Upgrading the performance of district heating networks

Technical and non-technical approaches

A Handbook

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The Upgrade DH project

The overall objective of the Upgrade DH project is to improve the performance of district heating (DH) networks in Europe by supporting selected demonstration cases for upgrading, which can be replicated in Europe.

The Upgrade DH project supports the upgrading and retrofitting process of DH systems in different climate regions of Europe, covering various countries: Bosnia-Herzegovina, Croatia, Denmark, Germany, Italy, Lithuania, Poland, and The Netherlands. In each of the target countries (Figure 1), the upgrading process will be initiated at concrete DH systems of the so-called Upgrade DH demonstration cases (demo cases). The gained knowledge and experiences will be further replicated to other European countries and DH systems (replication cases) in order to leverage the impact.

Core activities of the Upgrade DH project include the collection of the best upgrading measures and tools, the support of the upgrading process for selected DH networks, the organisation of capacity building measures about DH upgrading, financing and business models, as well as the development of national and regional action plans.

In addition, an image raising campaign for modern DH networks will be carried out in the Upgrade DH project. The outcome will be the initiation of DH upgrading process in the above-mentioned target countries and beyond.

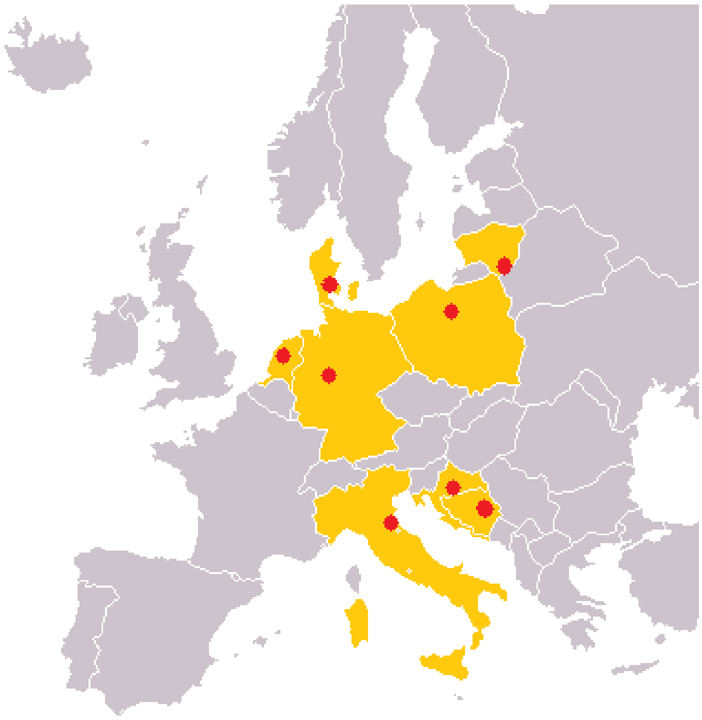

Figure 1: Upgrade DH target countries and demo cases

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Content

1 Introduction

The history of district heating (DH) begun somewhere during the ancient Roman Empire, when baths, houses and greenhouses were supplied with hot water. Simple DH systems were further developed during the middle ages until today. Naturally, today's systems are technologically completely different than the initial ones, however, the principle of transferring heat, usually by water (circuit water), from a heat source to heat sinks is the same. Especially in the last century, the idea of DH was to avoid wasting the heat from central power plants, Waste-to-Energy plants, or industries, and hence, to use it for consumer demands (Figure 2).

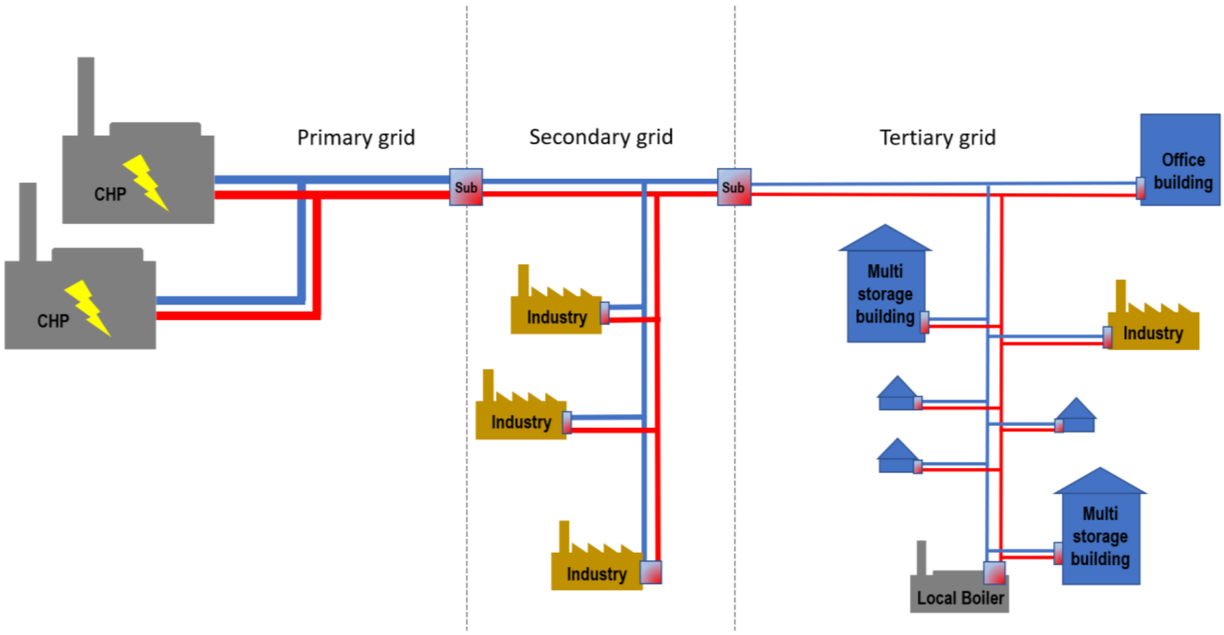

Figure 2: Example of a DH network with a primary, secondary and tertiary grid which is separated by substations (Sub.) and which supplies heat to different types of consumers (Source: D. Rutz)

The overall concept of DH today, is the supply of heat from one or several central heat sources via a network of pipes carrying hot water, and in some cases steam, to heat consumers. According to the EU Strategy on Heating and Cooling (EC, 2016), the contribution of DH in the EU accounts for 9% and is mainly driven by fossil fuels such as gas (40%) and coal (29%).

DH networks present a high potential for the transition of the heat sector, both technically and organizationally. They allow the integration of renewable energies, to improve the overall energy efficiency, as well as to facilitate sector coupling (coupling between heating, electricity and mobility). The goal is to retrofit DH systems, so that they are efficient and that they have zero (or close to zero) emissions and thus, that they contribute to mitigate climate change. Neither globally, nor in Europe, many DH system operators have yet exploited the real opportunities for lower CO_2 emissions, which were achieved by the forerunner countries Iceland, Sweden, or Norway (Werner, 2017). In 2016, modest improvements have been achieved by renewable energy sources integration in the DH sector worldwide, where modern renewable energy supplies approximately 9% of total global demand. Most of the renewable heat is supplied by biomass, with smaller contributions from solar thermal and geothermal energy (REN21, 2018).

In order to use this potential, many of the rather old and poorly maintained DH systems in Europe must be technically retrofitted or upgraded. This includes improvements for **heat use** (efficient integration of sub-stations, predictions of future insulation status of houses, etc.), **heat**

distribution (optimized piping, reduction of leakages, temperature levels, etc.), and **heat generation** (optimized mixture of heat sources, storage, etc.). In addition, also non-technical aspects need to be improved in many existing DH systems.

The overall upgrading process to improve the efficiency of DH systems is complex and sophisticated. It is time-consuming, long-lasting and implies high investments. Especially measures in connected buildings must be considered, for example when lowering the operation temperatures. It implies a direct cooperation with building owners and end consumers. Such a long and global process also has an impact on the city's or district's life that should not be underrated. That is why it should be very carefully planned in the long-term.

In order to assist in this process, **the current handbook** was elaborated to inform any stakeholders, such as decision makers, politicians, utilities, operators, end consumers, or potential developers of DH systems, about upgrading opportunities. Thereby, the ambition of the handbook is not to provide a detailed technical guideline for technicians, but rather to give an overview on retrofitting options. Furthermore, the handbook is translated in 6 languages (Bosnian, Croatian, Danish, Italian, Lithuanian, and Polish), as in many countries there is a lack of such information in national language.

2 District heating in Europe

According to the European Commission, heating and cooling in our buildings and industry accounts for about half of the EU's energy consumption (EC, 2018a). 84% of heating and cooling is still generated from fossil fuels while only 16% is generated from renewable energy. In order to fulfil the EU's climate and energy goals, the heating and cooling sector must sharply reduce its energy consumption and cut its use of fossil fuels (EC, 2018a).

Furthermore, heating and hot water alone account for 79% of total final energy use (192.5 Mtoe) in **EU households** (EC, 2018a). In 2016, the residential sector represented 25.4% of final energy consumption or 17.4% of gross inland energy consumption in the EU (EC, 2018b). Households use energy for various purposes: space and water heating, space cooling, cooking, lighting and electrical appliances, as well as other end-uses. An overview on the energy consumption shares in EU households is shown in Figure 3. **In industry**, 70.6% of energy consumption (193.6 Mtoe) was used for space and industrial process heating (EC, 2018a).

District heating in Europe serves currently approximately 60 million EU citizens, with an additional 140 million living in cities with at least one DH system (Euroheat & Power, 2018a). According to the Heat Roadmap Europe data, if the urbanisation trend continues and appropriate investments are in place, almost half of Europe's heat demand could be met by DH by 2050 (Euroheat & Power, 2018a). Results of the Heat Roadmap Europe project[1] indicates that DH can quadruple its share across Europe, from 13% today to almost 50% in the future. Table 1 shows the top 5 countries in DH applications based on a global survey.

DH networks present a high potential for the transition of the heat sector, both technically and organizationally. They allow integration of renewable energies, improve the overall energy efficiency, as well as facilitate sector coupling (coupling between heating, electricity and mobility). However, many DH systems in Europe still have a potential to improve the efficiency and to reduce the use of fossil fuels. Some systems often have poor maintenance, high customer heat costs and limited ability for user control undermining the image of DH.

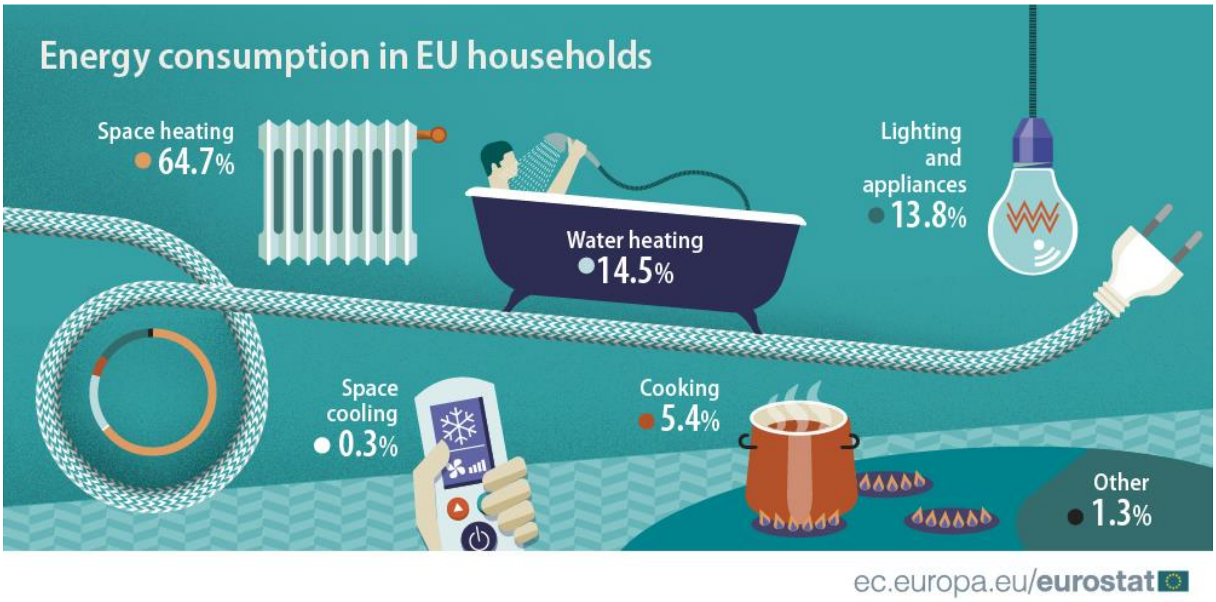

Figure 3: Energy consumption shares in EU households (Source: EC, 2019c)

[1] http://www.heatroadmap.eu/EU-Heating-and-Cooling-Strategy.php

Table 1: Top 5 countries in DH applications based on the 2013 summary table published by Euroheat & Power in March 2015 (Euroheat & Power, 2018b)

Top five DH countries	1	2	3	4	5	No data
Highest percentage of citizens served by DH	Iceland (92%)	Latvia (65%)	Denmark (63%)	Estonia (62%)	Lithuania (57%)	China and Japan
Largest total DH capacity installed in 2013 (in GWth)	China (463)	Poland (56.5)	Germany (49.7)	South Korea (30)	Finland / Czech Republic (23)	Denmark and Sweden
Highest increase in pipe length of DH systems between 2009 and 2013	Italy (58%)	Norway (53%)	Switzerland (52%)	China (43%)	Sweden / Austria (21%)	Iceland, Romania, South Korea, Slovakia
Greatest overall heating sales in 2013 (in million terajoule)	China (3.2)	Germany (0.26)	Poland (0.25)	Sweden (0.18)	South Korea (0.17)	Romania
Largest share of renewable energies (excl. CHP plants)	Iceland (76%)	Norway (61%)	Denmark (46%)	France (39%)	Switzerland (31%)	Bulgaria, China, Croatia, Italy, Japan and South Korea

2.1 Classification of district heating systems

"**District heating**" (DH) can be defined and classified in different ways. According to Eurostat (EC, 2018c), DH or city heating is the "distribution of heat through a network to one or several buildings using hot water or steam produced centrally, often from co-generation plants, from waste heat from industry, or from dedicated heating systems". However, in a broader definition, also other transport media than water or steam could potentially transfer the heat. Even broader, a "**district energy system**" may include, in addition to the distribution of hot transport media, the distribution of cold transport media for cooling. Therefore, often the term "**district heating and cooling**" (DHC) is used.

In the European energy statistics, Eurostat has included the term „**Derived heat**", which should not be mixed up with DH (Eurostat, 2019). Derived heat covers the total heat production in heating plants and in combined heat and power plants. It includes the heat used by the auxiliaries of the installation which use hot fluid (space heating, liquid fuel heating, etc.) and losses in the installation/network heat exchanges. For auto-producing entities (= entities generating electricity and/or heat wholly or partially for their own use as an activity which supports their primary activity), the heat used by the undertaking for its own processes is not included.

DHC systems are always very site specific and vary from one location to another, considering its size, climate, heat sources, technologies, history, and others. In order to characterize DHC systems, they can be classified into categories of common aspects.

2.1.1 Classification by the size of DH systems

A DH system can vary in size. It can supply large areas, as for instance the Greater Copenhagen DH system, but also only small areas or villages consisting of only few houses (Rutz et al. 2017). The size of the system can be characterized by the following parameters:

- Length of the piping system (trench length) [m, km]
- Number of substations
- Number of connected consumers
- Amount of investment costs [M€]
- Complexity (e.g. number of heat generators, connection points, grid levels)
- Distributed energy (sold heat) [MWh, GWh, TWh]
- Installed heat generation capacity [MW, GW]
- Spatial coverage of the district [km²]

Thereby, these parameters often correlate to each other, e.g. if the number of connected consumers is high, also the distributed energy is high and thus, the overall investment costs are high. However, sometimes the parameters are not correlated, e.g. in the case of having only very few consumers connected, but which have a very high energy demand (e.g. industries). Anyhow, this classification has no strict definitions and thresholds and is mainly used to broadly describe DH systems.

Often, the terms microgrids, small DH systems, and large DH systems are used, although the distinction is fluent. **Large DH systems** generally have a longer tradition as they historically were often connected to central combined heat and power plants. Today, large DH systems increasingly integrate also large-scale renewable energies, such as for example geothermal energy or bioenergy. Rutz et al. (2017) define small and micro DH grids as shown below, whereas large DH systems are just larger than these two categories.

Small district heating grids are local concepts to supply households as well as small and medium industries with heat, which is often renewable. In some cases, they may be combined with large-scale DH grids, but the general concept is to have an individual piping grid which connects a relatively small number of consumers. Often, these concepts are implemented for villages or towns. They can be fed by different heat sources, including solar collectors, biomass systems, heat pumps, and surplus heat sources (e.g. heat from industrial processes or a biogas plant that is not yet used). Fossil fuel boilers could be installed for peak loads and as a backup in order to increase the economic feasibility of the overall system. Small grids do normally have commercial operators and are larger than micro grids.

Micro heating grids are usually installed for fewer customers, e.g. 2 to 10. An advantage of micro grids is that these systems could be build easier and faster, because of the small number of customers, without long public procedures. The customers agree on a suitable accounting for the used heat and on who is the operator of the system.

Independent of the grid size, it is important not to oversize the grid during planning. Large dimensions cause higher heat losses and higher investment costs.

2.1.2 Classification by historical developments in geographical regions

Since DH was introduced in different European regions under different framework conditions and with different objectives, DH systems can be categorized based on their location.

Northern and Central Europe

DH systems in northern and central Europe show technical similarities. They are usually operated at 120-80 / 50-40°C. Steam systems are still found in some cities, but they are being converted to heated water. There is an ongoing effort to reduce temperatures and newer areas are now planned for low temperature regimes such as 70/40 or 60/30°C. Systems are operated with variable temperatures as well as with variable flows. Pipes are in general pre-insulated pipes and often polyethylene pipes for smaller dimensions. Renewable energy from biomass, heat pumps and thermal solar collectors are being increasingly integrated.

For the development of the DH sector in Europe, especially Denmark has a significant role, as it is one of the most advanced countries in the field of DH. DH is one of the most common ways in Denmark for heating buildings and supplying domestic hot tap water. In Copenhagen more than 98% of the floor area is heated by DH. DH was seen as a way to address the issue of high dependency on imported oil and to establish a reliable supply. To ensure that the huge investments in co-generation plants, transmission systems and distribution pipe networks become cost effective also in the national economy, extensive work for heat planning was made. Denmark was divided into small zones to define the most suitable heating solution: DH, natural gas or individual (oil) fired boilers. This national heat planning prevented competition and double investments in piping for natural gas and DH in the same geographical area. Most households connected to the public DH systems as there was an economic incentive to connect. The economic incentive is created via the tax legislation.

After 2000, the focus in the DH sector shifted again. Much interest has been given to energy efficiency and how to reduce losses from the pipe networks and on how to improve operation of end-user installations. Heat generation based on biomass, heat generation from solar plants, introduction of heat storage tanks, utilization of heat pumps, or geothermal energy are technologies found in various DH systems throughout the country. The huge restructuring of the energy sector combined with a focus on environmental impacts, energy savings, and economic impacts boosted the industry.

Eastern Europe

In Eastern Europe, DH is also a very wide spread and well-known technology. Compared to the DH systems seen in Western Europe, the systems in Eastern Europe / former USSR have been developed under quite different circumstances. Many systems have been constructed under a centrally planned economy system, and billing for heat (at the end user level) is one of the big challenges for the systems still today. In many Eastern countries, heavy industry using steam (and high temperature hot water) has closed down or has been restructured to other types of industry and accordingly significant parts of the income for the DH systems (and heat producers) have vanished.

DH in Eastern Europe was often operated with steam and superheated water. Pipes were often poorly insulated steel pipes which were stepwise replaced by pre-insulated pipes. The control of system parameters was often inflexible, for example the flow was fixed. Control of the load (heat supplied to the connected consumers) took place by adjusting the central supply temperature. This type of load control is simple, but has several disadvantages, e.g. that adjustment of the heat supply to the individual consumer is difficult. The consequence is that the system is operated with hydraulic imbalance leading to the situation where some dwellings are heated adequately, and other buildings suffer from low room temperatures. Original designs may have been for 150/70°C, but today, the systems are operated at much lower temperatures. The systems often struggled with thermal imbalances, fouling of heat exchangers and water leakages. The introduction of modern technologies and modern concepts is a big challenge today, as many systems suffer from lack of financial means and inadequate cost recovery.

Newcomer countries

In several European countries, the implementation of DH is relatively young. A challenge in these countries is that the houses are sometimes not equipped with water based central heating systems which is required for heat supply with DH. The introduction of DH is not just a conversion of the heat source, but also requires a significant investment to be carried by the home owners.

Another challenge may be to overcome the negative public perception of DH in some countries, where it is often considered as a centralized and socialistic technology. The willingness to rely on a public utility for heating may be quite different from how the systems are perceived in the Nordic countries and in the southern parts of Europe.

However, this image is being stepwise improved as today's systems can be highly efficient, cost effective, and based on large shares of renewable energies (e.g. solar thermal or biomass). A new approach for some of these systems is to facilitate sector coupling (heat, power, transport). Many of the newer renewable energy-based DH systems are small-scale systems.

2.1.3 Classification by technology generations of DH

Depending on the time of setting up DH systems and the used technologies, 4 different generations of DH systems can be distinguished, as described by Lund et al. (2014) as follows:

First Generation

The 1st generation is a steam-based system fuelled by coal. It was first introduced in the US in the 1880s and became popular in some European countries, too. It was state of the art until the 1930s and used concrete ducts, operated with very high temperatures. Therefore, these systems were not very efficient. There were also problems with reliability and safety due to the hot pressurised steam tubes. Nowadays, this generation is technologically outdated. However, some of these systems are still in use, for example in New York or Paris. Other systems originally built as 1st generation have subsequently been converted to later generations. (Lund et al., 2014)

Second Generation

The 2nd generation was developed in the 1930s and was built until the 1970s. This generation is characterized by burning coal and oil. The heat is transmitted through pressurised hot water as heat carrier. The systems usually have supply temperatures above 100°C, use water pipes in concrete ducts, mostly assembled on site, and heavy equipment. A main reason for installing these systems were the primary energy savings, which arose from using combined heat and power plants. While also used in other countries, typical systems of this generation were the Soviet-style DH systems that were built after WW2 in several countries in Eastern Europe. (Lund et al., 2014)

Third Generation

In the 1970s the 3rd generation was developed and was subsequently used in most of the following systems all over the world. This generation is also called the "Scandinavian DH technology", because a lot of the DH component manufacturers are based in Scandinavia. The 3rd generation uses prefabricated, pre-insulated pipes, which are directly buried into the ground and which operate with lower temperatures, usually below 100°C. A primary motivation for building these systems was the security of supply by improving the energy efficiency after the two oil crises which led to a disruption of the oil supply. Therefore, those systems usually used coal, biomass and waste as energy sources, while oil was mostly neglected. In some systems, also geothermal energy and solar energy are used in the energy mix (Lund et al., 2014). For example, Paris has been using geothermal heating from a 55-70°C source 1–2 km below the surface since the 1970s for domestic heating.

Fourth Generation

Currently, the 4th generation is being developed (Lund et al., 2014) as for example in Denmark (Yang et al., 2016). The 4th generation is designed to combat climate change and integrate high shares of variable renewable energy into the DH system by providing high flexibility to the electricity system.

According to the review by Lund et al. (2014) those systems must have the following abilities:

- Ability to supply low-temperature DH for space heating and domestic hot water (DHW) to existing buildings, energy-renovated existing buildings and new low-energy buildings.
- Ability to distribute heat in networks with low grid losses.

- Ability to recycle heat from low-temperature sources and integrate renewable heat sources such as solar and geothermal heat.
- Ability to be an integrated part of smart energy systems (i.e. integrated smart electricity, gas, fluid and thermal grids) including being an integrated part of 4th generation DH systems.
- Ability to ensure suitable planning, cost and motivation structures in relation to the operation as well as to strategic investments related to the transformation into future sustainable energy systems.

Compared to the previous generations, the temperature levels of 4th generation DH systems are reduced to supply temperatures of 70°C and lower in order to increase the energy efficiency of the system. Potential heat sources are waste heat from industry, CHP plants burning waste, biomass power plants, geothermal and solar thermal energy systems (central solar heating), large scale heat pumps, waste heat from cooling purposes (e.g. from the acclimatization of data centres) and other energy sources. With those energy sources and large-scale thermal energy storages, including seasonal thermal energy storages, 4th generation DH systems are expected to provide flexibility for balancing wind and solar power generation. For example, heat pumps can be used to use surplus power for heat generation when there is a surplus of wind energy (Lund et al., 2014). Therefore, large scale heat pumps are regarded as a key technology for smart energy systems with high shares of renewable energy up to 100% and advanced 4th generation DH systems (Lund et al., 2014). A challenge of low temperature DH systems is to ensure a minimum temperature for hot tap water in order to avoid legionella contaminations that can resist temperatures above 50°C for a few hours (see Figure 4).

