation measures using DHC, including use of RES, excess/waste heat, low-temperature grids transformation (district network and buildings);

- Implementing strategic long-term local/urban heat planning, including measures such as obliging, encouraging and/or supporting municipalities to screen which areas could be used for centralized RES-H generation, the potential of local renewable and waste energy production (and seasonal heat and cold storage), or the possible synergies for sector integration (heating, cooling and electricity) e.g.;

- Obliging DHC companies to develop long-term transformation plans describing measures and milestones on how the system will be decarbonised over the years;

- Introducing RES/excess/waste heat quota/obligations for DHC companies;

- Incentivising/facilitating use of excess/waste heat by e.g., obliging companies to provide data on their excess/waste heat flows, to develop excess/waste heat utilization concepts, establishing risk hedging structures, introducing excess/waste heat levies;

- Strengthening citizen/customer participation in DHC systems (e.g. through ownership structures, financial participation) and energy communities;

- Improving transparency by e.g., strengthening the information obligations for DHC companies.

List of figures

List of tables

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