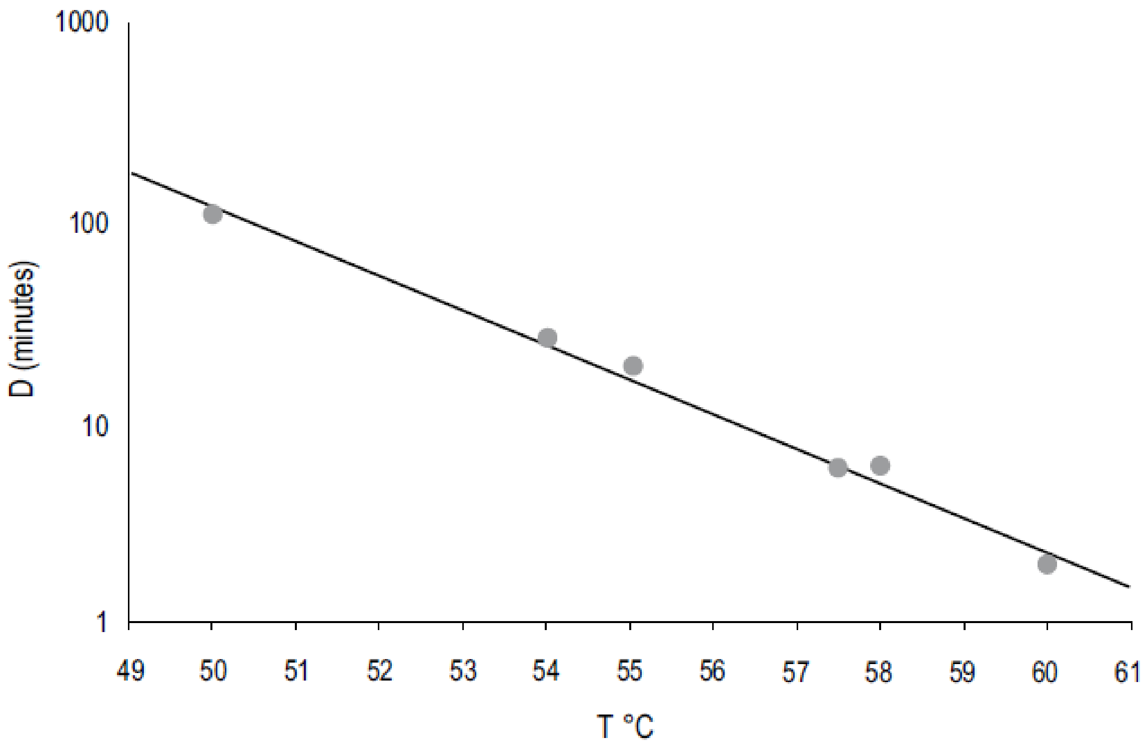

Figure 4: Decimal reduction times for Legionella pneumophila serogroup 1 at different temperatures (World Health Organization, 2007)

Depending on the size of the hot water tank and on national requirements, it may be necessary to heat the hot tap water permanently or at least temporarily to a temperature level of 60°C. Usually, this requires a slightly higher supply temperature at the heat source. However, there exist possible technical solutions to ensure 60°C for hot water supply, even if the flow temperature of the DH grid is lower than that.

2.1.4 Classification by technical issues

DH systems can be classified by considering various technical issues. In this chapter, some of the most frequent divisions are described.

Classification by heat generation

DH systems can be classified according to the location of the heat production into centralised and decentralised systems. Historically, most DH systems were operated with one or only a few **centralised** heat generators. Usually, the heat from cogeneration facilities which usually ran on coal, gas or oil, was supplied to the DH system. These systems often used only smaller heat storages in order to balance the operation of the system and to maximise the electricity generation.

However, nowadays there is a growing number of **decentralised** DH systems using heat from various decentralized generation facilities. A number of such systems are located in Denmark. An example is shown in Figure 5 for the DH system of Gram. It uses multiple technologies like solar thermal collectors, natural gas cogeneration, excess heat from industry, a heat pump, an electric boiler, a buffer tank and a seasonal storage.

Even though DH in Europe is still dominated by fossil fuels, the future trend is towards using renewable energy sources, i.e. geothermal, solar thermal, biomass, power-to-heat, and excess heat from various sources like from industries and from the service sector.

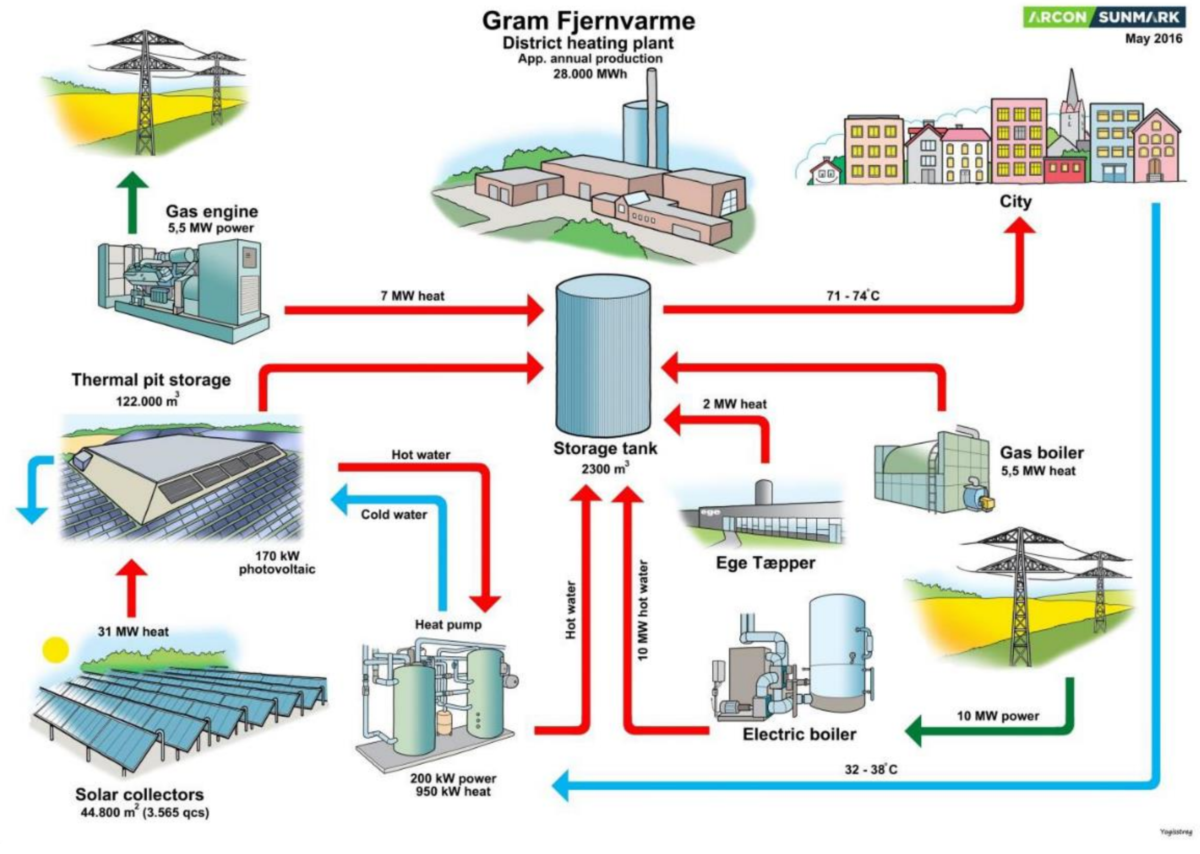

Figure 5 The decentralised DH system of Gram in Denmark with multiple heat sources (Source: http://www.gram-fjernvarme.dk)

Classification by heat distribution

DH systems distribute the heat through piping grids in which the heat transfer medium is transferred from the generation facilities to the final users. Steam and water can be used as the heat transfer medium, depending on the type of consumers, system age, etc. Different temperature levels are often associated to different generations of DH systems, as mentioned earlier.

For instance, **steam** was mostly used in the 1st generation of DH. However, some systems still use steam today, especially when industries are among the consumers. Steam is a rather inefficient carrier since its temperature levels are very high. In 1st generation systems, there was often not even a return pipe for the condensate, making it an open circuit with condensate being drained in the sewers.

In most of the systems today, steam is phased out and replaced by **hot water** with different temperature levels. As DH grids need some pressure for the transport of the circuit water, DH grids are always pressurised systems. This means that the temperature of DH systems can be above 100°C with a still liquid phase of the circuit water, as the boiling point of water under pressurized conditions is above 100°C. Today, many DH systems are still operated with circuit water temperatures at 100°C or above. Although these systems can be very efficient, the risk of higher heat losses, and thus efficiency losses increase with high temperatures. This applies especially for systems which are using badly insulated pipes.

Many DH systems operate with temperatures significantly below 100°C. If they are combined with pre-insulated pipes for higher efficiency, this could result in multiple benefits, including reducing losses in the distribution network below 10% and being able to use low temperature renewable energy and excess heat sources combined with thermal storages. Due to these benefits, a general trend today is towards **low temperature district heating** with supply temperatures below 50°C and “booster units” at the consumer side. The applicability of these systems depends on the connected buildings and heating infrastructure of the buildings.

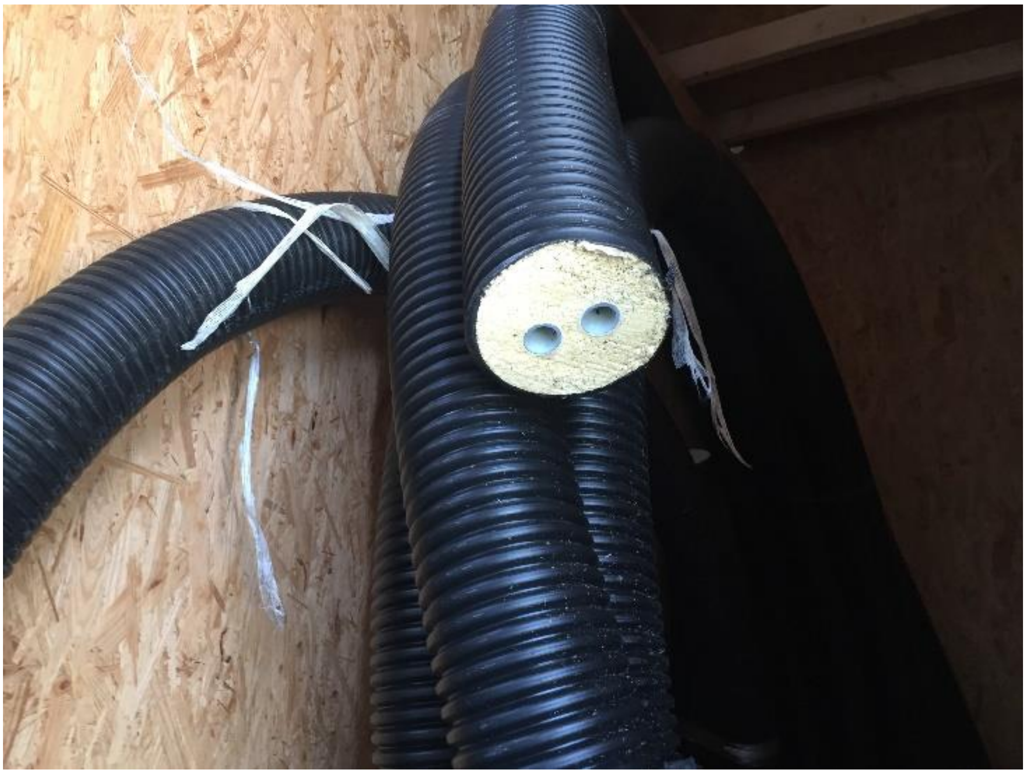

Figure 6: Low temperature DH enables the use of plastic piping (here a twin-pipe), which are less costly and due to its flexibility easier to mount (Source: B. Doračić)

Classification by heat consumption

The heat is usually transferred in the network to the final consumer using different levels of grids (see Figure 2), as classified in the guidelines of AGFW (AGFW FW 510, 2018). The **primary grid** consists of the pipes that are indirectly (heat exchanger) or directly connected with the heat generators. The **secondary grid** is a DH network separated from the primary DH network by a substation with different system parameters. The **tertiary grid** is the end-user's domestic installation. In some systems, only one or two levels exist.

Furthermore, direct and indirect systems can be classified. In a **direct system** the heat transport medium (also called **circuit water**) of the primary grid flows directly through the heating network of the consumers. In these systems, the water from the distribution network flows through the building pipes and radiators. Nevertheless, due to significant disadvantages of direct systems (e.g. high temperatures, problems in case of leakage), they are gradually being phased out. Today, **indirect systems** in which the primary grid is separated from the consumer piping systems through heat exchangers, are most common.

Another classification on the consumer side includes systems which supply **heat only for space heating** or systems which supply heat for both, space heating and domestic hot water. **Systems that provide also hot water** must operate the whole year, whereas systems for space heating only can be shut down during summer. For these systems, hot water is usually prepared with electric boilers. However, in modern DH systems, where sources like solar thermal and excess heat are used, DH systems also supply domestic hot water in order to increase the number of operating hours annually and therefore the feasibility of the whole system.

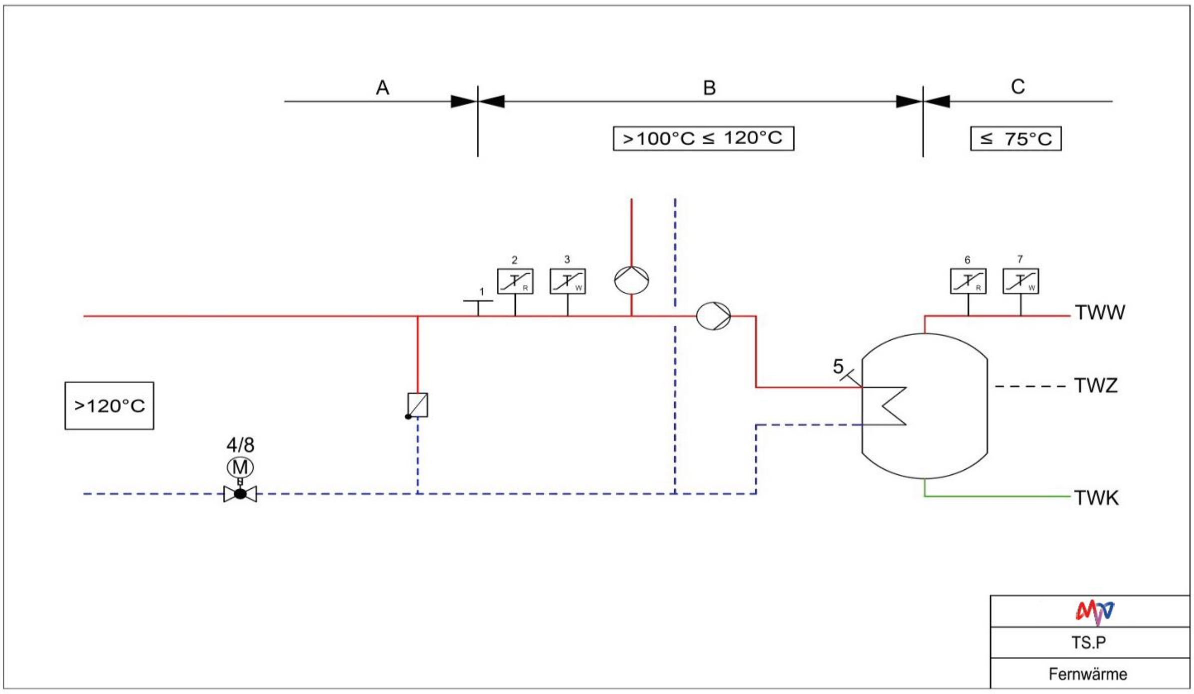

Figure 7: The scheme of a direct system (Source: MVV Netze, 2015)

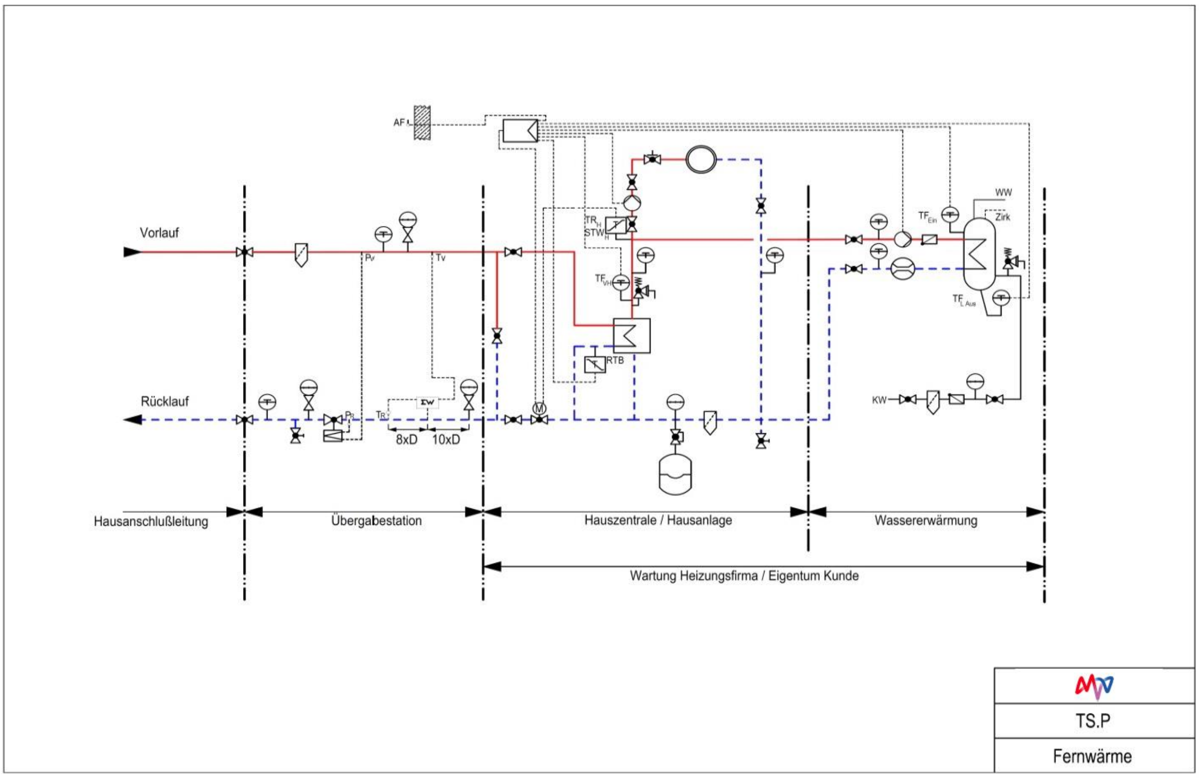

Figure 8: The scheme of an indirect system (Source: MVV Netze, 2015)

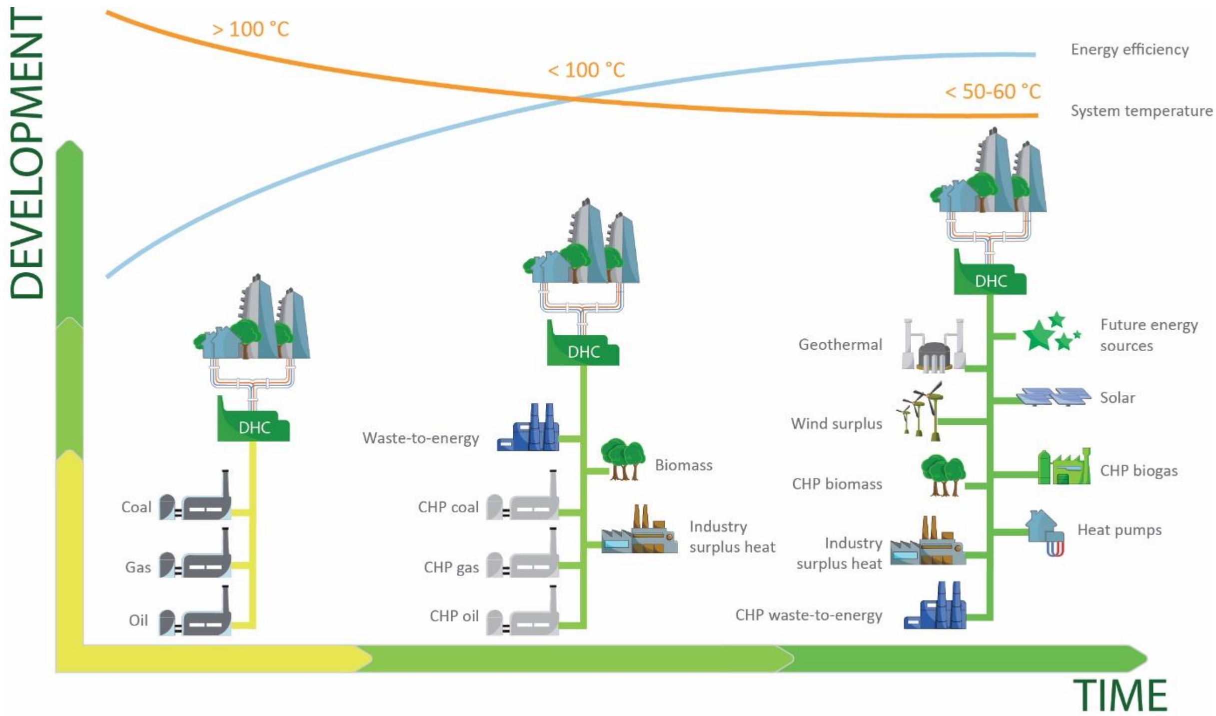

Figure 9: Development of DH systems with time (Source: Euroheat & Power)

2.2 Overview on today's district heating in Europe

In order to develop technical and non-technical DH upgrading options for DH in Europe, knowledge on the past development and on existing DH markets in European countries is important. A detailed statistical overview on today's DH in Europe is provided by the "Country by country" report from Euroheat & Power (2017). This chapter is based on the survey performed by Gerdvilla (market data of 2015) with members and associates of Euroheat & Power.

The total amount of DH heat sales to European customers is still relatively small. The share is around 11-12% of the EU's heat demand provided by 6,000 heat networks. DH is most common in the traditionally cold-winter countries in North/Eastern Europe. As Figure 10 shows, the largest DH market is in Germany, followed by Poland and Sweden. In southern Europe, it currently plays only a minor role. Approximately 60 million EU citizens are served by DH, with an additional 140 million living in cities with at least one DH system.

The total installed DH capacity increased since 2011 in ten countries (Figure 11), whereas the largest percentual increase took place in Switzerland (36%), followed by Italy (24%), Norway and Lithuania (both 16%).

The share of DHC compared to other heating systems is highest in Denmark, Lithuania, Sweden, Poland and Finland, as Figure 12 shows. The shares of all other countries are below 15%. The most noticeable decrease of the share took place in Sweden, where more customers have chosen electric heating, including heat pumps, due to low electricity prices. The share of electrical heating rose there by 4%.

In general, the energy supply of DHC in Europe becomes increasingly renewable, as Figure 13 shows. On average, the share of renewable energy in DHC increased by 10% from 2011 to 2015.

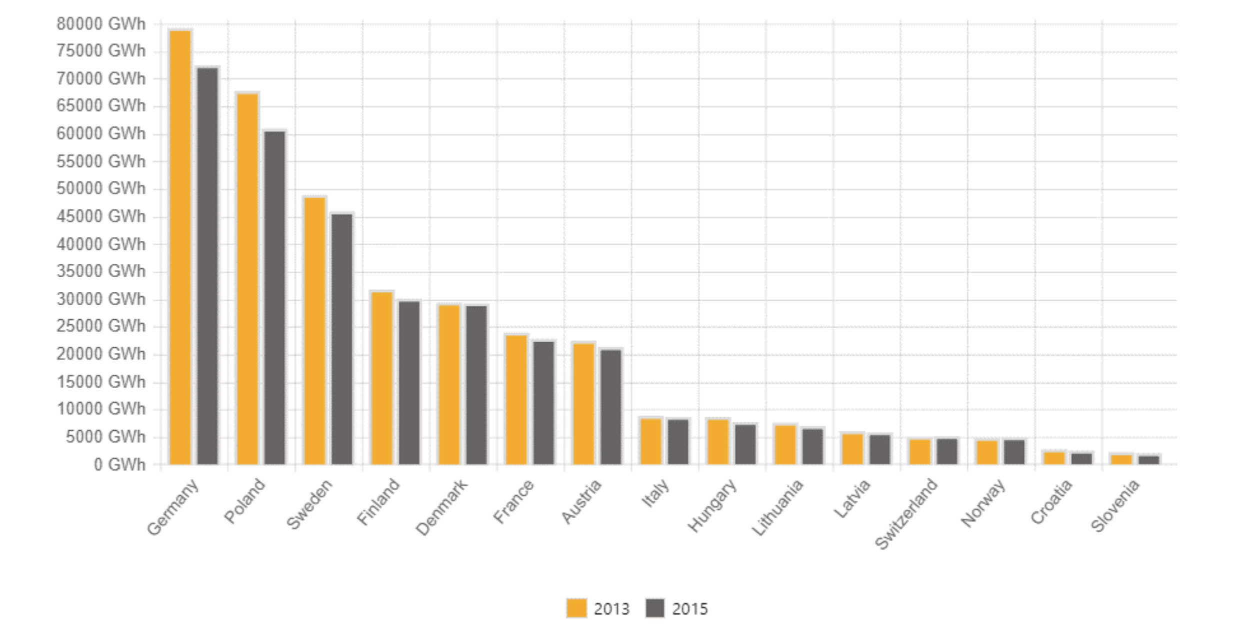

Figure 10: District heating sales to customers in GWh (Source: Executive Summary by Gerdvila, Country by Country 2017, Euroheat & Power)

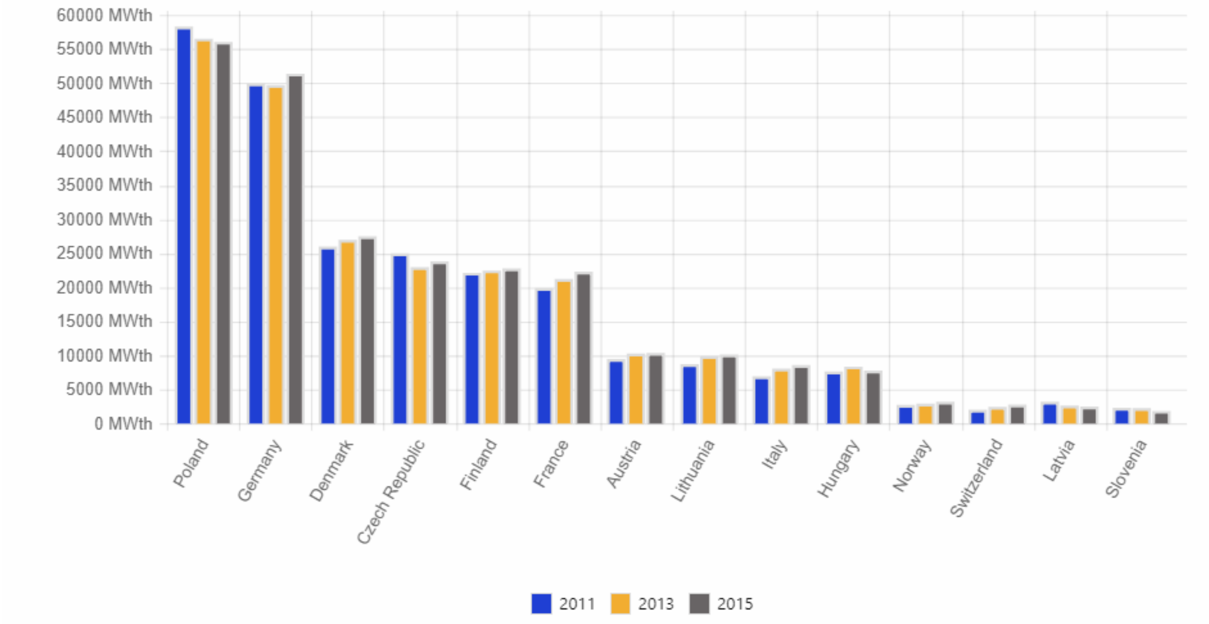

Figure 11: Total installed DH capacity (in MWth) (Source: Executive Summary by Gerdvila, Country by Country 2017, Euroheat & Power)

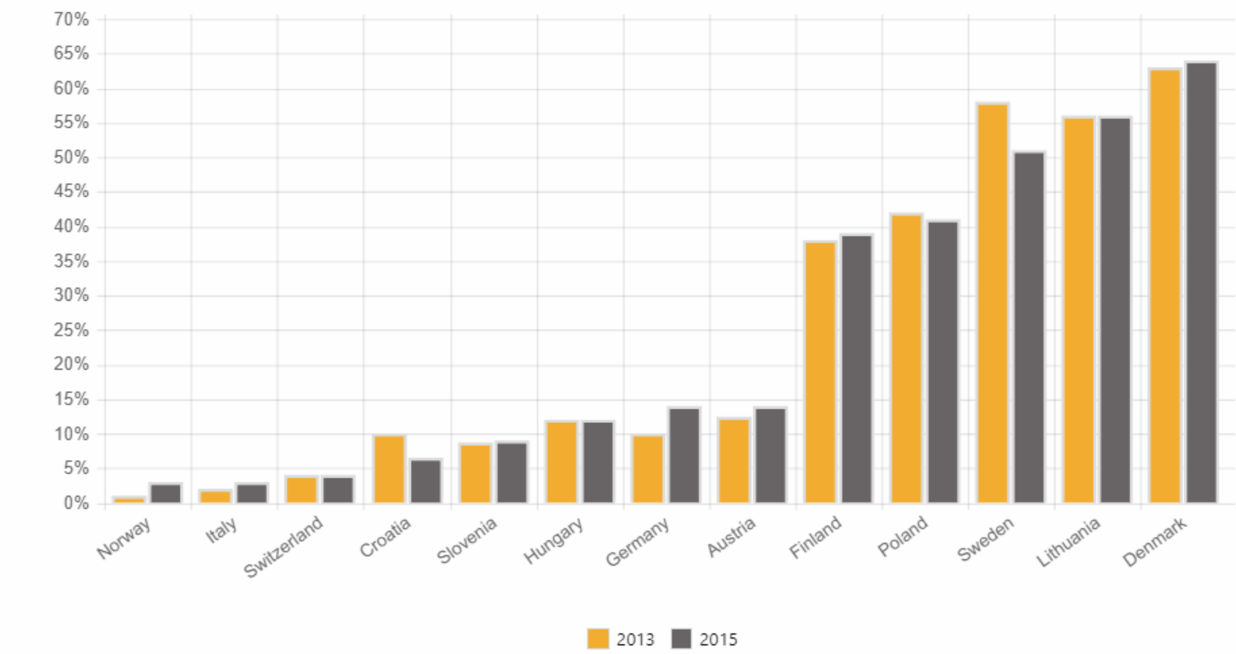

Figure 12: DHC share compared to other heating solutions in Europe (Source: Executive Summary by Gerdvila, Country by Country 2017, Euroheat & Power)

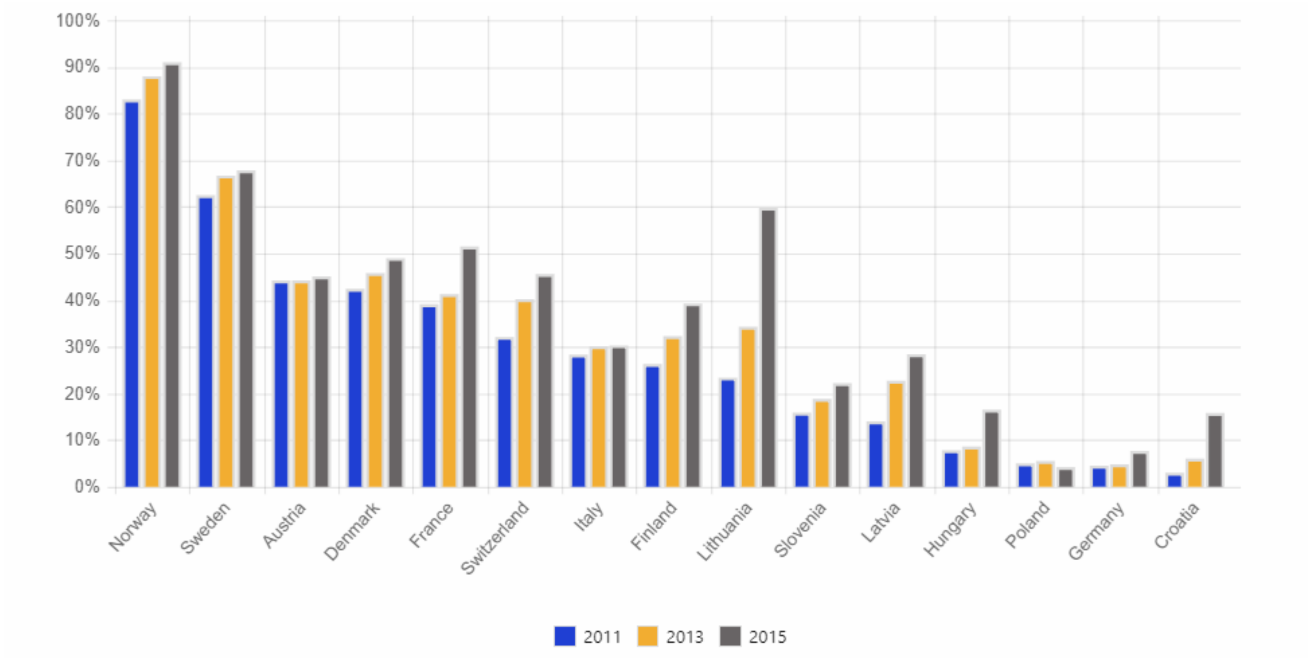

Figure 13: The share of renewable energies in DHC in Europe (Source: Executive Summary by Gerdvila, Country by Country 2017, Euroheat & Power)

2.3 General framework conditions: competitors of DH

Even though there are more than 7,000 DH systems in Europe, they cover only around 13% of the heat demand in European countries. This shows that most buildings are still heated by different means, mostly individual heating solutions on the household or building level. There are multiple reasons for this situation, which will be elaborated in this chapter.

The share of DH in covering the heat demand of a certain country depends significantly on the geographical location of the country in question, but also on the historical development. Denmark, Lithuania and Sweden are the European leaders in terms of DH utilization. The share of households connected to a DH system in Iceland is 92%, and it is completely renewable as it uses geothermal energy. Denmark is also known for using sustainable energy solutions, with 63.3% of its citizens being connected to DH. However, when moving southwards in Europe, less heat is generally needed, and therefore, the share of DH decreases considerably. Nevertheless, heating is still needed during the winter in countries like Spain, Greece, Portugal, etc., where different solutions are being utilized, e.g. air conditioning systems and individual boilers.

Countries of eastern Europe often have a high share of DH systems, but they often incorporate large and old over-sized generators running on fossil fuels with low efficiencies. For that reason, they are often perceived as a bad solution by the citizens resulting in increased tendency towards disconnecting from such systems.

The most frequent replacement for DH in southern and eastern European countries are **individual boilers** on the building or the household level. The fuels being used in such boilers in most cases are natural gas and biomass in different forms (wood logs, pellets). However, fuel oil is also used to some extent, although it is gradually being phased out. Natural gas boilers are usually used in cities, since one of the preconditions is to have the developed natural gas distribution network. Modern boilers have high efficiencies above 90% and are therefore popular solutions among citizens. However, natural gas represents a fossil fuel and is therefore not a sustainable solution for heating at the individual level. Also, using this fuel reduces the security of supply since most European countries are dependent on imported gas from the non-EU countries. Furthermore, fuel prices can vary significantly and are expected to rise in the future. Finally, from the energy point of view it is not efficient to use natural gas to produce lower value energies, i.e. heat.

Biomass boilers are a very often used in the rural settlements since biomass is usually present in the surrounding area and is therefore very cheap for the citizens. In some countries, citizens own forests and consequently have a completely own heating solution. Modern biomass boilers have a high-efficiency and high-quality filtration system which reduces the emissions of local pollutants significantly. These can be a good alternative to DH in areas where heat demand density is not high enough to implement such a system. However, many rural areas have a high share of old and inefficient biomass stoves. This results in high emissions of nitrous oxides, carbon monoxide and particulate matter. This can present a serious problem during the winter months, since these pollutants remain in the area and cause serious health problems for the citizens. The biggest barrier towards replacing such old boilers in rural areas are its demographics and the lower wealth of its population on the one hand, and the low operation costs of such system on the other hand.

In southern European countries, several households also use air conditioning units for heating during the winter months. It is usual in areas which have high cooling needs in summer and low heating needs in winter. Air conditioning units essentially present small air to air heat pumps. Heat pumps are expected to be a significant heat source in future energy systems. More precisely, air-to-water, ground-to-water and water-to-water heat pumps will be used as an alternative to DH systems in areas which have low heat demand densities, throughout Europe. However, using air-to-air heat pumps for heating as it is currently done, is an inefficient way of heating since the coefficient of performance is low during the winter, i.e. it is the lowest when heat is needed the most.

DH is generally economically feasible in areas which have high enough heat demand densities. Therefore, most neighbourhoods of cities could be connected to DH. A useful tool for the analysis of the potential for DH is heat demand mapping with geographical information system (GIS) tools, which can graphically show the scope of the potential DH system, as it can be seen in Figure 14.

The potentials for DH are currently very high. In order to achieve a sustainable and decarbonized heating sector, DH should be expanded to cover a much higher share of heat demand. This must be combined with the implementation of energy saving measures in buildings in order to enable the use of low temperature heat produced by various renewable sources like solar, geothermal etc. The remaining part of heat demand in low density areas should be covered by individual heat pumps, as mentioned earlier in this section.

One of the biggest barriers currently towards the increased share of DH in Europe is the **competition of this sector with natural gas.** However, DH is also in competition with all other heating options. A heating system which was once chosen, will usually not be changed at short notice. This has been solved in countries like Denmark by specifically defining zones in which DH networks will be built and the ones in which natural gas networks will be built. In other words, municipal heating plans physically separate DH areas, where all households have to be connected to this heating source, and natural gas areas. However, the situation is completely different in south-eastern Europe, where DH and natural gas are usually both present and available to consumers at the same time. Due to the lack of knowledge of the broad public on DH and the low natural gas prices in some locations, it is not unusual for the new buildings to connect to a natural gas grid rather than the DH grid, despite its availability at the location.

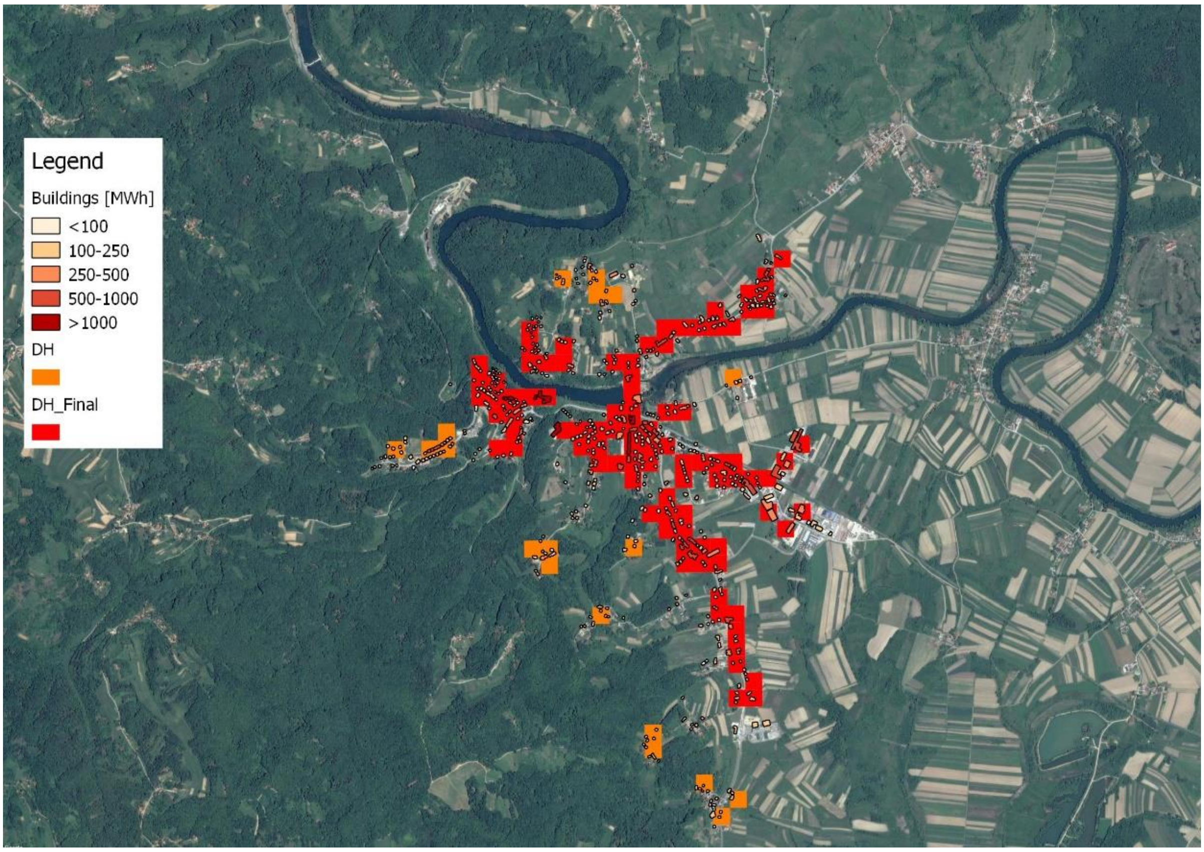

Figure 14. Heat demand map of the city of Ozalj in Croatia which also shows parts of the city in which it would be feasible to connect to a DH system (orange and red parts) (Source: Doračić et al. 2018)

Figure 15. Natural gas and DH grid in the city of Velika Gorica in Croatia (Source: T. Novosel)

3 The upgrading process

DH networks present a high potential for the transition of the heat sector, both technically and organizationally. They allow the integration of renewable energies, to improve the overall energy efficiency, as well as to facilitate sector coupling (coupling between heating, electricity and mobility).

Usually, the overall upgrading process to improve the efficiency of DH grids is complex and sophisticated. It is time-consuming, long-lasting and implies high investments. Impacts on the connected buildings must be considered, for example when lowering the operation temperatures. It usually implies a direct cooperation with building owners and end consumers. Such a long and global process also has an impact on the city's or district's life that should not be underrated. **That is why the upgrading process should be very carefully planned in the long-term.**

Ideally, the overall upgrading process is planned in a **holistic process as a single project** that considers all aspects of a system, including heat generation, distribution and use in order to maximize the efficiency of the overall system. However, as this is often long-lasting and expensive, in many cases only parts of the overall system are upgraded in smaller steps. This has the advantage of being faster and of spreading the investments, but it includes the risk of making less harmonised and thus, less efficient improvements of the overall system. As each DH system is very specific and individual, there exists no unique standard upgrading process. Nevertheless, the procedures can be similar, and several aspects of the process are described in the chapters below.

It is important that all **stakeholders** are involved already in the planning phase to ensure acceptance: heat suppliers including excess heat from industry, DH operators, housing associations, building owners, end users and local policy makers. A concrete scheme including technical and organizational measures based on a detailed diagnosis of the current situation should result from the planning phase. Regarding the high investment and duration of the retrofitting scheme, the diagnosis should also consider the future evolution of the thermal demand, based on currently available demographical trends and scenarios as well as local boundary conditions.

Moreover, the question of the **cost-effectiveness** and the financing of the measures proposed must be considered in detail. The upgrading scheme should specify which business and organizational models will be relied upon for the realization of the different measures planned, including also fund raising and citizen participation models.

The upgrading scheme should also aim at **increased efficiency, service-quality and competitiveness** as well as **reduced CO_2 emissions**. Furthermore, primary energy consumption needs to be reduced. DH is ideal for low-grade surplus heat use and for the integration of renewable energies. Moreover, it should result in the improvement of the image of DH at local level, contribute to the energy transition and increase its acceptance by citizens. Therefore, the scheme should include an open communication strategy and involve end-consumers via different participation models.

In order to use this potential, retrofitting of DH systems should first consider the heat demand of consumers and then upgrade the existing distribution system, including the substations and consumer connections: reaching lower leakage rates and heat losses, reducing operation temperatures, adapting piping dimensions and hydraulic, introducing modern IT-based management systems and options for user heat supply control. This makes the heat distribution more efficient, but also improves the efficiency of the heat generation. Moreover, it facilitates the integration of renewable energies and waste heat. In a second step, the distribution systems should be retrofitted, and finally efficiency measures can be implemented on the generation side. The share of renewable and waste heat can be introduced and increased gradually. This must go together with predictions of future heat demand as well as with efficiency measures of the consumers.

3.1 Motivation of companies for upgrading processes

Climate change mitigation through the decarbonisation of the heating sector in Europe with sustainable heat generation, as well as reduction of costs are the main overall motivations behind the upgrading projects of DH systems. International and national political and non-political framework conditions influence the implementation of upgrading measures. However, it must be recognised that the implementers of the upgrading measures are the DH companies, which can have very different motivations to do the upgrading.

Within the Upgrade DH project, different already implemented upgrading projects (good practice projects) were investigated (Upgrade DH, 2018a). Based on this, the following section summarizes how companies are dealing with the different goals and what their motivations are. Therefore, the motivations behind the projects are classified in three categories: **company goals, economic benefits**, and **environmental impacts.**

3.1.1 Company goals

Strategic company goals are influenced by the type of the company. DH companies can be public or private, have one or several shareholders, be profit-oriented or non-profit-oriented. Furthermore, company goals are influenced by marketing objectives (green image), political decisions, and legal requirements. Thus, company goals can be formulated by the management of the company, by the shareholders, or by politicians.

Specific company goals can be a high motivating factor to implement upgrading measures. Due to the company's self-interest, the willingness to apply efforts for reaching the set goals is higher. Based on Hungenberg & Wulf (2015), company goals can be classified towards three dimensions: content, target, and timing. These three dimensions can be complemented by the dimension of scope of application, priority, and responsibility (Töpfer, 2006).

When setting the goals for DH upgrading measures, they can be categorized according to the **timing** into short-term, mid-term, and long-term goals. In Hungenberg & Wulf (2015), the related amount of time for short-term goals is up to one year, as these goals often refer to one financial year. The determined amount of time for mid-term goals is about two or three years, while long-term goals are determined up to five years and in exceptional cases up to ten years. For DH upgrading projects, these time periods need to be adjusted and extended as the duration of upgrading measures are generally longer than normal company timeframes. Hence, the period for **short-term goals** remains to one year, the period for **mid-term goals** is increased to about five years and the period for **long-term goals** is ten years and longer. The adjustment of time periods and timing relationships is illustrated in Figure 16.

Table 2 shows different company goals which were identified within the investigated projects of the Upgrade DH project (Upgrade DH 2018a), divided by the three timing categories.

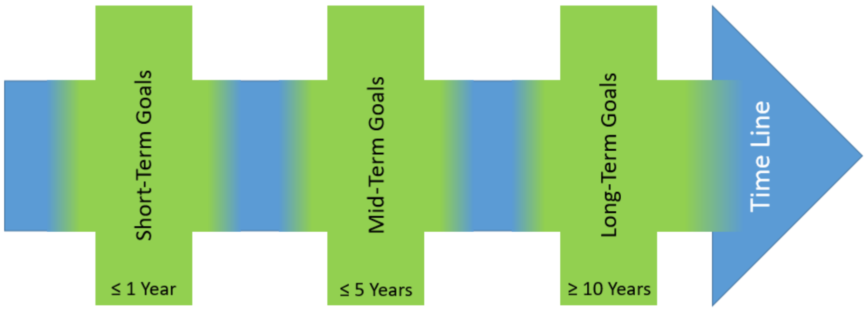

Figure 16 Typical timing of goals for DH upgrading measures

Table 2 Company goals for upgrading measures

Short-Term Goals	Mid-Term Goals	Long-Term Goals
• Economic benefit • Primary and secondary energy savings • Optimization of the installed capacities • Start to increase the share of renewables	• Transforming and renovating the DH system, using up-date technology • Acquisition of new customers • Further increase of the share of renewables • Integration of different energy/heat sources	• Resource-friendly and sustainable heat generation • Decarbonisation of the DH sector • Stay competitive in the heating sector • Increased security of heat supply, and less price fluctuations

3.1.2 Economic benefits

The economic benefits of upgrading DH can be at three levels: economic benefits for the company (profit maximization), economic benefits for the heat consumers (especially if consumers are shareholders), and economic benefits for the local economy.

Depending on the specific company goals, the key motivation of companies for implementing upgrading processes are usually economic benefits. Reduced costs or savings and increased revenues can be used for further investments, to satisfy shareholder payments, or to decrease heat prices. This depends on the overall strategic company goals. If profits should be maximized, a strategy is to decrease the operating costs while keeping the same revenues, which equals to improve the systems energy efficiency and increase the profit. If heat prices should be minimized, a strategy is to just decrease the operating costs with upgrading measures.

An approach to decrease operating cost can be the transition to other energy sources, which have lower and steadier costs. The use of locally available energy sources, like wood chips, can substitute fossil fuels which are often imported. Using local or regional energy sources can have multiple benefits. For the company on one side, it reduces the dependency from international suppliers. This leads to reduced risks for the DH system operator which results in a higher security of heat supply for the customers. In the case of wood chips, costs are often more stable, which facilitates the calculation of the heat generation costs. In addition, local businesses are supported which contributes to the local economy.

Furthermore, several projects show, that the upgrading measures aim to reduce the energy demand for both, primary energy demand and secondary energy demand. The primary energy demand is targeted by reducing consumption or displacing fossil fuels. The secondary energy demand is targeted by reducing electrical energy for operating the system and its components. A comparison of power demands (Figure 17) for the network's pumping process before and after the upgrading measures of a dedicated project demonstrates the potential of energy savings.

Another important economic indicator is the project's **payback period**. Especially for comprehensive projects like renovating the entire DH system, profitability or the return of investment are decisive aspects. The high investment costs need to amortize after an estimated period. Longer amortization periods of the high investment costs can be often compensated with the other running and operating costs. An example of an illustration of the amortization through the cash flow is shown for the Green Energy Park Livno, Bosnia and Herzegovina, in Figure 18.

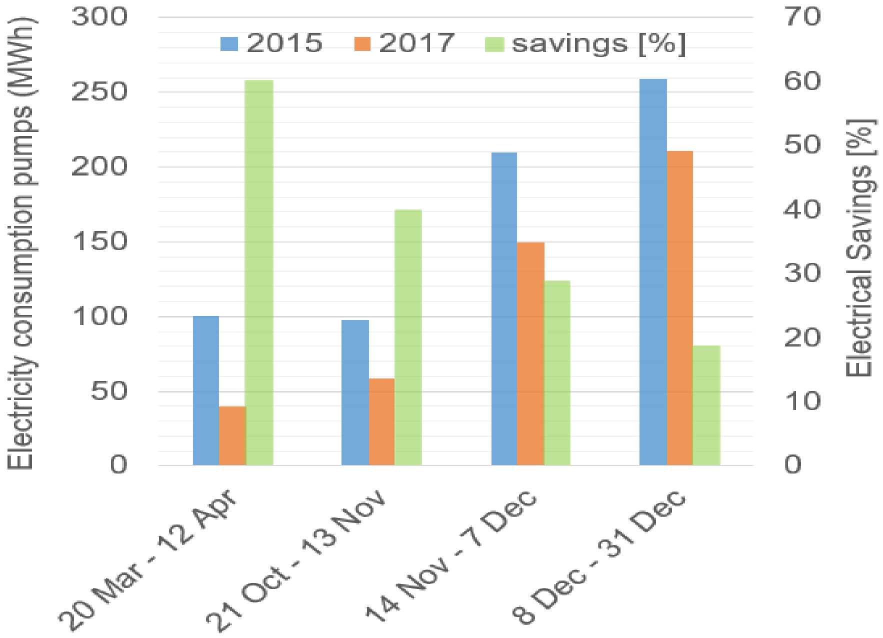

Figure 17: Power demand for pumping operation in 2015 and 2017 (Upgrade DH 2018b)

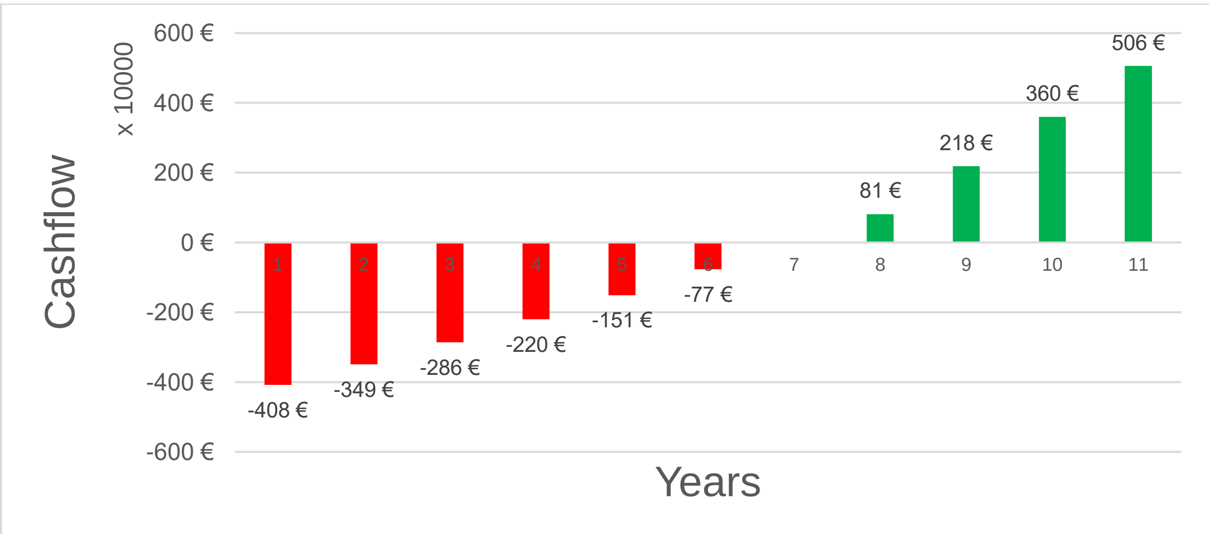

Figure 18: Estimated cash flow of the upgrading project Green Energy Park Livno, Bosnia and Herzegovina, (Upgrade DH 2018a)

With software-based optimization tools, upgrading measures aim to optimize the operation planning, especially for cogeneration power plants (Kühne & Hinz, 2016). Furthermore, the optimum can be set for the maximum of profit to achieve an economic benefit. It aims the most efficient operation planning, relating to all economic aspects using the installed capacity. Based on different parameters, calculations and estimations, it is possible to optimize the operation without hardware retrofitting measures, such as for example new heat generation plants, new pumping systems for the distribution networks, or new heat exchangers. Therefore, all possible operation modes, sources of revenues and conceivable effects for the system are investigated (Kühne & Hinz, 2016).

A further economic objective is to acquire new customers. New customers are on the one hand a new source of revenues by selling heat, and on the other hand, new customers contribute to the company’s growth and can promote the popularity of DH.

3.1.3 Environmental impacts

The improvement of the environmental impacts can be an important target for the upgrading process. Thereby, the motivation for increasing the environmental performance from the company viewpoint can be manifold:

- **Idealistic motivation**: this applies especially to DH cooperatives, public companies, or companies owned by the heat consumers.
- **Marketing motivation**: through a green image of the company, more customers could be gained.
- **Forced motivation**: through mandatory requirements or legislation, companies could be forced to fulfil certain environmental requirements, e.g. obligations on emission reductions.
- **Economic motivation**: improvements on the environmental performance could contribute to the economic benefits, e.g. in the case of cheaper fuels or within the CO_2 emission trade scheme.

The reduction of CO_2 emissions and the improvement of DH system's efficiency are the key elements for most goals on environmental improvements. Thereby, especially improvements on the efficiency have a positive impact on the DH company itself.

Efficiency gains due to upgrading measures often imply also economic benefits caused by less fuel consumption or electrical energy savings. The efficiency's improvement is an important driver for the reduction of CO_2 emissions. Therefore, the increase of the system's efficiency affects the heat generation, the heat distribution and the heat consumption. It leads to energy savings for the whole process chain. In particular, old DH systems using out-of-date technology (compare the retrofitting project Green Energy Park Livno; in Upgrade DH, 2018b), have a very high potential to upgrade their performance by upgrading their efficiency. But even more up-to-date systems have high efficiency potentials that are driven by the target of optimization (Optimisation of Pumping Operations in the DH System Ferrara; in Upgrade DH, 2018b). In these cases, the aimed goal is mainly to improve the performance without a greater impact of the entire system, using almost exciting technologies and equipment.

The good practice projects of the Upgrade DH project (Upgrade DH, 2018a, b) showed a wide range of feasible upgrading measures and addressed issues. Some examples showed that, due to additional equipment, the heat generation process was optimized to generate more useable heat by combusting the same quantity of fuel. In addition, the distribution network showed a high potential for optimization affecting inefficient pipeline technology, inefficient equipment (pumps, heat exchangers in substations), and inefficient operation. The adjustment of the network operating parameters to reduce heat losses, pressure losses or the electrical power is an important leverage for the system's efficiency.

Various upgrading measures aim to increase the consumer's awareness for heating and their heating behaviour, in order to increase the overall efficiency. With further renovation measures for houses and buildings, the goal for lower heat demand and the goal of a higher comfort level for users are addressed. A further optimization measure was to increase the level of automation. Therefore, one option is to reduce or simplify procedures. This can also include internal processes and decision paths. Another option is to implement automation strategies for the setting of the system's parameters.

Within the project Upgrade DH also other, more specific measures were detected which contribute to increase the environmental performance, for example the improvement of the system's flexibility, increasing the operating hours for CHP plants or the reduced operation of peak-load plants. Another measure is the switch to low-temperature DH. All measures can contribute to the overall increase the efficiency, but they have influences on the company's individual operation strategy and planning as well. In particular the improvement of the flexibility of a system with regards to the heat-generation becomes more and more important for prospective development (Kühne & Hinz, 2016). Even though, the reduction of CO_2 emissions is a more familiar goal for the discussion about climate change and flue gases, nitrogen oxides (NO_x) take part in this discussion as well. Hence, the focused reduction of NO_x in the flue gases of CHP processes is an additional target for retrofitting measures (Upgrade DH, 2018b).

Besides efficiency measures, CO_2 emissions can be mainly reduced by the substitution of fossil fuels by renewable energies. If the entire DH systems will be upgraded, renewable energy sources can be easier integrated. The integration can either lead to primary energy savings by reducing the consumption of fossil fuels, or it can build new capacities for the system. An important key factor for this development is the diversity of heat generation technologies. With a well-designed heat generation structure and a well-planned upgrading project, all available energy sources and available technologies can be used in an optimal way. This mixture of heat sources allows to reduce the use of fossil energy sources and to save primary energy. In addition to the inclusion of renewable energy sources, also the inclusion of surplus or excess heat can improve the environmental performance of the DH system.

3.2 Capturing the initial state

The first step in developing an upgrade of a network is to build up an accurate picture of the current operational efficiency of the overall system. This analysis provides a baseline for assessing possibilities and for measuring the benefits of improvement works.

The initial state can be analysed in various levels of technical and non-technical detail. An initial analysis of the operation of the network can give an indication of where resources can be used to maximise the benefits of an upgrade. Initial questions such as those below will assist to give an overall view of the general 'health' of the network:

- Is the network delivering enough heat to the end users?
- Is the heat supplied at a price which is affordable to the users and comparable to alternative methods of heat generation?
- How is the heat supply service charged to the customers? Is it a lump sum (e.g. per square meter of heated space) or per unit of sold heat?
- Does the network have a high level of heat loss? That is, a large difference between the heat output from the generation plant and the heat used by the end users?
- Is the network known to be old and in disrepair? What is the level of failures, and maintenance costs?
- What is the current heat supply to the network? Is there a need to upgrade the supply for economic or environmental reasons?
- What is the policy framework of the country / region? Is there a political and social drive to upgrade heat generation and distribution?

Technical indicators that can be used to capture the initial state of the DH system are presented and explained in chapter 5.

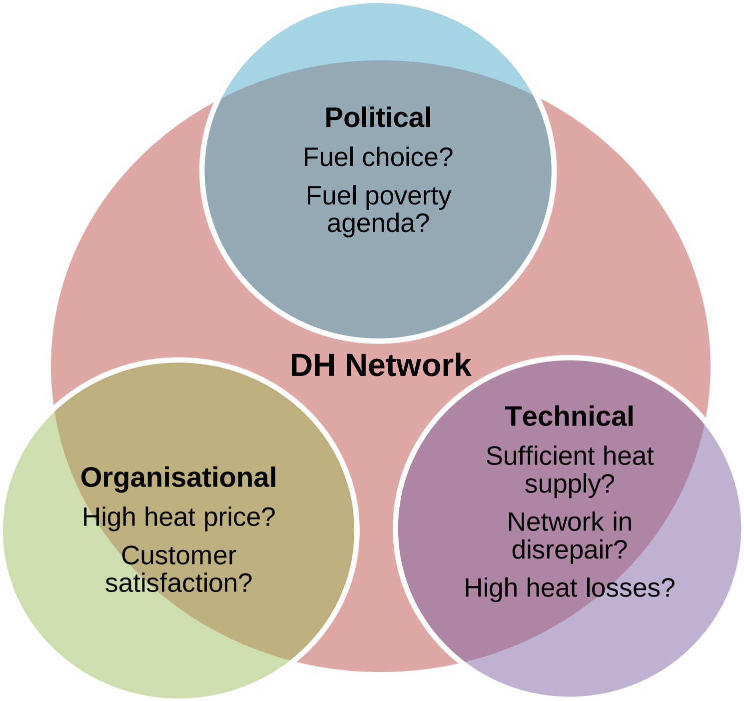

Figure 19: Driving factors for DH network upgrade projects (Source: COWI)

The required **basic data** are the number of energy generators, the installed capacity, ages of the installations, network length, temperature levels and the number of customers. These data are usually easily accessible. For more complex questions like the performance, network characteristics or operation modes, it is necessary to contact different responsible persons of a DH system. Several detailed data and system's parameters are essential to operate the system, but they are only known by a few staff members.

If some of the very specific data are unknown, it is sufficient for the first picture to make estimations. In this case, it is crucial to describe the procedure shortly. For example, if the total electric energy for the system's operation is not recorded (which is needed to calculate the queried performance indicator), the individual consumptions of boiler houses and distribution pumps can be summed up.

However, more and more frequently the relevant data are available for all operator's staff with excess to the SCADA (Supervisory Control and Data Acquisition) of a DH system. Due to the advancing developments in the field of digital measured value acquisition and the connection of sensors, actuators and control units, the quality and quantity of available data is generally improving for many DH systems. This leads to data sets with high resolution and frequently updates, that could lead to new and time-dependent analyses.

However, in case of **missing data**, a period of monitoring and additional data acquisition may be required. If the network is not currently monitored, installing temperature sensors and heat meters at key points on the network for a period of time could provide valuable data. Likewise, fuel input monitoring (e.g. half hourly gas metering) if not already in place, will be necessary to analyse the energy balances.

In old networks with high heat losses, **aerial thermal imaging** can provide information on heat losses. A drone or small plane equipped with thermal imaging and GPS technology is flown over the network to collect data. The data collected is then compared with the location of DH pipework to show where there is a larger heat loss. This method is used to specifically look at the physical condition of the network and requires little additional data. An example is shown in Figure 20.

Figure 20: Thermal imaging of a DH network showing a major leak on a pipeline (Source: COWI)

Because the replacement or retrofitting of measurement technology is usually associated with high costs, the costs and benefits should be compared before the implementation. The currently ongoing research project NEMO in Germany develops a method and a **guideline for monitoring DH systems** requirements in order to continuously improve the system (AGFW, 2018b).

The outcome of capturing this initial state of the system helps to prioritize measures and to make first decisions. While analysing the results, it is possible that specific upgrading opportunities are obvious and that experts may instantly give advice on the most important improvements, without further detailed analysis.

3.3 Analysing the data

The collected data and information must be analysed and evaluated with the aim to narrow down the possible upgrading opportunities and to identify the overall upgrading potential. The collected information is used in a step-wise approach to point out weaknesses or anomalies in the system. Thereby, it must be considered that every DH system and the framework conditions of the analysed network is very individual.

In case that the data are collected automatically, it is usually necessary to validate the data and to start some cleaning process. This means to detect invalid data, gaps, missing data points, inconsistent data, or unrealistic data. Considering that modifications in DH systems often needs a lot of time, it is inevitable to consider sufficient time for that.

The **method of data analysis** should be chosen according to the amount of data available and the desired outcome of the analysis. There are several methods and software packages available which can assist with data analysis, from a simple excel spreadsheet to a complex thermodynamic analysis.

To get the initial overview on the DH system, an **analysis of heat inputs and outputs** can be made, which can be related to the age and the general condition of the network. On the other end of the scale, a full hydro-thermo-dynamic analysis can provide detailed data on operational parameters.

The level of detail required will depend on the network and the anticipated improvements. Older networks, which are known to be inefficient may not require so detailed modelling as newer networks, since in inefficient systems, first improvements can be achieved relatively easy.

However, when considering a low or very low temperature DH grid and the incorporation of low temperature waste heat sources, or renewables, a **detailed model** can be very helpful. In these cases, the network operation will need to be fine-turned to ensure enough heat supply, whilst maximising the environmental benefits of renewable energy technologies. For low temperature DH grids, special consideration should be also given to the heating systems within the building to ensure that sufficient heat can be supplied at lower temperatures.

There are also existing commercial computer programs available, which can calculate effects of changes to the system (Upgrade DH, 2018a). A **thermo-hydraulic model** can give a detailed insight into the operation of the network. This can be used to make a statistical analysis, or to monitor the network in real time allowing for constant adjustments. Model development will require that there is a reasonable level of data available on the network. There must be at least information available on heat supply, pipe sizes and locations and heat consumptions at the user level. Figure 21 shows a TERMIS model for a small town in Denmark with a single heat source.

Figure 21: Example of TERMIS baseline model (Source: COWI)

3.4 Identifying upgrading options: feasibility studies

The potential for upgrading the network is based on the analysis of the data and will typically come up with several options which are technically possible. This forms the basis for a feasibility study, the purpose of which is to assess each option and to make a comparison to facilitate decision making.

Possible upgrading measures are presented in the brochure "Best practice examples on upgrading projects" (Upgrade DH 2018a). In this brochure, different and already successfully implemented upgrading projects from various European countries are collected and described. An overview on the characteristics of upgrading projects is presented in Table 3.

Table 3: Characteristics of upgrading projects (according to Upgrade DH 2018b)

Retrofitting types	Targets of the retrofitting measure	Affected areas
	Primary energy savings	Primary grid
Technical	Efficiency gains	Secondary grid
Economical	Share of RE	Tertiary grid
Organisational	Integration of surplus heat	Heat generators
Management	Economic improvements	Business models
	Substitution of fossil fuels	Substations

The feasibility study should typically include:

- An assessment of the existing supply network / method of heat supply
- Details of heat load to be supplied (in as much detail as is relevant for the upgrade proposed)
- An overview of the options considered
- A technical analysis of the potential options
- A financial analysis including capital costs and benefits over a defined business period
- Details of any permits of permissions required to carry out the project
- Conclusions as to whether the proposed upgrade measure is technically and financially viable together with the next steps to progress the project

3.5 Setting-up evaluation criteria to compare the different options

For some networks where there is an obvious technical problem, such as high heat losses and leaks in the network, the evaluation of the options will be a relatively simple cost/payback calculation. However, many network upgrades are driven by requirements for energy efficiency and reduced CO_2 emissions. In these cases, it is much more difficult to create a solid basis on which different options can be evaluated.

When assessing the feasibility of a DH upgrading project, it is important to consider the drivers for the project. Some projects may not provide significant financial savings on operation, but may meet other objectives, such as climate change goals or significant improvements in the standard of living in certain areas. In Denmark, an attempt has been made to provide a level playing field for the analysis of options via the socio-economy method. This approach takes a holistic view of the effects of a project by analysis of the impact on society as a whole. By an assessment and comparison of projects in this way, municipalities in Denmark can gain an overview of the impacts of a project over and above those which are included in a basic economic review.

The Danish Energy Authority supplies and updates a guideline of the inputs to the calculations of socio-economic analysis of DH projects and the method by which the analysis needs to be carried out. This means that analysis has to be carried out based on the same input data for all projects, and therefore, it provides a more balanced basis on which to assess viability.

In some cases, a project may have conflicting objectives, or certain parts of an upgrading project may only meet certain objectives. Where this is the case, it is particularly important to have an overview of the hierarchy of objectives to be met, so that the project can be assessed and planned accordingly.

3.6 Developing an implementation plan

Once a feasibility study has been completed and shown that a project is viable, the next steps are to plan the financing and implementation of the project.

Upgrading projects for DH usually have relatively high investment costs. Therefore, a positive **business case** is important for the success of a project in getting funding. Due to the high infrastructure costs, DH projects typically have a long payback period. This makes it in some cases difficult to source financing from the private sector. Therefore, DH projects are often (at least partially) financed by the public sector.

In cases where a project can show a non-financial benefit, there may be financial assistance available to bridge the gap to make the project financially viable. The level of funding and mechanism depends on the country and area in which the project is located. Different schemes are applied in different countries and often also within different areas of a particular country. This may include a grant or loan from a CO_2 reduction scheme, or a grant / investment from the public sector where the project contributes to a significant improvement in the quality of life for citizens.

Once a decision is made to go ahead with the upgrading measures, based on the feasibility study, the design and planning will need to be developed in further detail. The level of design and planning work required will depend on the size of the project and the level of impact. However, the general issues to consider at this stage are:

- A **detailed design** of the technical solution should be carried out, including site plans, new plant to be installed, connections to any existing systems, etc.
- A **stakeholder analysis** should be carried out to assess those, who are affected by the project and to determine how information is disseminated, who is responsible for communication / answering questions etc. This is particularly important if the project will have a direct effect on consumers heat supplies, or if it causes disruption to their daily lives.
- Based on the technical design and stakeholder analysis, a detailed **timescale** should be drawn up for all project activities.

This input should lead to a **detailed implementation plan** of the project. Once this is completed, the project team should carry out a detailed review of the project to confirm that it is still possible to carry out as planned. Assuming this is the case, decisions can be taken on the method of procurement for the project to move to the implementation stage.

Throughout the entire planning and implementation process for an upgrading project, it is important to consider how it will affect the end users. Usually, an upgrading project will affect the users in some way during the project implementation and will also lead to changes in the way they interact with their heat supply in the future. A **plan for informing users** and potentially a **training plan** to inform about the new system should be considered early in the project process. During the design phase, it is important to consider the interaction between the heat user and supplier, which is also key to the success of the project.

3.7 Implementation of the upgrading measures

The implementation of the upgrading measures should be carried out according to the implementation plan put in place. Where there is an impact on the heat supply of consumers, special consideration and planning should be undertaken throughout the project to ensure that the works cause as little disruption as possible to consumers.

During the implementation phase of the measure, it is important to inform and to train consumers. Often, upgrading projects involve some changes regarding the way the heat is supplied to the building, which also affects the consumers. For the project to be successful in achieving long term goals, the users will need to be included in the project and educated on the changes to their heat supply.

3.8 Continuous monitoring of the success of the upgrading measures

For some upgrading projects, the impacts can be seen very soon after implementation. For example, an upgrading measure to reduce pipe leaks can have an immediate effect on the amount of make-up water required. However, many benefits can be only seen after a certain period of time and continuous monitoring is therefore key to measure whether an upgrading project has met its goals.

The type and frequency of monitoring will depend on the aims of the project. Depending on the type of project, it may include the following monitoring measures.

Heat metering at the point of use is key to measure the progress towards the goals for most DH upgrading projects. If the amount of used heat as well as the flow and return temperatures are measured at each point of use, and if the temperatures and the flow of water from the plant is known, network losses can be calculated. The higher the frequency of data collection from the meter, the more detailed a picture can be drawn-up on how the network is operating and what the effects of certain parameters (e.g. outside air temperature) are on the efficiency of heat supply.

As mentioned above, the amount of **extra make-up water** required to be added to the network will provide a measure of how much water is lost from the network.

Depending on the project aims, the **level of complaints from users** will provide a basis on which to assess whether the project has been successful. In projects where the supply temperature is lowered, the level and nature of customer complaints will give an idea of whether the flow temperature regulation is satisfactory for the heating needs of the consumers. It may also indicate that further information is required.

In some countries it may be preferable to **ask the users** for their opinions on the supply of heat instead of relying on the level of complaints. Cultural differences and, in some cases, low expectations of heat supply may mean that a low level of complaints does not necessarily correlate with a well-functioning heat supply.

4 Non-technical aspects

Non-technical aspects need to be addressed in any upgrading project in order to use the full potential of the technical upgrading. This ideally results in economic and environmental benefits. The "Collection of best practice examples on upgrading projects" (Upgrade DH, 2018a) shows examples of improvements, where technical and economical improvements go hand in hand. These examples show, that each case has specific strengths and weaknesses, which need to be defined in order to find the best upgrading measure.

Chapter 4 shows several ways of detecting system bottlenecks with different tools as for example data analysis. As part of the Upgrade DH project, a template for the **global assessment of DH systems** has been developed (Miedaner et al. 2018). It shall help to not only list and understand current technical indicators of a DH system, but also to assess non-technical aspects. This includes for example organisational questions, but also guidelines and templates for **interviews** with different stakeholders who may indicate potential upgrading measures.

Especially, if the communication structure between all relevant stakeholders is not very strong, it is highly recommended to initiate communication between the different actors. Even better than interviews, is the set-up of common **working groups** with representatives from different stakeholder groups. This can be a platform to discuss different viewpoints, problems and challenges in the overall upgrading process. Recommendations on setting up a local working group are provided by Miedaner et al. (2018).

4.1 Strategies and policies

Historically, many DH systems are using the surplus heat of larger combined heat and power plants, which are often operated with fossil fuels such as lignite, hard coal, fossil oil, or natural gas. The initial goals of the plants were often to maximize power generation, heat was often considered as a by-product. The first and most important aspect for upgrading procedures is the question on the current and **future purpose of the energy generation facility**. Thus, any upgrading measure should consider the following issues:

- **Future changes in the power sector**: Due to climate change and energy policies in Europe, the energy transition is proceeding, and considerable changes are expected in the power sector. A main objective of centralized CHP plants in the past was to provide base load electricity, whereas heat was considered just as a by-product. With the increasing integration of more decentralised RE in the power sector, these power plants are steadily replaced. Furthermore, they are less flexible, which is required by the new power sectors, and hence, less compatible with new power systems. In addition, several governments are deciding to phase-out fossil power or CHP plants (e.g. as currently discussed in Germany).
- **Efficiency requirements**: The electrical efficiency of fossil power plants is in the range of 30% to 40%. The connection of DH to these plants was often a measure to increase the overall efficiency by using a share of the heat. However, the amount of heat used to increase the overall efficiency depends on the heat demand and on the location of the plant. Especially coal power plants are often installed in vicinity to the coal mines and often far away from heat users. Furthermore, the decreased heat demand during summer decreases the efficiency of these plants. In future energy systems that operate without fossil fuels, it is questionable if these locations and operation modes still make sense in the long-term.
- **Future heat demand**: The future heat demand of an existing DH system may change. On the one hand, the efficiency status of buildings may increase, thus, requiring less heat, on the other hand, new settlements and districts may be connected to DH.

Furthermore, the upgrading of the piping grid and of the overall DH system may change the overall heat demand.

Official strategies and policies play a very important role on the implementation of upgrading procedures on different levels: the European, national and local levels. Due to the variety of strategies and policies, it is not possible, nor the aim of this handbook to summarize all these issues. Therefore, in brief only the most important recent legislation on the European level is summarised which requires Member States to transpose them into national legislations.

At the end of 2018, three key pieces of legislation in the **Clean Energy for All Europeans Package** have been published and entered into force as of 24 December 2018. The revised Renewable Energy Directive (RED II) (EU, 2018/2001) establishes a binding EU target of at least 32% for 2030 with a review for increasing this figure in 2023. The revised Energy Efficiency Directive (EU, 2018/2002) sets a 2030 target of 32.5%, also with a possible upward revision in 2023. The new Governance Regulation (EU) 2018/1999 includes the requirement for Member States to draw up integrated National Energy and Climate Plans for 2021 to 2030 outlining how to achieve the targets and submit the draft to the European Commission by the end of 2018. (EC, 2019a)

The **Renewable Energy Directive** (EU) 2018/2001 (RED II) defines 'district heating' or 'district cooling' as the distribution of thermal energy in the form of steam, hot water or chilled liquids, from central or decentralised sources of production through a network to multiple buildings or sites, for the use of space or process heating or cooling. This revised directive has several important aspects for DH and cooling and its upgrading measures included which are summarised here. The content of RED II needs to be transposed by the Member States into national legislations:

- District heating and cooling currently represents around 10% of the heat demand across the Union, with large discrepancies between Member States. The Commission's heating and cooling strategy has recognised the potential for decarbonisation of DH through increased energy efficiency and renewable energy deployment.
- Member States should, in order to facilitate and accelerate the setting of minimum levels for the use of energy from renewable sources in buildings, allow, inter alia, the use of efficient district heating and cooling or, where district heating and cooling systems are not available, other energy infrastructure to fulfil those requirements.
- Member States should, in particular promote energy from renewable sources in heating and cooling installations and promote competitive and efficient district heating and cooling.
- In the area of DH, it is crucial to enable the fuel-switching to energy from renewable sources and prevent regulatory and technology lock-in and technology lock-out through reinforced rights for renewable energy producers and final consumers, and bring the tools to final consumers to facilitate their choice between the highest energy-performance solutions that take into account future heating and cooling needs in accordance with expected building performance criteria. Final consumers should be given transparent and reliable information on the efficiency of district heating and cooling systems and the share of energy from renewable sources in their specific heating or cooling supply.
- In order to protect consumers of district heating and cooling systems that are not efficient and to allow them to produce their heating or cooling from renewable sources and with significantly better energy performance, consumers should be entitled to disconnect and thus discontinue the heating or cooling service from non-efficient district heating and cooling systems at a whole building level by terminating their contract or, where the contract covers several buildings, by modifying the contract with the district heating or cooling operator.

In any upgrading project, national and local policies need to be considered. This concerns the legal aspects of the individual upgrading measures, but especially also the long-term strategies and developments, e.g. impacted by the RED II. Policies on energy transition, closure of coal CHP, and sector coupling should be considered which may be included in policy documents, such as National renewable energy action plans (NREAPs), special plans, local environmental action plans, sustainable energy action plans, or energy efficiency action plans (EEAPs).

4.2 Stakeholders

DH systems may include several stakeholders. Very important ones are the **consumers** who pay for the heat supply and thus sustain the DH grid as well as the building owners and landlords. Heat consumers can be public consumers, households, private companies and the industry. It is important to satisfy their expectations and to offer high services at competitive energy supply such as natural gas heating systems or individual heating systems. A crucial aspect is the heat price.

Another important stakeholder is the **heat supplying organisation** which can be a single company or several companies in charge of the different services such as heat supply or grid operation. In many cases, this will be a single company or at least closely related companies. With the overall upgrading of DH, it is likely that more heat generating organisations may be involved. For example, if waste heat is newly integrated, the new provider will be another important stakeholder.

A large impact on the overall business model of the upgrading project is the **ownership** nature of these heat supplying companies as they could be publicly or privately owned or a combination of them (see business models, chapter 4.6). In some cases, also the heat consumers can be shareholders, or become shareholders during the upgrading process. This may be very relevant for covering the potentially high investment costs of upgrading measures.

A special role in the upgrading process have the **managers and technicians** of the heat supply organisations. They know the technical and managerial details and will make decisions on the individual upgrading measures. However, it is highly recommended to also involve independent **external experts** and consultants that have the expertise and experience in implementing upgrading projects. As external persons, they have a different view on the system as well as experiences from upgrading other systems. An important factor is to consider the upgrading of the overall system and thus, to elaborate long-term strategies and solutions and not only small adjustments in order to solve little individual problems.

Independent of the ownership nature of the heat supply organisations, **politicians** may play a key role in the upgrading process, as they can actively promote or block any measure. Of course, they have more influence in public organisations, but also for private organisations they can be crucial. For example, they have an influence on the strategic plans, energy plans, and on issuing permits which may facilitate the implementation of upgrading measures.

For a sophisticated upgrading process, it may make sense to make a **stakeholder analysis** describing the objectives and relationships of the different parties. This could result also in some recommendations on how deeply to involve the different stakeholders, especially the heat consumers, in the upgrading procedure.

4.3 Financial analysis and options

A very important part of every upgrading project is the calculation of its financial viability because the project will most probably not be implemented if the profitability is not proven to the investors or owners. The advantage of DH upgrading projects is that the investor is usually the company which already operates the existing system and therefore the minimum payback time can be longer than in the case of new systems built from scratch. In order to calculate the project viability, a detailed feasibility study must be elaborated. Therefore, all the costs and revenues during the project lifetime must be defined. Costs can be divided to capital costs and operational costs.

Capital costs include all the investments which must be made in the project in order to implement it. Therefore, they occur at the beginning of the project and prior to the start of operation. These can generally be divided into costs for planning, feasibility studies and documentation, technologies and for civil works.

Operational costs can be different with regards to the type of the upgrading project. They can include insurances, interest expenses, costs of labour, property taxes, utilities expenses and depreciation of assets. Furthermore, if the heat generation systems are upgraded, an important aspect in the analysis are the fuel costs.

In order to complete the analysis, the benefits of the project also must be defined, i.e. the expected revenues during the lifetime of the project. These can vary significantly with the type of the project. For example, revenues can include increased sales of heat, reductions of fuel use, additional revenues from the added commodity, etc.

DH upgrading projects are often capital intensive, with significant upfront costs. Therefore, a bank loan is necessary in order to implement the project. The exact amount of loan depends on the existing capital of the investor, i.e. the equity or personal investment of the project investor, which is usually in range of 15-30% of the overall investment. The rest is then covered by loans or grants if possible.

4.4 Permitting procedures

After the feasibility study is performed and after it is decided that the upgrading project will be implemented, the next step will be to assess if permissions are needed. This depends on the planned activities. Many upgrading activities, such as the replacement of single components that do not have impacts of public interest, may not require permissions. However, many activities that may impact the public (economically, environmentally or socially) may require permissions. Furthermore, the type of permits and the time that is needed to get the permits depends on the local framework conditions and legislation.

A major difficulty for getting the permits in upgrading projects is the complexity of the measures if several upgrading measures, such as for the heat use, distribution and generation, are planned at the same time. Especially the permitting procedures for the heat generation technologies can be very time consuming. This is especially the case when geothermal sources are involved. It can take several years to get a permit.

The more technologies and options are included, the more challenging is the permitting procedure. Often, also several authorities are in charge for issuing the different permits. For example, the European Commission has listed several challenges in relation to getting the **permissions for bioenergy projects** (EC, 2019b):

- Too many process steps and permits issued by separate authorities
- Permits are subject to a wide range of legislative acts
- A lack of clear timetables
- A lack of local knowledge and capacity to analyse complex bioenergy permit applications
- A lack of clear procedures to obtain energy grid access
- Local resistance to bioenergy projects

The following section describes some aspects related to permitting procedures relevant for upgrading projects, without having the ambition to be complete.

Spatial planning / planning permissions

Spatial planning (sometimes also referred to urban planning, landscape planning) includes methods and approaches used by the public and private sector to plan the use of land at various scales, but usually at larger scales. It coordinates the practices and policies affecting spatial organization. Special planning may include use, urban, regional, transport, infrastructure, and environmental planning. Spatial planning takes place on local, regional, national and inter-national levels and often results in the creation of a spatial plan.

These spatial plans may have an impact on DH grids, as they may include e.g. priority areas for grid extensions. Furthermore, they may influence the issuing of permissions, such as planning permissions. For instance, the construction of a new CHP plant may be permitted only in a dedicated zone of the spatial plans which is rather industrial than residential.

For the integration of solar heating in DH, usually ground mounted collectors are used for which a planning permission for the area (local plan) might be needed. However, also for rooftop solar collectors or collectors used as carports, a local planning permission may be needed. The risk for environmental damage from solar collectors is very low. There can be leakages from collector fluids to the ground, reflection disturbances from the solar collectors, or esthetical “damages”. These problems are normally handled in the planning permission, so that a special environmental permission can be avoided. (SDH, 2012)

Building / construction permits

A building or construction permit is usually required to comply with national, regional, and local building codes. It may be related to spatial planning and planning permissions. Generally, the new construction or refurbishment must be inspected during construction and after completion.

For upgrading projects, this may be required for the construction or refurbishment of any new buildings for heat generation, but also for the construction of the piping grid. For example, a building permission is normally not needed for ground mounted solar collectors unless a building or a storage tank is included. For roof mounted collectors a building permission might be needed since it must be proven that the weight of the solar collectors is not too high for the construction (SDH, 2012).

Environmental permissions

Depending on the nature of the upgrading measure, an environmental assessment (EA), environmental impact assessment (EIA) or sustainability assessment (SA) may be needed in order to obtain an environmental permission, e.g. according to the Federal Emission Control Act in Germany. It may regulate the protection of people, animals, plants, soil, water, atmosphere and cultural assets from pollution and emissions. Hence, it regulates impacts on air, noise, vibrations, water, people and similar issues.

Environmental permissions may be especially relevant in an upgrading project for the heat generation facilities, especially if it is related to combustion technologies, as applied for biomass installations. For solar thermal collectors, impacts could be caused by the leakages and emissions of collector fluids (e.g. water, glycol) to water bodies (SDH, 2012). For example, in water sensitive areas, it may be a requirement to only use water and no glycol in the collector cycle. For ground source heat pumps and geothermal plants, in addition to the environmental permission, also permissions on mining or ground water may apply. Furthermore, it may be required to conduct also an EIA for the heat distribution in a piping network.

Permissions according to heat planning / energy planning

Heat plans or energy plans might put restrictions on the kind of fuel used for heat production. For instance, a new biomass boiler cannot be approved together with a natural gas fired CHP-plant in Denmark and solar DH can only be approved if socio-economic aspects are positive (SDH, 2012). Especially issues on grid access in the power generation sector, which can be linked to DH through CHP facilities or through-power-to-heat projects, regulations on energy planning may apply.

4.5 Contractual issues

The implementation of upgrading projects for DH may require concluding a set of different contracts with the involved stakeholders. A very good legal document which specifies essential contractual issues of the DH utility with the heat consumers (heat supply contracts with the heat consumers) in Germany is the so-called Directive on the general conditions for the supply of DH (Verordnung über Allgemeine Bedingungen für die Versorgung mit Fernwärme; AVBFernwärmeV) (BMJV, 2019).

Another very good overview on contractual issues for small DH systems is provided in a guideline by Laurberg Jensen et al. (2017) which basically also applies to many upgrading projects. Hence, extracts from the guideline are briefly summarised below.

The heating and cooling business is regulated in Europe and there are regulative means to mitigate risks of monopolism. DH is a local issue where customers, employers, owners and production facilities remain principally the same decades after decades. Contracts and legislative obligations are ensuring the quality of the DH service and the protection of the heat consumer rights. (Laurberg Jensen et al., 2017)

Moreover, in the development phase of DHC projects, contracts provide risk mitigation and a reliable fundament for the technical layout of the DH project size. In general, it must be highlighted that the most important contracts in DH projects should involve professional advice of a lawyer. Contracts must comply with different legal frameworks and therefore, it can be difficult for an unexperienced person to prepare a binding document that will define all aspects of the heat supply and consumption transparently and clearly and in accordance with national legal and regulative framework. (Laurberg Jensen et al., 2017)

For DH upgrading projects, the following contracts may apply:

- Planning and construction contracts with implementing companies
- Heat supply contracts with the heat consumers
- Ownership contracts with shareholders
- Contracts with energy regulators and utilities
- Contracts with fuel suppliers (for bioenergy projects)
- Land access contracts
- Operation and maintenance contracts

Usually the heat supply contract for households and public buildings in force are publicly available, so new projects can use them as template. On the other hand, the heat supply contracts for industry are rarely publicly available. (Laurberg Jensen et al., 2017)

4.6 Business models of DH upgrading projects

Business models for DH upgrading projects are project specific. They are characterized by the following aspects:

- Strategic objectives (objectives on public targets, company issues, cost reduction)
- Ownership structure
- Investment plan
- Economic aspects: revenues, profit, non-profit
- Contractual and permitting issues
- Involved stakeholders

A sustainable business model should enable all the involved stakeholders, i.e. investors, end users, local government, etc. to achieve the planned benefits. For investors and end users, the most important are financial returns, however, for the local government the required benefits could be also social, environmental, etc. The local government is often included in such projects at least throughout procedures and documentation which are dictated by the legal framework. However, different ownership models can be applied for DH upgrading, depending on the already existing structure. A guideline for small renewable heating and cooling grids, which partly also applies to upgrading projects, is provided by a guideline by Sunko et al. (2017). Usually, three different models can be applied, i.e. fully public model, the public private partnership or private model.

In the **fully public model**, the risk of investment is covered by the municipality or city and the project is implemented by the public utility. If it has a lower internal rate of return, it can be spread across other projects of the public utility with higher rates of return, that way reducing the risk.

In the **private model**, the project is completely developed and implemented by the private investor, in which cases they seek to maximise the profit. However, a form of private ownership can be a cooperative, where citizens decide to invest in the system and where no profit is needed, leading to lower heat prices.

Finally, the **public private partnership** has gained popularity recently since it merges the benefits of both public and private partner involvement. In this kind of a partnership the private investor participates in designing, investing, building, owning and operating the energy supply system for a certain number of years, normally 15 to 25 years.

5 Technical upgrading options

Besides the non-technical upgrading measures, the technical upgrading measures are equally important, if not even more important. They are including the integration of new technologies, the optimization of existing technologies, as well as the and replacement of worn out equipment and components. Technical upgrading measures can be classified as shown in Figure 22.

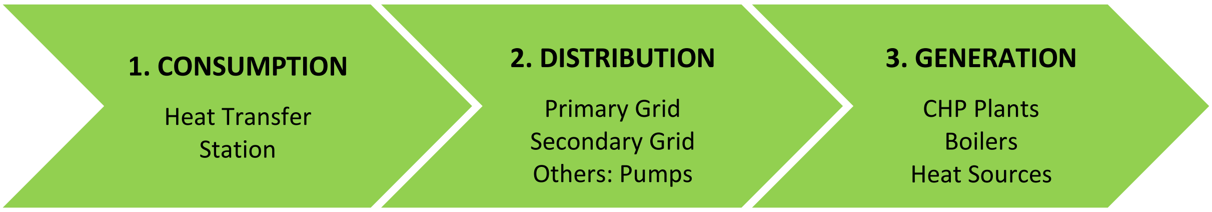

Figure 22: Classification of technical upgrading measures (Roth, 2018)

As already mentioned in chapter 3.2, it is essential to assess the actual condition of the complete DH system, starting with heating systems of the consumers and substations followed by the heat distribution (distribution and transmission network) and the generation plants. As a basis to start the technical upgrading process, the template “Global assessment of district heating systems” (Miedaner et al., 2018) can be used for assessing the initial state. It also includes guidance on assessing individual system components which are shortly described in the chapters below (5.1.1; 5.2.1; 5.3.1). With the collected data of the assessment template it will be possible for experts to get a first overview and hints of most relevant areas, where upgrading and optimisation measures could “best/ easiest” (based on experiences) lead to improvements on the DH systems.

5.1 Substations and heat use

The consumption of heat in buildings is a key to the efficient supply of heat. When upgrading a DH network, there are two major points regarding end users:

- Energy efficiency improvements to the building and the way in which heat is used in the building can, of course reduce the overall requirement for energy supply.
- Some existing building heating systems are not adapted to lower flow temperatures and will need to be upgraded.

These two points are partially interrelated, as higher levels of insulation will increase the likelihood that a dwelling can operate at a lower temperature. They are discussed in further detail in the following sections.

5.1.1 Assessment of the heat use infrastructure

The **annual heat supply** is an important indicator for the overall system’s size. Furthermore, it is an element for the calculation of other indicators. Moreover, it is the main source of the DH revenue.

The complexity of the heat use infrastructure is indicated by the **number of heat consumer substations**, especially the connected households. The sizes of the individual heat consumers have an influence of the system’s operation modes. Residential buildings have other requirements to the system than industries. Usually, heat demands of residential buildings are more fluctuating than those of industries. Hence, buildings have high peak loads while industries have high base loads. These circumstances also effect the selection of the heat sources.

The type and method of **integration of consumer substations** has an impact on the overall system. Each consumer substation will create a pressure loss in the system, which will need to be considered when designing the overall system, for example the pump requirement. Factors such as the type of the used valves and the amount and type of heat exchangers should be considered in the infrastructure design.

The **temperature levels** of the customers have an influence on the minimum needed temperature levels of the DH system. Even without the consideration of heat losses and without additional components on the consumer side, the minimum required supply temperature for consumers correspond to the minimum supply temperature of the DH system. Due to varying heating systems, the required temperatures are varying as well. Hence, it is necessary to analyse all temperatures. Another important aspect in this consideration are the design temperatures of the radiators or other heating systems, since these temperatures, together with the net temperatures design the size of the house substations. Often, the radiators are oversized and allow for a reduction of the temperatures. It is essential, that the radiators are equipped with thermostatic valves. In case that buildings were retrofitted with insulation, a reduction of the supply temperatures is possible.

The type and concept of **consumer substations** integration into the overall system needs to be assessed as it makes a difference how the hot water preparation is done. Furthermore, the **pressure losses** due to the main regulation valves and heat exchangers must be assessed. The pressure loss of the valve (KVs value) should be minimum 2/3 of one of the heat exchanger or even more, if the noise emissions allow it. The pressure loss of the valve should be as high as possible, since it is designed for full load. Most of the year the substations are operated at part load which means that the pressure loss of the valve is much lower than in the design mode. Since there is a square relation between mass flow and pressure loss, that means in case of a 50% reduction of the mass flow, the pressure loss amounts to only 25% of its design mode. This again can lead to a very unstable operation of the valve (permanent opening and shut down of the valve) and may cause damage to the heat exchanger and even may have repercussions on the network.

Heat mapping of an area can provide valuable input on the energy consumption. In Figure 23, the size of the dots indicates the total heat consumption of a building whereas the colour indicates whether they are supplied by DH (green) or other supply. Where data on heat supply and consumption is available, this gives a good visual overview of areas where there should be focus on reduction of consumption and/ conversion to DH and low carbon fuels.

Low DH supply temperatures can be challenging regarding the heat supply in buildings. To ensure that comfort levels in building are met and that hot water is supplied without risks of legionella, careful consideration of the buildings to be supplied by a low temperature network must be undertaken.

In areas where new buildings will be connected to low temperature DH, the heating systems in the buildings can be designed for lower temperatures. Typically, this will include:

- Underfloor or surface heating wherever possible
- Where underfloor heating is not possible, radiators should be sized according to the operational temperature
- The building design should avoid water tanks and long piping on the hot water system

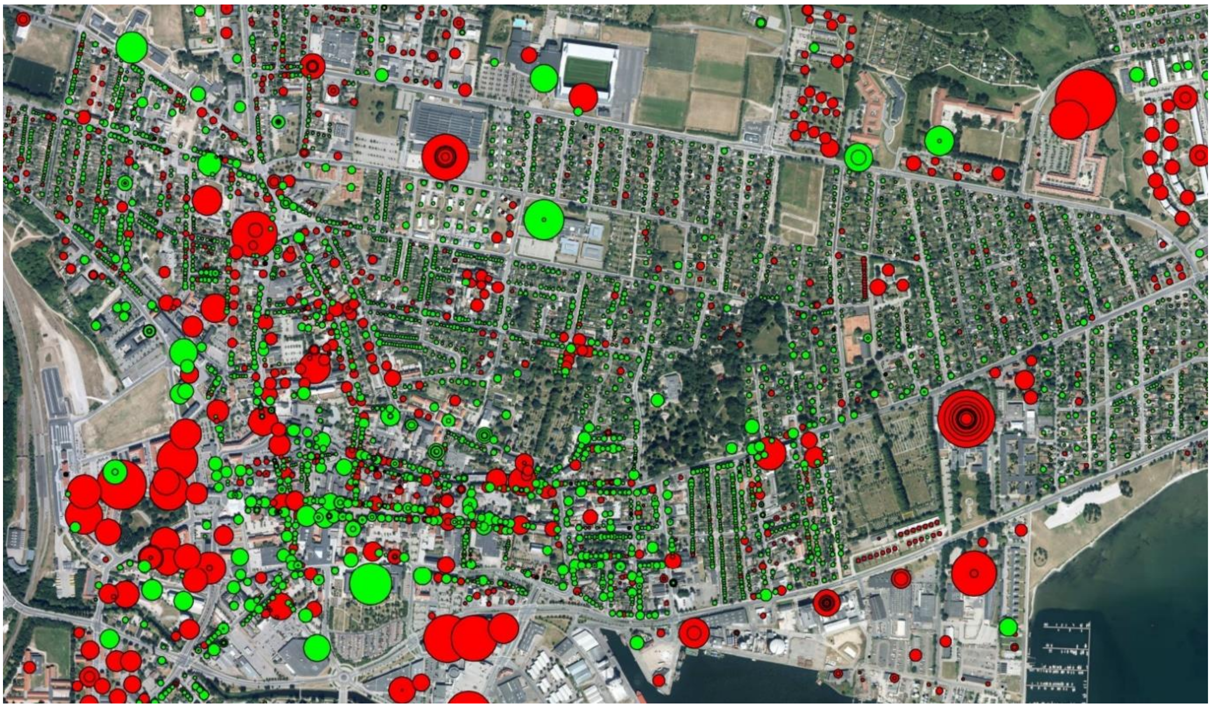

Figure 23: Energy Consumption and Supply (Source: COWI A/S)

It can be challenging to connect **existing buildings** to very low temperature networks, if the buildings were originally designed to be heated with much higher temperatures. In some cases, particularly in older buildings, improvements in insulation levels can mean that the original radiators are oversized for the current heat losses of the building. In this case, lower temperature supply could be possible. In other cases, extensive refurbishment of the internal heating system could be the only option.

Hot tap water supply via a low temperature DH system can also be a challenge in existing buildings due to the risk from legionella. This issue can be managed using a specially designed heat exchanger, which contains a small electrical element specifically for hot water.

Improving the **energy efficiency of existing buildings** is a major challenge, which is difficult to implement in the private sector. Although building regulations, policies and incentives try to stimulate improving energy efficiency, many buildings are still highly energy demanding. The long lifetimes of building materials compared with the slow rate of renovation mean that the energy use of existing building stock is slow to change.

A study from the University of Aalborg in Denmark (Wittchen et al., 2014) gives an indication of the expected energy consumption of the existing building stock in the year 2050, if energy renovations will be carried out in line with the building regulations. This is shown in Figure 24.

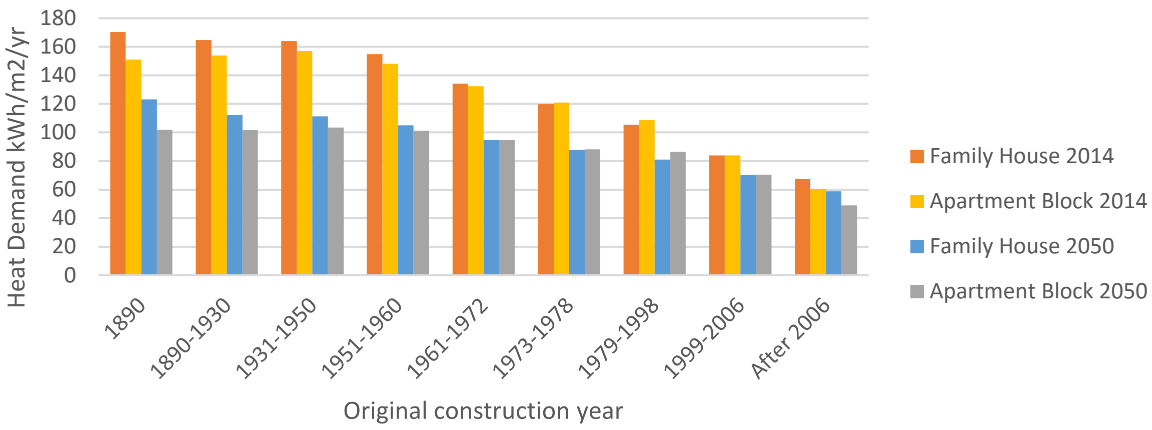

Figure 24: Potential for reducing energy demand 2050 (Source: Wittchen et al. 2014)

Although it is based on Danish data and energy efficiency improvement rates, it shows that a significant reduction in heat consumption could be achieved, particularly for those dwellings built before the 1970s which have a reduction in heat consumption of up to 30% per m².

In contrast to incremental changes, a **total renovation plan** (overall upgrading strategy) gives an opportunity for significant gains in all areas of efficiency and facilitates development of a low temperature network. This is the case in Albertslund, Denmark, where the local municipality has a goal that their entire heat and electricity supply will be carbon neutral by 2025. A part of the implementation of this involves replacing the entire old DH network (established in 1964, with a current operating temperature of approximately 90ºC) with a low-temperature network (with an operating temperature of 50-60ºC).

Most of the dwellings in Albertslund (Figure 25) were constructed in the 1960s and 70s and therefore represent a challenge in relation to low-temperature heating. Insulation standards and heating installations are not designed for a low flow temperature and cannot provide adequate heat with flow temperatures of 50ºC. The municipality has an ambitious programme of renovation of buildings to high standards of energy efficiency, which includes improvements to insulation as well as installation of underfloor heating. Apartments are connected in phases in line with the renovation plan and the termination of the high-temperature distribution system. The low-temperature circuit is supplied via the return from the "old" DH system, which is mixed to 55°C through a shunt valve.

Figure 25: Buildings in Albertslund, Denmark before (left) and after (right) refurbishment (Source: COWI)

5.1.2 Retrofitting options of substations

Several different options on how to connect the consumers to DH exist. This can be divided into the following three **connection options**, as it is shown for multistore buildings for example in Figure 26. The first option is the traditional one with a central substation in the basement of the multistore building. In the second option, the so-called flat station solution, includes in addition to the central substation, also micro heat exchanger in the flats. Finally, the last option is to have flat station solutions without substations.

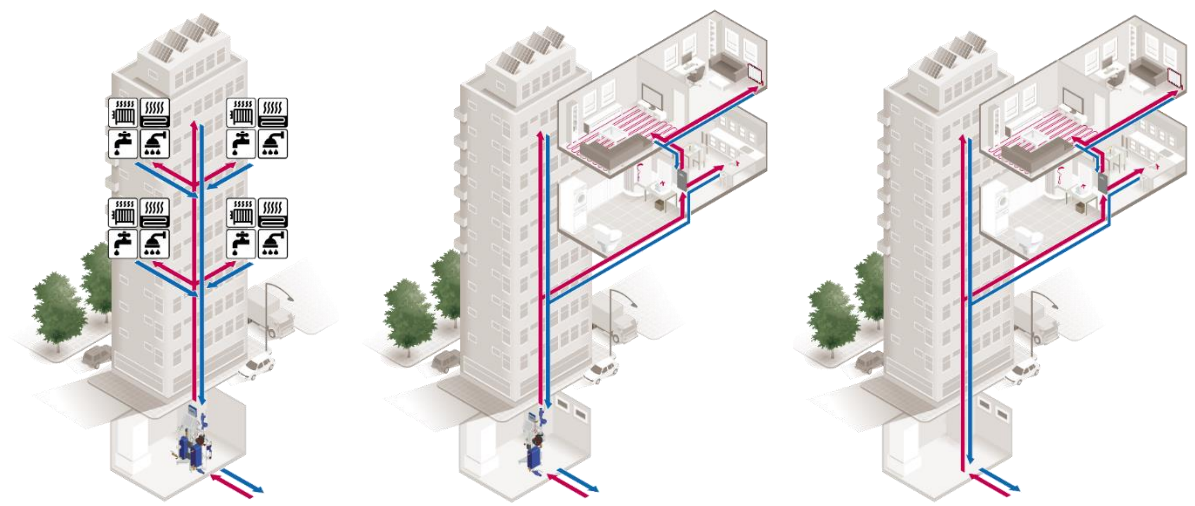

Figure 26: Connection concepts of households to DH (Source: Alfa Laval / Cetetherm – COOL DH project)

Traditional DH stations often include domestic hot water tanks for load levelling and for ensuring a sufficient low return temperature. However, for multifamily houses well designed heat exchangers (5 pipe connections) will do the job just as well. Where water quality is "hard" it is recommended to install a water softener before the heat exchanger for domestic hot water in order to avoid scaling.

The advantage of using well insulated **micro heat exchangers** in the flats is that the DH supply temperature can be reduced to about 8°C above the required DHW temperature, which in some cases is down to 45°C, when the volume of hot water is less than 3 litres in the pipes.

The combination of a lower number of risers (the vertical pipes shown in Figure 26), no need of DHW tank, and lower temperatures, reduces the overall heat losses. However, the cost will be slightly higher than the traditional solution.

Direct coupled DH heating, which is not very common today, requires radiators with higher pressure rating and clean DH water. The advantage of such system is a lower return temperature and less cost. This practice is only used in few places e.g. in Denmark.

For direct coupled systems it is needed to have two monitored flow meters one for the supply and one for the return pipe. Furthermore, shut-off valves are needed to automatically close the connection to the DH system in case of a detected leakage.

Smart metering with data transfer in real time from the energy meter can, besides information on energy use and patterns, also give information on poor delta T, high return temperatures, as well as undesired fluctuations that can be addressed by the DH company. Furthermore, the collected data can be used to detect leaking pipes in the ground which can cause high heat losses.

Remote control can also include an on/off control device to adjust space heating so that the buildings themselves can act as a peak load shaving device during periods with high demand for preparation of domestic hot water.

5.2 Heat distribution and piping technologies

An essential part of the DH systems is the heat distribution network, which connects the heat generators with the heat sinks. Usually, the heating network consists of a supply pipe delivering the hot water or steam from the source to the sink, as well as of a parallel return pipe which returns the "used/cold" water back to the heat generators. The objective is to guarantee a reliable heat supply which is adjusted to the grid needs and which is as efficient as possible.

To achieve this, different **piping technologies** are available, which vary in size and characteristics. In the DH history, many different piping technologies have been used, some have not survived because pipes turned out to fail prematurely or because of unsatisfactory energy efficiency. Others have proven their robustness over decades. (Frederiksen & Werner, 2013)

The choice of the appropriate piping system is mainly affected by the medium (steam or water), temperature level, amount of heat that should be transported and the grid length. Development goals for new heat distribution technologies are usually to reduce investment costs, needed space, installation time and operational costs.

5.2.1 Assessment of the heat distribution infrastructure

The **network's length** gives information about the expansion and widespread of the network. This information is an important element to calculate performance indicators like the heat-use-density. Thereby, not only the total length is an important information, but also the accumulated length of the pipe type with a certain diameter.

The **connected load** reflects the sum of the entire heat load of all buildings, without any net simultaneity factor. The simultaneity factor means the network input (maximal load sum of all heat generation facilities at the same time, usual in the past year) in *MW* divided by the connected heat load in *MW* is a very important performance factor. The factor should be lower than "1". The lower the factor is, the better and more economical is the performance.

The **age of a DH network** together with the actual technical condition of a network gives an indication, whether the operation mode is o.k. or if it needs improvement. It is important to know, whether the operation mode (temperatures, pressures, etc.) have changed in the past. The operation and maintenance costs, the age and the present condition can help to draw up an investment plan for the network.

The main **characteristics of the network** must be known such as if it is a primary or secondary network. Furthermore, it is essential to know what kind of piping has been installed: pre-insulated pipes, channel type, over ground pipes, etc.

The **quality** of a DH network can be described by following indicators:

- **Number of refills per year**: Refills mean how often the complete water volume of all pipes has been changed in one year. This assumes, that the water losses have been measured. The water losses can be measured through measuring the water, which has been treated and refilled into the network at the water treatment plant, also called make-up water.

- **Corrosion**: Corrosion inside or outside corrosion. In case of inside corrosion the water quality has to be improved at the water treatment plant see (AGFW FW 510 2018). Outside corrosion can appear in channel type pipes or over ground pipes. Inside corrosion should never appear.

- **Condition of the channels in case of channel type pipes**: Very often channel type pipes are or have been flooded, due to either corrosion, or because of the channel has been flooded through ground or rain water. If a channel has once been flooded, the heat losses will rise, and the performance gets worse. These channels can be detected by thermography. Channel type pipes should be retrofitted by pre-insulated pipes.
- **Heat losses**: Heat losses should be as low as possible. It is therefore important to know how high they are and how they were determined (see also "number of refills per year" above).
- **Water temperatures**: The lower the temperature of a system is, the higher is usually the efficiency and the easier is the integration of renewables. Heat losses decrease with lower operation temperatures. If there is a gliding temperature operation mode, it should be stated, how it looks like, for example one Kelvin outside temperature change causes *3.5 K* flow temperature change, etc. Normally, DH systems are always operated with a gliding temperature mode.
- **Number of shut downs**: In case that the network will be shut down for maintenance reasons, dilatation zones (U – pipe expanders) must be fixed, before reducing the temperature below 80°C in the flow pipe. Otherwise the network can suffer afterwards from statically failures. If networks are shut down, specific repair methods must be adapted.
- **Failures per km**: The number of anomalies/failures per km pipe trace and year should be as small as possible.
- **Water quality**: The water quality should coincide with the standards, such as e.g. with the AGFW FW 510 2018 standard in Germany.
- **Statistical information**: The number of connections, connection load per km pipe trace or heat demand per km² are just statistical figures and serve as an indicator for heat density.

The **networks pumps** are one of the major electric energy consumers. Oversized pumping capacity or out-of-date technologies do often result in high operation costs. Furthermore, they highly influence the performance indicator of kWh_{el}/MWh_{th}. This means *kWh* electricity of pumping energy divided by *MWh* heat sold. High values indicate some problems with the network and or network pumps. Thus, the control of pumps is very important. Frequency controlled pumps are state of the art. The size of the network pumps should be carefully calculated by using any proved hydraulic calculation model and they should be controlled according to the point in the network with the lowest differential pressure, which should not be less than 0.7 bar.

5.2.2 Lifetime of DH pipes

The evaluation of the remaining service lifetime of DH pipes can be easily assessed with a simple questionnaire or template. The **lifetime of DH pipes** depends on multiple factors related to the environmental conditions, but also to the operational management. For example, it depends on the temperature levels, temperature variations, and on the circuit water quality. The end of the lifetime could result in leakages, but also in thermo-mechanical fatigue or thermo-oxidative ageing phenomena leading for example to a reduction or loss of the insulation properties. The calculated service life of plastic jacket pipes is at least 30 years (AGFW FW 401, 2018), but there are many examples of installations running for much longer periods without any problems.

The **long-term behaviour** of the pipe mainly depends on the thermo-stability of the rigid polyurethane foam and how it is bonded to the flow pipe. Long-lasting high temperatures cause thermal degradation, which lead to a reduction in strength (AGFW FW 401, 2018). However, due to the short lifespan of existing DH networks compared to other infrastructure systems, there is a lack of long-term experience for lifetime estimation of the system components. There are different approaches for the life cycle assessment of infrastructure networks. These include statistical lifetime models, thermal aging models and damage accumulation theories. All methods for estimating the (residual) life are subject to uncertainties.

An important characteristic of DH pipes is its tolerance to temperature changes of the heat transport medium (circuit water). These changes put large forces between the soil and the piping system, as the pipes expand or shrink with changing temperatures. An indicator that describes this tolerance is the number of full load cycles that a system should at least withstand until it fails. A **full load cycle** is the largest temperature spread between the temperature during the installation of the system and the maximum operating temperature. The absolute number of tolerable full load cycles varies largely between the different types of DH pipelines and provides an indicator for the layout of the system. With increasing shares of renewable energies in DH systems, it is expected that temperature changes in the DH piping are increasing (Sauerwein, 2013a, 2013b).

Depending on the intended operation of the pipe for 30 or 50 years, different numbers of full load cycles are expected as shown in Table 4.

Table 4: Calculated of full load cycles for different pipes (based on AGFW FW 448, 2018; prEN 13941)

	Calculated full load cycles for 30 years	Calculated full load cycles for 50 years
Transmission pipelines	100 – 250	170 – 420
Distribution pipelines	250 – 500	420 – 840
House connections	1,000 – 2,500	1,700 – 4,200

For the assessment of heat distribution infrastructures, there does not exist a 100% correct procedure that can be suggested. There are ongoing research activities to improve the quality for the estimation of remaining service life or the evaluation of a current status (AGFW, 2015, 2018a). However there exist some procedures that enable conclusions on the current status of a DH pipe (system).

One option is to perform a simple **condition check of the piping system**. For this purpose, a visual observation and a check of important characteristics like heat, pressure and water losses can provide initial evidence. Applicable methods and technologies for condition check procedures and the identification of deviations in DH pipelines are described in the acknowledged rules of technology for DH, cooling and CHP published and periodically updated by AGFW (2018). The included procedures of (AGFW FW 435, 2018) are classified into seven groups:

1. **Operational techniques**

   These techniques use system parameters and measurements to detect leakages. Frequent critical pressure drops, or frequent refill of DH water are indicators for leakages in the system. The techniques allow a better localisation and contribute to a more effective implementation of further measures.

2. **Visual procedures**

   The visual inspection of piping condition is essential for the assessment of maintenance status of piping systems. Identified defects which have not yet led to a failure, can be investigated and evaluated. These defects effect the planning of maintenance measures and strategies. In addition to the preventing usage, visual procedures can also be applied to locate the actual spot of leakages in the system. The visual instrument Crawler-Eye is described more detailed in the catalogue “upgrading instruments” (Upgrade DH, 2018c) of the Upgrade DH project. In practice, the use of thermal imaging via airplane gives a further benefit. With simultaneous network mapping, it is possible to document the true network rout. Especially for old networks, the documentation is often inadequate, incorrect, or even lost.

3. **Mechanic-technological procedures**

   Mechanic-technological procedures includes the wall thickness measurement of the pipes by ultrasound. The results allow an investigation of the material condition and are used as indicator to estimate the remaining operating live time of the pipe and improve the planning of maintenance measures.

4. **Portable procedures**

   Thermographic procedures and correlation analysis are applied to detect the actual spot of a leakage (based on estimated location of previously applied operational techniques). Both applications allow a precise localisation, but they work with different principles. The instrument thermal imaging via air plane which is rated to the thermographic procedures is also described in the catalogue of upgrading instruments (Upgrade DH, 2018c).

5. **Tracer substances**

   Tracer substances are used to localise the actual spot of a leakage (based on estimated location of previously applied operational techniques). The application of tracer substances does not affect the system’s operation.

6. **Wall thickness measuring by inspection robot**

   The use of inspection robots for the wall thickness measuring by ultra sound improves the quality of results for a more valid statement about the pipeline condition.

7. **System specific / integrated procedures**

   During the installation (and production) of DH pipelines, it is possible to integrate surveillance systems. These systems, for example, are used to check if water ingresses into the insulation. Therefore, a wire is placed in the insulation of pre-insulated pipes that allows, with additional equipment a continuously surveillance. The wire is also recognizable in Figure 29.

Figure 27 Visual inspection with the “Crawler Eye” of the German Institut für Angewandte Bauforschung Weímar gGmbH (Source: AGFW)

Figure 28: Thermal imaging via airplane (Source: SCANDAT GmbH)

Furthermore, the quality of the DH piping system is also influenced by the quality of the **heat transport medium** which is described in AGFW FW 510 (2018). The water quality has an impact on the operation lifetime of the piping network, because it influences the rate of corrosion for the steel made medium pipe. Furthermore, water with insufficient quality can lead to malfunctions in the network caused by deposits in the pipelines or valves. Decisive for the assessment of the water quality are the individual water constituents and their composition. For the application in DH, the corresponding worksheet classifies two operating modes: saline circulation water and low-salt circulation water (AGFW FW 510, 2018). The guiding values for the two different modes are individual, but the assessment criteria are the same. The criteria for the assessment of DH water are:

- Electrical conductivity at 25°C
- Appearance
- pH value at 25°C
- Oxygen
- Sum of alkane earth (hardness)
- Iron
- Copper
- Sulphide
- Sulphate
- Acid capacity $K_{S8.2}$
- Acid capacity $K_{S4.3}$

Since the water characteristics can change over the time, it is advisable to monitor the water quality or implement periodic assessments. Hence, the assessment of DH water quality is a long-term preventive methodology and one of the first indicators for potential further failures (exemplary caused by corrosion). DH water is used in a closed circuit and leakages should be avoided as much as possible. (AGFW FW 510, 2018)

5.2.3 Overview on modern piping technologies

The biggest part of the DH piping system is usually laid underground (mostly in soil) and quite a few are overland or in tunnels or inside buildings.

Underground-laid pipelines

The basic structure of commonly used piping technologies consists of two concentrically placed pipes (see Figure 29). The function of the inner medium pipe (grey) is the transport of medium without leaks, it is surrounded by insulating material (yellow) to reduce the heat losses. The exterior jacket pipe (black) is responsible to protect the insulation and the medium pipe against water and damaging from outside. The up-to-date earth-laid pipelines are additionally equipped with two wires inside the insulation that can help to detect leakages. (AGFW, 2013)

The use of different materials for the three main components characterize the different piping systems. Most common are all-bonded, directly buried plastic jacket pipes, which can also be seen at the different investigated upgrading projects within the Upgrade DH project (Upgrade DH, 2018b).

In **Plastic Jacket Pipes (PJP)** the medium pipe is usually made of steel, but especially with the expansion of low-temperature grids plastic medium pipes can also be used. The jacket pipe is made of polyethylene (PE), or high-density polyethylene (PEHD) and force-fitted by the insulation material, which is made of cellular polyurethane foam (PUR-foam) (Frederiksen & Werner, 2013). Therefore, the pipeline segments were produced pre-insulated.

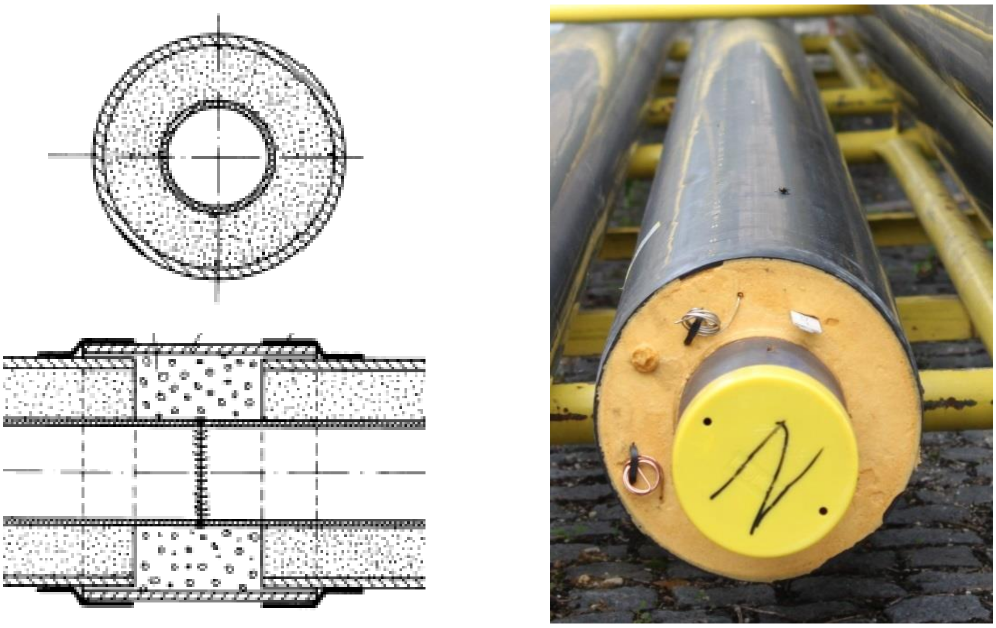

Figure 29: Section drawing of PJP and PJP connection (Source: AGFW, 1993) (left) and PJP pipe (Source: D. Rutz) (right)

For the connection of two pipe segments, the medium pipes are welded, and the jacket pipes are connected by a sleeve. PJPs are not suitable for application above 120°C (continuous operation). Only for a short period of time, the technology can cope with temperature loads up to 130°C-140°C. The common use of PJP pipes are in the range up to DN 600, but diameters with DN 1200 are also feasible. Based on the same technology but only for small medium pipe diameters it is possible to place the suppling and returning pipeline in the same jacket pipe (double pipe/ twin pipe). (AGFW, 2013; AGFW FW 401, 2018)

More information on historical development, joints, formed components, etc. are shown by Frederiksen & Werner (2013). The relevant normative guidelines are “EN 13941 - DH pipes - Design and installation of thermal insulated bonded single and twin pipe systems for directly buried hot water networks” or “DIN EN 253 - DH Pipes – Pre-insulated bonded pipe systems for directly buried hot water networks”.

Another relevant but not so common variation are **Steel Jacket Pipes** where the medium pipe and the jacket pipe are usually made of steel. The heat insulation of the medium pipe is realized by attaching fibre insulation material to the pipe, or by creating a vacuum in the space between the medium and the jacket pipe. Because of the jacket pipe’s material, it is additionally necessary to protect it against corrosion caused by environmental impact (e.g. water) to ensure long-term use. This technology is suitable for applications with supplying temperatures above 130°C. It has benefits for networks with a low number of branch pipelines and therefore especially for DH transport lines with large diameters. (AGFW, 2013)

Another form of underground-laid pipelines are **in-duct laid pipelines**. These pipelines are installed underground as well, but cased in concrete channels, that provide mechanical protection. Because of the construction, the channels contribute to a protection against moisture, which allows good conditions for the pipeline’s insulation. In case of soil with a high level of groundwater, additional measures need to be implemented to keep up the channel’s water resistance. The shape of the channel can vary, one common example is the hooded channel (Figure 30). (AGFW, 2013)

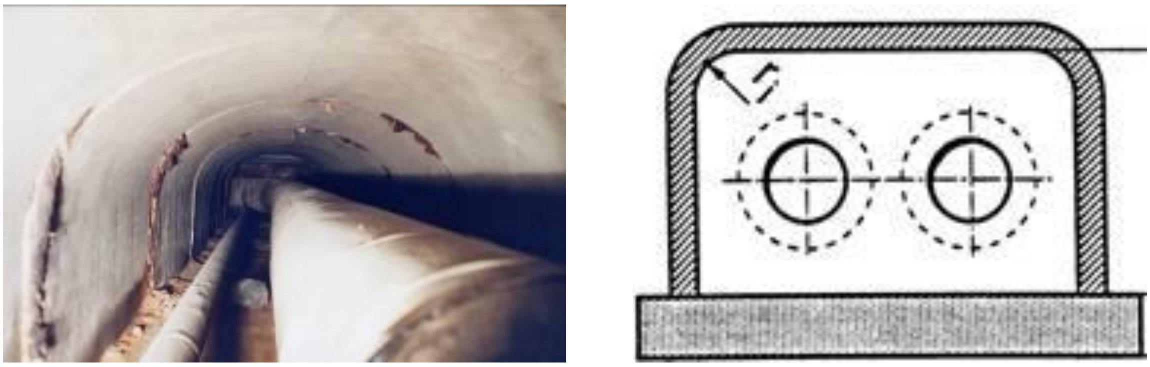

Figure 30: Underground-laid pipeline, picture of a hooded channel (AGFW, 2013) (left) and a rectangle hood according to DIN 18178 (AGFW, 1993) (right)

Hooded channels consist of two parts. The bottom part (“base plate”), is made of in-situ concrete or ready-mix concrete, and the hood is usually pre-built. The pipelines are mounted with bearings on the bottom and roofed by the hood. Due to construction-conditioned small joints, hooded channels are less applicable for soil with much and high groundwater. (AGFW, 2013)

Where space is not the problem, **overland pipes** were sometimes installed. They are a cost-effective alternative solution to realize DH networks. The building methods must consider urban planning and landscape protection requirements. The pipelines can be mounted on concrete bases or steel constructions. Further options for specific local requirements are hanging constructions or piping bridges. Thereby, pipelines can be routed for example, along streets. Hanging pipes can be also attached to bridges. Although the installation of overhead pipelines can be very practical, its rather negative appearance must be considered, especially in urban and inhabited areas. (AGFW, 2013)

Pipelines can be also installed as hanging overhead pipelines in buildings (Figure 31). Thereby, a considerable reduction of construction costs is achievable. Especially in the case of buildings that are close together pipelines inside the cellars or underground car park could be suitable. However, building statistics must be considered. Controlling elements must be accessible and the wall-feed through must be well-planned. (AGFW, 2013)

Finally, it needs to be mentioned that in many DH systems, different types of pipes are used, as systems are often historically grown.

Figure 31: Examples of above ground and overhead pipelines (Source: AGFW, 1987)

5.2.4 Retrofitting options of the heat distribution system

The options to upgrade an existing pipeline are quite limited. In the case of a detected local leakage, considerable efforts are needed to reach these leakages, especially in underground laid pipelines. In this case, a trench must be excavated. The most common retrofitting option, to improve the efficiency of the system, is the replacement of out-of-date with up-to-date technology, which was also described in the best practice examples of the Upgrade DH project (Upgrade DH, 2018a).

The technologies of piping systems were advanced over the last decades and new technologies were developed. New pipes can lower the investment costs, reduce the heat losses and reduce failure risks. Thus, the **replacement of the pipes** is a frequently applied option to upgraded DH systems.

A project in Denmark (Energy Renovation with Focus on Low-Temperature DH in Albertslund; Upgrade DH, 2018a) showed, that it is possible under certain conditions to install an entire new network without exposing the old pipelines. Thereby, it was also possible to decrease the network's operating temperature levels and to allow low-temperature DH. Hence, the systems' heat losses were reduced due to new pipelines as well as by lower temperatures. However, it depends on the legal national standards if the old pipes can be left in the ground as it was the case in this example.

A possibility to improve the efficiency of the distribution system is to **decrease the operating energy demand**, which is mainly caused by the operation of the pumps to circulate the water through the DH system. Their energy consumption cannot be eliminated, but several projects showed significant potentials to optimize their operation and to reduce the consumption of electric energy to a minimum. This minimum is related to the minimum supply pressure. The pressure level at the systems point with the lowest pressure value must be higher or equal to the value of the minimum supplying pressures to guarantee the correct functionality. With a retrofitting of a SCADA system (Supervisory Control and Data Acquisition) and the necessary measuring instruments, it is possible to control continuously the adoption of the network's pressure level, in accordance to the minimum required pressure drop. Due to the SCADA system and additionally implemented VSD pumps (variable speed driver), it is possible to reduce the power demand for heat distribution, without downgrading the security of supply. Besides the implementation of supervising technologies, in the collection of best practice instruments and tools (Upgrade DH, 2018c) a general approach for the "Mass flow adjustment to the actual needs/demands, to save pumping energy and to achieve low return temperatures" can be found.

Another option to upgrade heat distribution systems is the **connection of two separate DH grids,** as it was shown in one of the Upgrade DH best practice examples (Interconnection of Two Separated DH Networks in Italy; Upgrade DH, 2018a). The distribution grid was extended to achieve multiple benefits. Two separated and independent operating networks, with individual heat generation plants, were connected. The achieved advantages were to diversify and improve the fuel mix, to increase the heat use from a waste-to-energy plant, and to acquire new costumers. This was possible as the pipeline, which was installed between the two networks, was routed through a residential area with potential new consumers. This advantage was also considered during the project planning, supported by a special software tools, i.e. Optit's solution for network development optimization. The used software for this calculation as well as other upgrading tools and instruments are described in Upgrade DH (2018c).

Performance monitoring and data collection are retrofitting measures which are aiming mid- or long-term goals. Their influence does not directly affect the system, but it is a relevant step towards a sustainable improvement of the systems. The implementation of software tools, monitoring systems, surveillance systems and data collecting are contributing to identify the system's weak points and initiate continuing upgrading measures. For this purpose, it also includes the identification of faulty components and therefore the planning of maintenance strategies and measures. (Upgrade DH, 2018b)

5.3 Heat generation technologies

As the general trend in the energy sector and the related policies is moving towards 100% renewable energies until 2050, upgrading measures on the heat generation are related to the integration of renewable energies. Any sophisticated upgrading planning process should therefore elaborate and plan the full switch of heat generation from the existing generation mix to a full coverage of renewable energies, even if the short-term actions will only partially replace the existing technologies. This strategic planning will allow long-term cost reductions as all technical changes are planned with the same overall target and thus, technically contradicting short-term measures can be avoided.

For example, in the long-term strategy, the phasing out of coal power generation and the related shut down of coal power plants will require other technologies that substitute the heat generation for DH. As the location of the coal power stations were chosen strategically in the past according to the needs of a coal power plant, it is likely that this location is not the best option for the set-up of new renewable heat generation facilities. Renewable energy generators, which may be much smaller in size may be ideally installed at several decentralized sites, and not at the original site of the coal power plant. Thus, it could be contractionary in the short-term to install these facilities on the site of the coal power plant, even if that would be the lowest short-term cost solution. However, this would usually also require changes in the piping system, as the network is designed for the centralized heat generation system. Furthermore, in some cases, existing coal CHP stations could be upgraded in a way to substitute coal with biomass and thus benefit from the already developed centralized heat generation system, its pipes and other installations. More is described in chapter 5.3.3.

Furthermore, for upgraded DH systems, the linkages between heat generation with the heat distribution and use is much more important, than it was for older DH systems. For example, the integration of solar thermal energy can be more efficient at rather low DH temperature systems, although the integration at higher temperatures is generally also possible. So, the heat demand and temperature level at the heat consumers need to be planned together with the heat generation planning.

The following chapters will give an overview on the currently available renewable energy and heat storage technologies that could be used for the stepwise or complete switch of DH to fully renewable DH systems. Chapter 5.3.8 will then provide some guidelines on how to detect a good mix of the technologies in order to maximize the benefits.

5.3.1 Assessment of the existing heat generation infrastructure

For the assessment of the existing heat generation infrastructure, it is very important to have **maps with all heat generation facilities** and the network available. Besides all generation sites, the maps should include all pumping stations, installed in the whole system. For the generation facilities all inputs and outputs (thermal and electrical) and of course the fuel type and annual demand should be available. With these data, the technical conditions can be evaluated, for example the thermal and electrical efficiency of each generation site. The calculated efficiencies can then be compared with the state-of-the art heat generation facilities and thus describe the technical performance.

It is furthermore important to know the **age** of the important components, like boilers, turbines, water treatment facilities, and network pumps. Taking the performance data, the data about the age as well as the actual operation and maintenance costs into consideration, it is possible to develop an investment plan for the heat generation, according to the needs.

Heat storages serve for a more flexible operation mode of the heat generation. Especially if the heat generators also generate electricity (CHP), storages can be important. According to the size of the heat storage, the CHP plant does not need to work in times of low electricity prices and thus can save money. In times of higher electricity prices, the CHP will work and charge the storage with surplus heat, while the rest of the heat goes directly to the DH system. Operation modes like this become increasingly important, the more fluctuating electricity prices are. The size of the storage and the heat demand of the DH system determine the operation time without using the whole CHP plant for heating supply.

The **provision of cold** from a DH system is a good possibility to increase the heat demand during summertime and thus improve the profitability. Since the heat demand for domestic hot water preparation during summertime accounts only for about 10-15% of the max. winter capacity, the specific heat losses during summer period are rising. Additionally, many CHPs are operating at a lower efficiency, compared to wintertime, due to the part load. Accordingly, every surplus of heat sold during summertime improves the profitability.

Meanwhile, there are absorption chillers on the market, that can operate economically at DH flow temperatures of some 80°C, which reflects the regular summer flow temperature in most DH systems. The experience shows that it is better to sell heat for cooling systems, which supply data centres than cooling for air conditioning.

It is important to know the heat losses of the DH system. In order to determine the **heat losses** precisely, the measured generated heat (cold), as well as the measured heat (cold) sold to the customers are necessary. Most important is that both values must be measured directly by adequate heat meters. Any other method of determining the heat sold, e.g. by m² of living area, is not correct, in this context. It is also important to take absolutely the same period of time for generation and heat sold to determine the heat losses. This means, that the value “heat sold” must be taken from all customers at the same time.

As the upgrading measures may consider the shift towards renewable energies, the assessment of the existing heat generation infrastructure should also include details on the **share of renewables** and its related impacts. The primary energy demand demonstrates the value of consumed primary energy. Compared with the amount of generated heat it is a significant factor for the discussion of the system's environmental performance. The less the value is, the more environmental-friendly is the system. But in this case, the system's capacity needs to be considered. Using the primary energy factor makes it easier to compare systems with different capacities. Like the primary energy demand, GHG emissions are indicators for environmental friendliness. All relevant gases can be converted into CO_2-equivalents and cumulated, in order to allow comparability. Furthermore, the fuel supply illustrates the dependency or independency from other countries.

5.3.2 Integration of solar thermal heat

Solar thermal collectors are widely applied for domestic hot water preparation and for supporting the heating systems, e.g. for individual heating systems in German households. The technology is well developed and uses high standards. Even in colder climatic regions, solar thermal collectors find applications. In Europe, solar thermal collector systems have successfully been implemented in more than 200 DH networks with a minimum power of 700 kW at each plant. A short technical overview of solar collectors for small DH grids is provided by Rutz et al. (2017).

Solar district heating (SDH) plants consist of large fields of solar thermal collectors feeding their produced solar heat into DH networks. The solar collector fields are either installed ground-mounted or on roof-tops. Today, the plant capacities range up to 100 MW_{th} for the presently largest systems installed. Typical shares of the solar thermal plant are up to 20% of the total heat supplied for a complete coverage of the summer load of the DH network. With large heat storages, used also for CHP optimization and power-to-heat, solar thermal shares up to 50% can be reached. Today, competitive heat prices below 50 €/MWh are achieved due to scaling effects and optimized systems.

Solar DH plants find application in a wide range of concepts and within very different boundary conditions. The main differences are:

- **The concept of solar thermal integration in DH:** centralized or decentralized integration (Figure 32)
- **The kind and the size of the DH networks in which they are integrated:** they range from districts or villages to large cities as supply areas

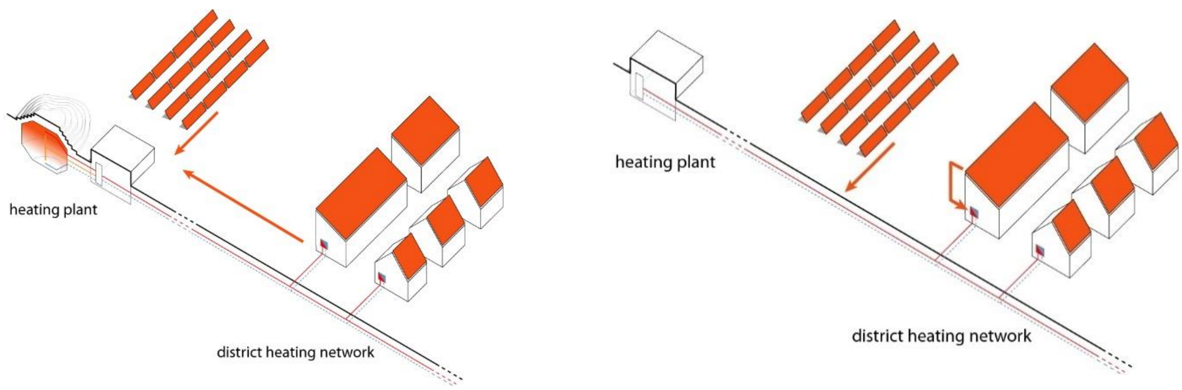

Figure 32: Concepts of solar thermal integration in DH: in central SDH systems, the collectors deliver heat to a central heat distribution unit (left), in decentral SDH systems (right), the solar collectors are placed at suitable locations and connected directly to the DH network (Sources: Solites)

Solar district heating for districts

A local SDH system is a good option for heating renovated buildings or new urban districts. Usually, solar thermal contributes up to 20% to total the heat supply, although the addition of seasonal storage can increase the solar fraction to as much as 50%. As an example of a local SDH system, a biomass heating system was combined in a residential area Vallda Heberg, Sweden, with 680 m² of roof-integrated solar thermal collectors. The system was installed in 2013.

Figure 33: Solar DH in the residential area of Vallda Heberg, Sweden (Source: Jan-Olof Dalenbäck)

Solar district heating for rural communities

SDH can ideally provide heat for small villages and communities. SDH systems delivering heat to towns and communities in the countryside allow for a fast and comprehensive transition to local renewable resources. In Büsingen, Germany, a 1,090 m² collector system provides the entire heat load for 100 buildings in summer, preventing the uneconomical operation of a biomass boiler. This DH network is operational since 2013.

Figure 34: Heating plant with solar thermal collectors in the village Büsingen, Germany (Sources: left: Solites; right: D. Rutz)

Solar district heating for urban areas and cities

Large urban DH networks typically source thermal energy from combined heat and power systems, heating plants, or industrial waste heat. Provided that enough area is available, the SDH integration is one possibility for increasing the proportion of renewable energies in these larger DH systems. For example, in Graz, more than 16,500 m² of solar thermal collectors feed heat into the city's district network and subsystems at several locations.


Figure 35: Solar thermal collector field in Graz, Austria, which feeds into the Graz DH network (Sources: left: SOLID; right: D. Rutz)

Smart district heating

Large solar plants can also be combined with other technologies for heat and power production. Denmark has several smart DH plants. One of them has been installed in Gram and is equipped with 44,800 m² of solar thermal collectors, a heat pump, gas-fired CHP units, an electrode boiler and backup fossil fuel boilers. The plant's pit thermal energy storage measuring 122,000 m³ allows for flexibility in the use of these energy generation technologies to offset power price fluctuations.


Figure 36: Solar DH collector field in Gram, Denmark, with a seasonal pit thermal energy storage (Sources: left: Gram Fjernwärme, right: D. Rutz)

In general, the use of solar thermal heat is possible in many locations. The more southern the location is in Europe, the higher is the irradiation and thus the higher energy outputs could be used. However, for SDH, the **land availability** is a key issue. As a rule of thumb, on one hectare of land, solar thermal collectors can provide up to 2 GWh heat per year. It is the most efficient means to generate renewable heat in terms of land required, as e.g. the cultivation of energy crops requires more land for providing the same amount of energy. However, finding and developing land areas for large-scale solar heating plants, which can be closely connected to the DH system, remain a major challenge for project developers, as the competition of land areas is high, in particular in urban areas. In order to meet this challenge, the following steps have been proven for large SDH projects:

- Analysing possible areas regarding political and legal aspects
- Involving all stakeholders, also including politicians and local citizens
- Considering the overall ecological concept of the area for the collector field

Another challenge for SDH is the **seasonality** and weather-related **fluctuation** of solar thermal heat collection. More heat can be collected during summer when the irradiation is high, whereas in winter, in the season with the highest heat demand, the irradiation is lower. Furthermore, daily changing irradiation needs to be balanced. This challenge is technically tackled by the integration of different storages, which is explained in chapter 5.3.7.

Depending on the overall DH concept, the integration of SDH furthermore needs to carefully consider the **temperature levels** of the supply and return flows. In general, the lower the DH temperature levels are, the more efficient can the solar thermal heat be directly integrated in the system. Figure 37 shows this dependency under German weather conditions, with different collector types and with different DH operation temperatures.

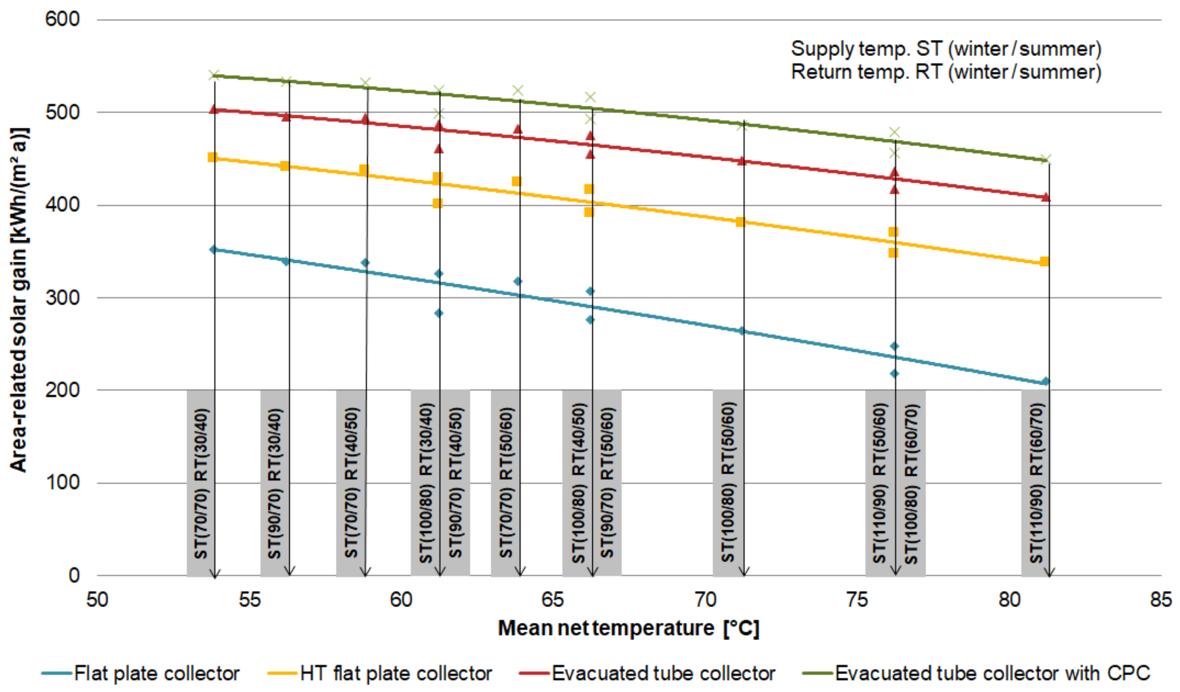

Figure 37: Specific solar heat yield per collector area versus DH network temperatures and collector types (weather data for south Germany) (Source: Solites)

The integration of the solar thermal plant needs to be well designed so that low return temperatures of the DH grid can be heated up by the solar collectors. Most solar thermal plants, which are integrated into DHC networks, are **centrally connected** to the main heating plant. In this case, the solar thermal plant can be integrated parallel or in series as shown in Figure 38 and Figure 39, depending on the complementary heat generators.

A **decentral integration** of the solar thermal plant can be convenient in the case of several smaller distributed collector fields feeding into larger DH systems. In such a case a direct feed-in can be realized (without heat storage). Suitable substations have been developed for this application and allow to feed-in at constant temperatures, even in situations when solar irradiation is strongly fluctuating.

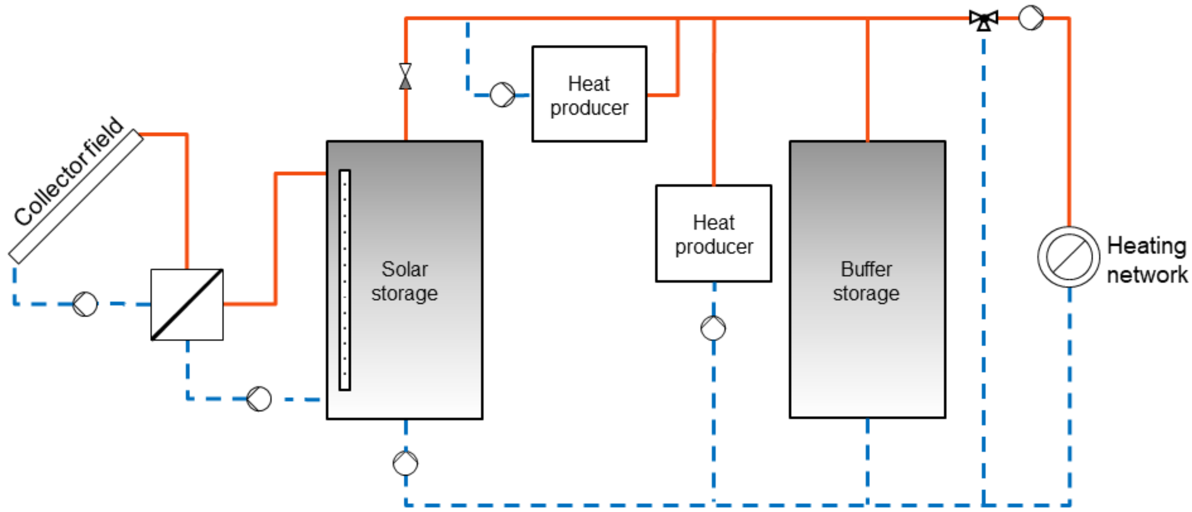

Figure 38: Connection of the solar thermal collectors in series to the DHC grid with a temperature raiser outside the solar thermal storage (Source: SOLITES)

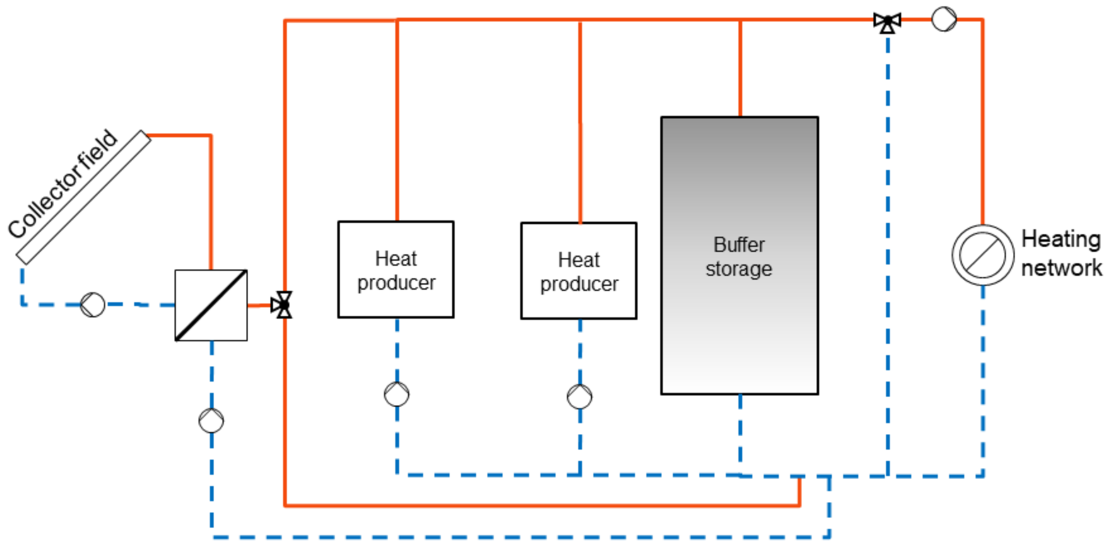

Figure 39: Connection of the solar thermal collectors in parallel to the DHC grid to raise the return flow of the DH grid (Source: SOLITES)

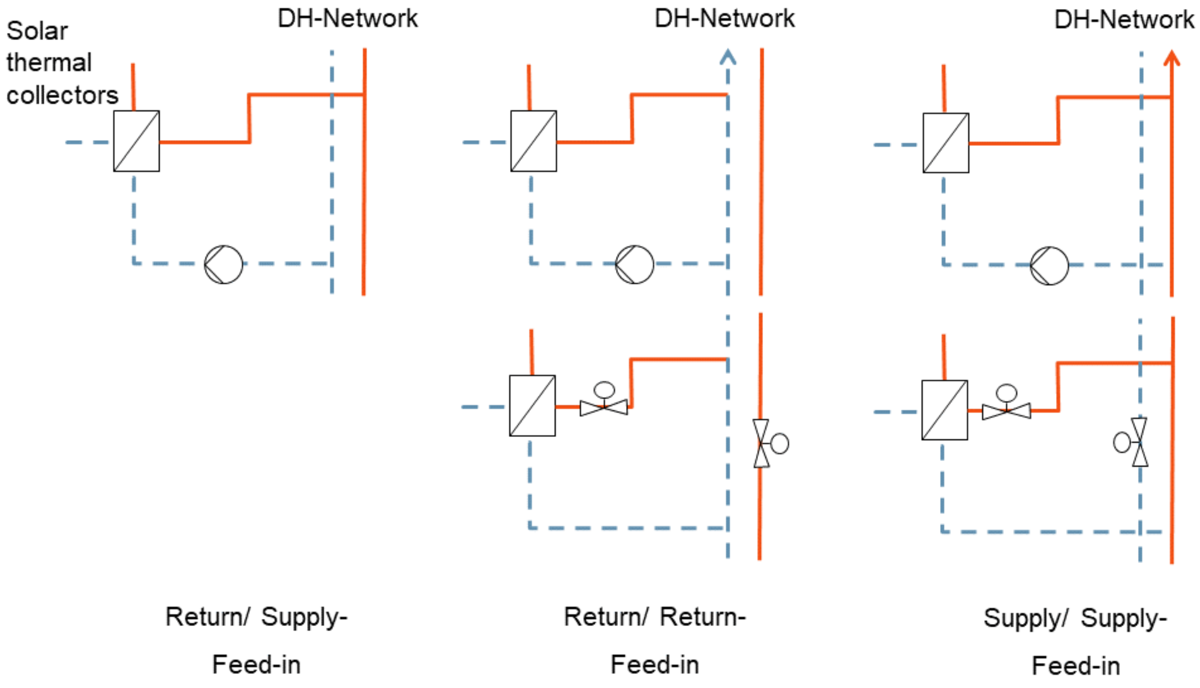

Figure 40: Three concepts of decentral feed-in of solar heat into DH systems with a pump (upper row) or with adjustable valves (lower row) (Source: SOLITES)

5.3.3 Integration of biomass heat

Biomass is the **organic matter** created by living (plant material, humans and animals and their excreta), or recently living organisms. It also includes secondary products when biomass is used, such as bio-waste, paper, wood products, etc. Primary organic matter is produced by photosynthesis of plants that take CO_2 from the atmosphere, water and the energy from the sunlight and build carbon-based compounds. These carbon compounds contain the stored energy from the sun, which can be released again by combustion. More information on biomass use in small modular renewable heating and cooling grids available in the CoolHeating handbook (Rutz et al. 2017).

Biomass is currently by far **the largest renewable energy source** in the EU. In 2012, biomass and waste accounted for about two-thirds of all renewable energy consumption in the EU. To be effective in reducing greenhouse gas emissions, biomass must be produced in a sustainable way. Biomass production involves a chain of activities ranging from the growing of feedstock to final energy conversion. Each step along the way can pose different sustainability challenges that need to be managed. (EC, 2019).

The European Commission has issued non-binding recommendations on **sustainability criteria** for biomass (EC, 2019). These recommendations are meant to apply to energy installations of at least 1MW thermal heat or electrical power. They:

- forbid the use of biomass from land converted from forest, and other high carbon stock areas, as well as highly biodiverse areas
- ensure that biofuels emit at least 35% less greenhouse gases over their lifecycle (cultivation, processing, transport, etc.) when compared to fossil fuels. For new installations this amount rises to 50% in 2017 and 60% in 2018
- favour national biofuels support schemes for highly efficient installations

- encourage the monitoring of the origin of all biomass consumed in the EU to ensure their sustainability.

For DH systems, the use of biomass is generally very interesting, as many different options for the integration of biomass in existing systems are available. As for other RE technologies, the selection of biomass technologies for upgrading DH depends on the current status of the system, the framework conditions and objectives.

Biomass pathways are characterized by many different feedstock sources, technologies and uses. This allows the integration of biomass in many DH systems, depending on the needs of the system. For larger DH systems, the following biomass can be used: bulky waste wood (furniture, from the construction, painted wood, etc.), saw dust, wood chips from forests (residues, energy wood), wood chips from short rotation coppice (SRC)[2], industrial pellets (wood pellets, mixed biomass pellets), torrefied biomass, biomethane (from anaerobic digestion of bio-waste), and pyrolysis oil. A key challenge for the use of biomass, especially for larger and centralized plants are the logistics of biomass. Therefore, new approaches, such as the use of intermediate bioenergy carriers (torrefied biomass, biomethane, pellets, biomethane) is of high interest, as they reduce logistical problems.

Figure 41: Typical biomass feedstock types for the use in DH: woodchips, pellets, torrefied pellets, pyrolysis oil (from top left to bottom right) (Sources: D. Rutz)

Although biomass is renewable and an important energy source, in future DH systems, also other RE technologies should be included in order **to reduce the amount of required biomass**. This is important due to the increasing competition about biomass for energy, food, feed, and products, which is linked to increased land use competition.

[2] For further information please see Rutz et al. (2015) „Sustainable Short Rotation Coppice - A Handbook“ at https://www.srcplus.eu/images/Handbook_SRCplus.pdf

Two very different approaches for upgrading DH systems with biomass apply, namely the installation of new biomass-fired boilers and CHP units, or the replacement of fossil fuel installations with biomass installations.

In the first approach, the **installation of new biomass-fired boilers or CHP units**, the heat generation system allows maximum flexibility in the selection of the right technologies as this represents a completely new installation. New installations are ideally located in close vicinity to the heat consumers to minimize piping. It may make sense to install several units at different locations. In most cases, the chosen technology will consist of one or several smaller woodchip boilers or woodchip CHP units with gasification, steam cycle or Organic Rankine Cycle (ORC) technologies. From the environmental viewpoint, the completely new installation may be the best solution. However, new locations of the units must be found which can be a challenge for bioenergy projects. Furthermore, the initial investment cost may be higher than for the replacement of fossil fuel installations with biomass installations.

In the second approach, the status of a large centralized power plant remains the same and biomass is used either as **complete substitution** of the original fuel, or as **co-firing**. The ultimate goal is the complete substitution of the fossil energy systems by biomass or other renewable energies. However, some companies may opt to use the co-firing as an intermediate solution to achieve this goal.

Co-firing is the combustion of the original fuel with biomass at the same time and at the same location (but not necessary at the same installation). Co-firing can be carried out directly (in the same combustion chamber), indirectly (after pre-treatment), or in parallel (separate combustion).

Direct biomass co-firing is relatively simple and cost efficient, but it is more sensitive to variations in fuel quality and heterogeneity. Technical issues may limit the share of biomass firing. Usually, ash deposition, fouling, slagging and corrosion may increase. This may shorten the lifespan of devices which are in direct contact with the combustion gasses like superheaters, heat exchangers, selective catalytic reduction (SCR), etc. Direct co-firing systems include various technological solutions:

- *Co-milling*: blending of coal and biomass, combined milling in the original system and injection through the coal burners or feeding system.
- *Co-feeding:* separate milling of coal and biomass, and incorporation of the milled biomass to the main flow.
- *Combined burner:* biomass and coal are milled separately and transported to the burner, where coal uses the original ports and biomass uses new ports or unused ducts. In this case, though feeding does not involve fuel physical mixing, combustion stages takes place simultaneously and with similar aerodynamics to original design.
- *New burners:* the fuels are co-fired using independent feeding lines. Coal is fed through the original injection system, whereas biomass is transported to specific dedicated burners or inlet ports penetrating into the combustion chamber. New burners (injection systems) may replace former coal burners or may be installed in new positions in the combustion chamber. This option may involve the use of different combustion systems.

The main **indirect co-firing** systems are:

- *Separated burning*: burning of biomass in a separate boiler or system and introduction of flue gases downstream the radiant section of the original boiler.
- *Coupled plant*: separate burning in a new boiler specially designed and built for biomass firing. The original and the new system couple their heating fluid circuits. Combustion gases are not mixed, and exhaust gas must be treated separately.
- *Gasification systems*: the biomass is transformed into gas (with heating value) by means of a gasifier. The resulting syngas is either directly or with a previous treatment, injected in the original combustion chamber or boiler through new dedicated ducts.

- *Pyrolysis*: biomass is transformed into a mixture of gas, bio-oils and char by means of pyrolysis. Fractions may be separated and introduced into the boiler in different sites.

Within a power plant or CHP unit, often various boilers or CHP units are used. This allows a more flexible operation of the overall "plant" and reduces risks (e.g. maintenance, break down). If several CHP units or boilers are used, biomass can be co-fired by different means in the different units, also known as **parallel co-firing**.

In conclusion, the advantage of direct co-firing is low CAPEX, but only small percentages of biomass can be used (less than 20%). The advantage of indirect cofiring is that higher biomass shares can be used (up to 50%) while CAPEX can be higher. Parallel co-firing is the most flexible solution during operation.

The coal industry has already a lot of experience with co-firing of biomass, because of relatively low CAPEX requirements, scalable solutions and a lot of options to co-fire. IEA Bioenergy Task 32 maintains a database that lists 150 co-firing initiatives. A pertinent example is the Drax power station – one of the largest in Europe – which is for the most part fired by biomass. However, for the future it is expected that more complete retrofits (full conversion) will be implemented.

Figure 42: CHP plant in Salcininkai, Lithuania, in which a biomass boiler (5 MW_{th}) replaced one of the three natural gas CHP units. The remaining two gas CHP units have a capacity of 3.5 MW_{th} and 6 MW_{th} (Sources: D. Rutz)

Figure 43: CHP plant of Ena Energie in Enköping using wood chips from waste wood (right) and from short rotation coppice (SRC) (Sources: D. Rutz)


Figure 44: Wood chip fired CHP plant and its steam turbine of the Stadtwerke Augsburg Energie GmbH in Germany (capacity: 80,000 t/a wood chips; 7.8 MWel; 15 MWth) (Sources: D. Rutz)

5.3.4 Integration of geothermal heat

Geothermal energy is energy stored in the form of heat beneath the surface of the solid earth. Depending on the depth, geothermal energy can be divided into two sectors, shallow geothermal energy and deep geothermal energy. The most common usage systems for shallow and deep energy are shown in Figure 45.

Shallow geothermal energy describes the use of the geothermal heat up to a depth of approximately 400 m through wells, collectors and geothermal probes. The shallow underground can be used for heating buildings as well as for cooling purposes via a low-temperature DH network and a potentially reversible heat pump system.

Deep geothermal energy refers to the thermal use of the underground from 400 m depth and deeper. Deep geothermal energy can be utilized in open systems (petrothermal and hydrothermal doublets) as well as closed systems (deep geothermal probes). Deep geothermal probes offer the advantage of location independence without exploration risk, but they are usually only economically viable if the borehole already exists. The decisive advantage of open systems is a significantly higher heat extraction (thermal output of approx. 1 to more than 50 MW_{th}) compared to closed systems (max. several hundred kW_{th}). Due to the high energy demand open geothermal systems are well suited for DH systems. For open systems, the thermal energy is provided either through production of already existing deep thermal water (hydrothermal systems) or via artificially created heat exchangers in *hot dry rock* (petrothermal systems). The thermal water is pumped to the surface through the production well, where a part of its heat energy is extracted via a heat exchanger. After heat extraction the thermal water is usually pumped back to the ground through an injection well. Mostly these geothermal doublets are drilled in deviation from a single drilling site. Typical well depths are in the range of 2,000 to 4,000 m. Depending on the geothermal system (geology, hydrology and operation aspects), a combination of several production and / or reinjection wells can be used.

Besides heating purposes in DH networks, deep geothermal energy can also be used for **electrical power generation**. Geothermal power plants require a minimum heat source temperature of around 100°C as well as sufficient flow rates of the thermal water. Yet, the efficiency of the power generation process is only around 10% for these low heat source temperatures.

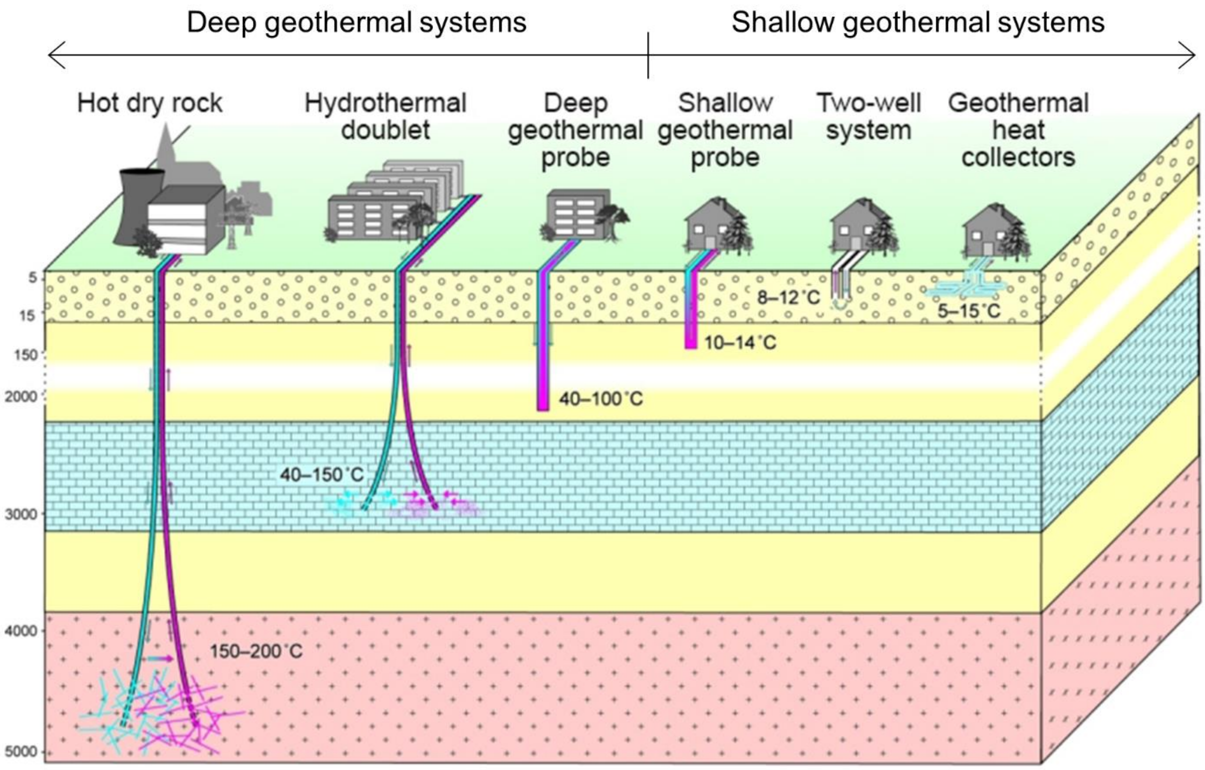

Figure 45: Different types of geothermal energy usage (based on: Bayerisches Landesamt für Umwelt, 2016)

The **geothermal potential** strongly depends on the local geology and hydrogeology. Thus, the areas with the highest geothermal potential are influenced by the geological conditions of Europe (Figure 46). High enthalpy resources are associated with active volcanic areas such as Iceland, Turkey and Italy. Medium enthalpy systems, associated with high-temperature thermal ground water in sedimentary basins are found in various geological settings, e.g. the Molasse basin in the Northern forefront of the Alps. Geothermal DH systems were mostly built in regions with favourable geothermal conditions and high temperature resources.

The **interactive GeoDH map**[3] provides an overview of the geothermal resource assessment and highlights the areas where potential for geothermal DH exists. Based on information in terms of geological data, already operational DH systems and heat demand, it shows the potential in 14 European countries (Italy, France, Germany, Netherlands, Ireland, United Kingdom, Slovakia, Slovenia, Czech Republic, Romania, Bulgaria, Poland, Denmark, and Hungary) (GeoDH, 2014).

The **application** of deep geothermal energy in DH systems requires the coincidence of a high geothermal potential and a high heat demand.

In 2017 geothermal DH accounted for a capacity of 4.9 MW_{th} and a total annual heat production of 11.7 GWh_{th} all over Europe. The average annual growth rate over the last years was around 10%. By the end of the year 2017 the number of plants in operation is 294 (Figure 47).

3 https://map.mbfsz.gov.hu/geo_DH/

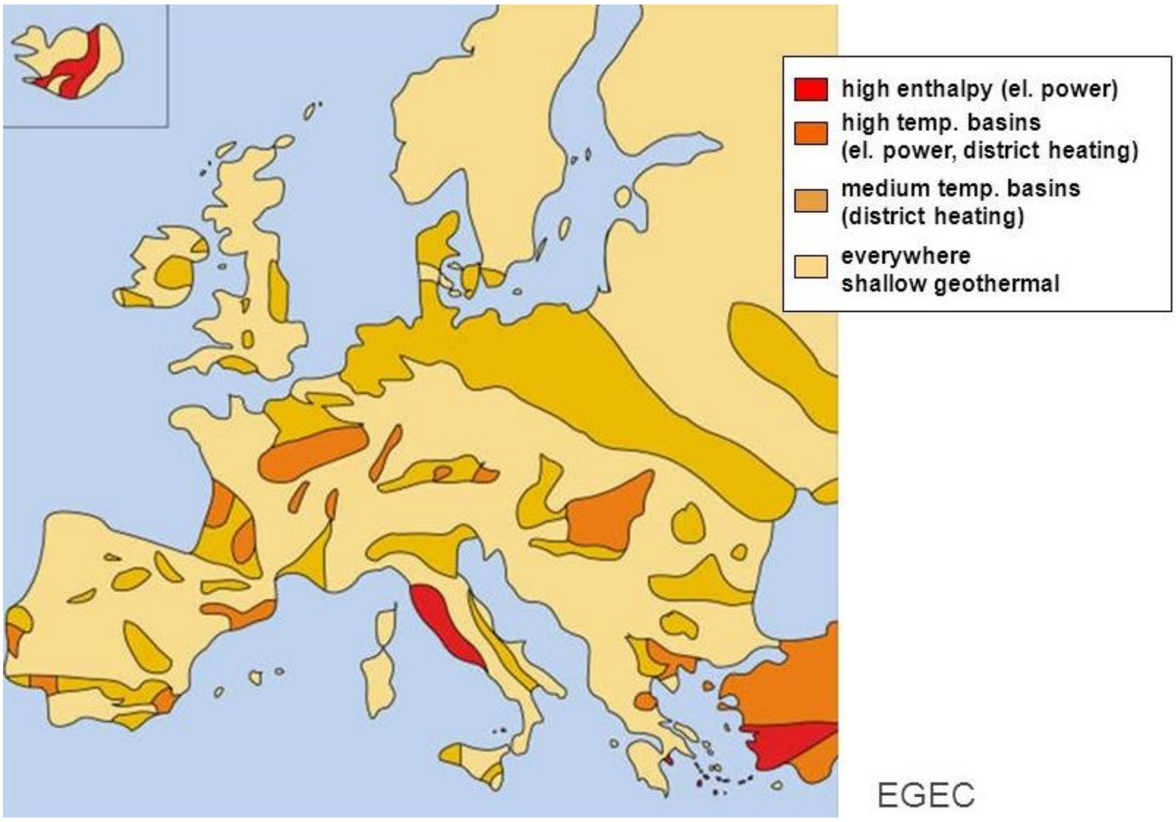

Figure 46: Simplified overview of the geothermal potential in Europe (Source: EGEC, 2014)

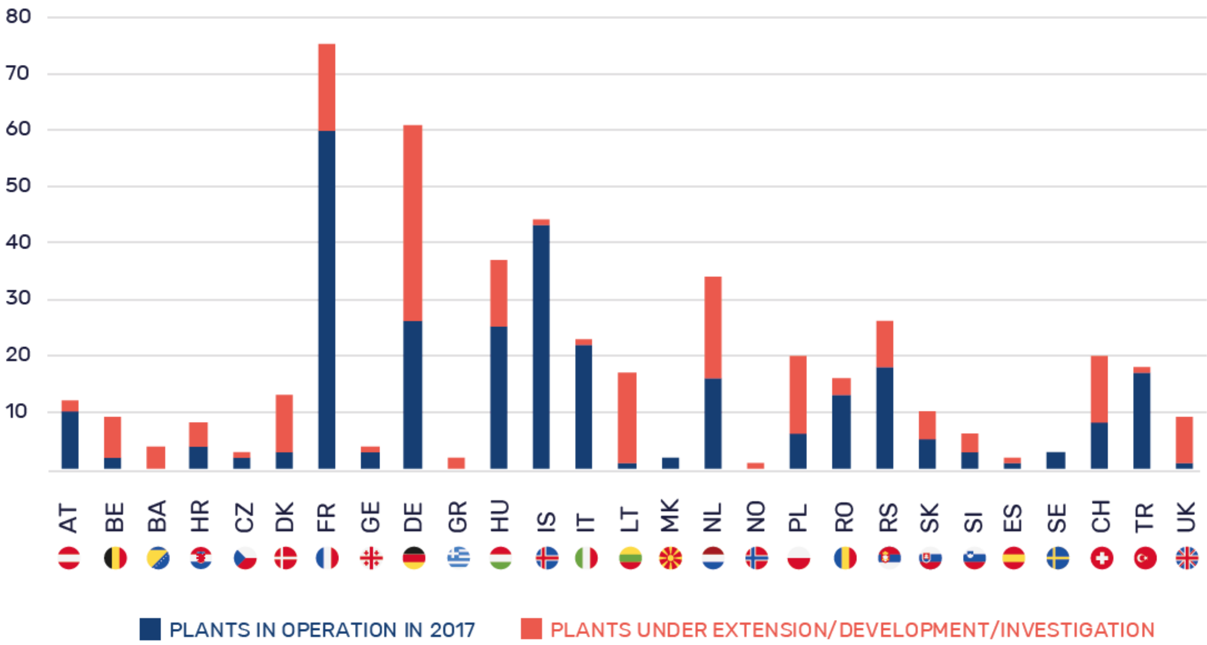

Figure 47: Number of geothermal DH plants in operation and under extension/development/investigation by European country (Source: EGEC, 2018)

The **temperature range** of deep geothermal resources is very wide. High enthalpy systems can reach peak temperatures of >180°C (Arnórsson, 1995). Thus, it seems possible to supply even 2nd generation heat grids from such sources, or at least to use them to raise the grids' return temperature (Sandrock et al., 2019).

If required due to insufficient reservoir temperatures or high inlet temperatures of the heating network, the temperature can be raised to the desired temperature level using heat pumps.

Deep open geothermal systems are zero-emission heating systems that are capable and very well suited for base load applications in DH systems. In order to successfully realize such a system, attention must be drawn to some **specific aspects**.

If the DH network is already available, the main investment cost of a deep geothermal system is caused by the drillings. As there are several risks during the drilling work as well as the risk of insufficient flow rates or insufficient temperatures of the geothermal resource, it is recommended to conclude a geothermal exploration risk insurance.

The most common technical problems in geothermal utilization have been related to the chemistry of the geothermal fluids which sometimes contain considerable concentrations of minerals and gases which can cause scaling and corrosion in wells and surface installations which the geothermal fluids flow through (Gunnlaugsson et al., 2014). In order to prevent such problems, suitable measures must be taken like the selection of proper materials and components. A very important component is the electrical submersible pump, which is used in the production wells.

5.3.5 Integration of excess heat

According to the analysis of the EU funded project STRATEGO[4], 2,943 PJ of excess heat (not including heat from thermal power generation) were in 2010 released by 1,222 considered facilities in Europe (Persson 2015). This excess heat could theoretically supply more than 30% of the energy consumed for space heating and hot water needs in private households, which corresponds to 9,349 PJ in 2016 (EC, 2018d).

Excess heat can be characterized by temperature levels, energy amount, industry sector and processes, its appearance, or how it can be used. In this handbook, a closer look will be taken at the subject of industrial excess heat and at two examples focusing on low temperature excess heat.

Generally, excess heat can be used in different ways, classified into internal uses in the process, internal use in the plant and external use. External use may be either outside of the business, but still in close distance to its appearance or at a different location e.g. in a DH system. The latter will be the focus here.

There is a range of influencing factors for a possible use of excess heat that needs to be considered (Hirzel et. al., 2013):

- **Energy amount:** The energy amount is depending on the heat capacity of the medium that can be used and the quantity of the flow as well as the temperature difference between the provided energy and the minimal required temperature.
- **Temperature level:** The higher the temperature level of excess heat is, the easier it can be used in different other processes. If the temperature difference between heat source and heat sink is larger, the dimensions of heat exchangers can be reduced.
- **Composition and type:** (gaseous/ liquid/ solid and chemical properties): For the choice of components as e.g. heat exchangers, valves and pipes, the composition and type of medium that carries the excess heat must be considered. Corrosive parts of a medium may shorten the lifetime of components drastically. To avoid e.g. condensation of corrosive liquids, a minimum temperature of the heat source may have to be kept.

4 http://stratego-project.eu/

In the case of natural gas this minimum temperature is stated with 120°C. Besides some fluids can bare the risk of scaling which reduces the flow, and also the efficiency of heat exchangers and other components.

- **Appearance:** Excess heat may be based on radiation or convection, which are more difficult to use than if the energy is bound in a fluid.
- **Simultaneity:** Ideally the excess heat appears at times of heat demand. Otherwise, heat storages can help to balance supply and demand.
- **Durance:** On the one hand the durance of excess heat throughout the year must be clear. The more continuous the heat can be used the faster the investment will amortise. On the other hand, in case of external use for e.g. DH, an agreement should be made for how long the access heat can be provided and used and how changes should be handled.
- **Distance:** If heat source and heat sink are close to each other, investment in infrastructure and heat losses will be lower.

Figure 48 visualizes different uses of excess heat and which technology can be used for harvesting the energy.

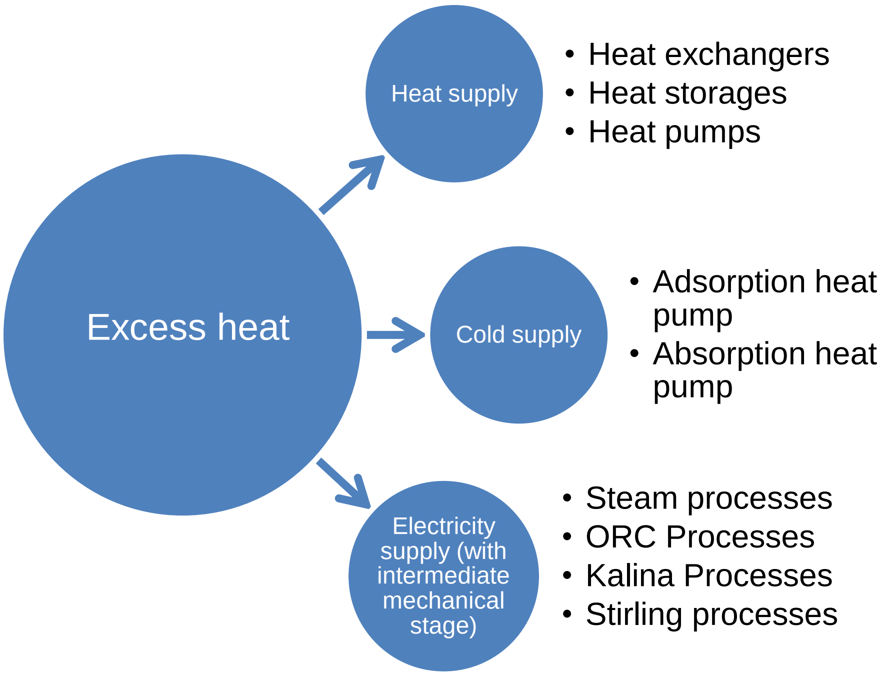

Figure 48: Use of excess heat and applicable equipment (Based on Hirzel et. al., 2013)

Industrial excess heat

Industrial excess heat can have very different characteristics, referring to the above explained influencing factors. An advantage about industrial excess heat is, that it often appears in large quantities and partly on high temperature levels.

To quantify the theoretical usable excess heat in Europe, the STRATEGO project evaluated different sectors, focusing on industrial sectors. The analysed sectors are: chemical and petrochemical, food and beverage, fuel supply and refineries, Iron and steel, non-ferrous metals, non-metallic minerals and paper, pulp and printing.

Within these categories, fuel supply and refineries account for 1,059 PJ (36%) of the excess heat. According to Persson et. al. (2014), most of the excess heat is close to larger cities and therefore close to areas with high heat demand.

Figure 49 gives an overview of the plants and facilities in Europe that were considered in the statistics. Besides the general overview, it can be seen that some industries are not existing in all countries.

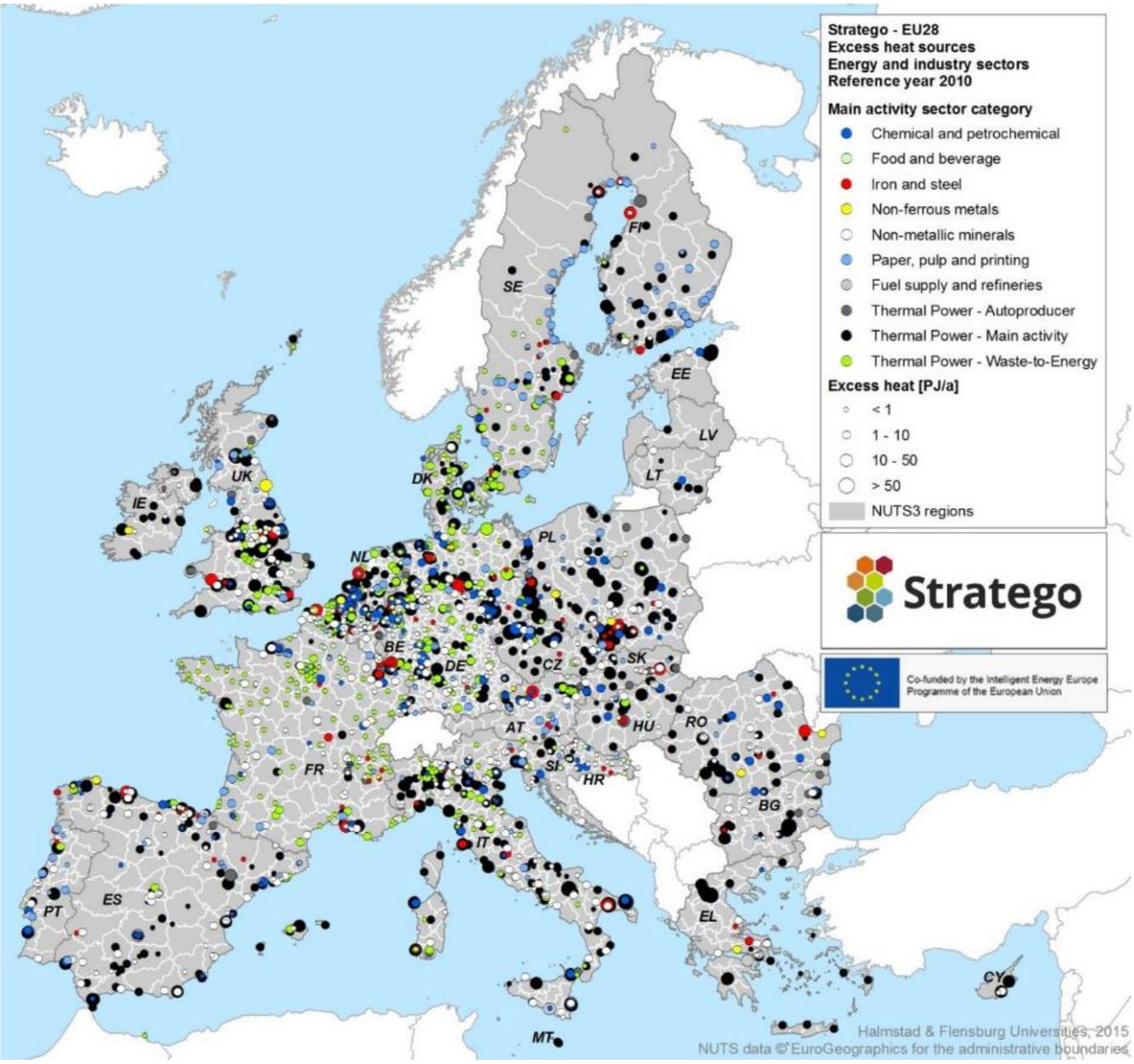

Figure 49: Mapping of different industrial excess heat sources in EU28 countries by the STRATEGO Project (Source: STRATEGO project)

As the map of the STRATEGO project indicates, many plants in the **iron and steel industry** can still improve their efficiency by reducing excess heat. Li et. al. (2016) have analysed the potential of integrating excess heat from two different steel plants in China into a DH system.

In the given case, three excess heat sources have been localized:

1) Slag-flushing water of blast furnaces (<100°C)
2) Cooling water of blast furnaces (35-45°C)
3) Low-pressure mixed saturated steam (143°C)

To reach the required temperatures for the DH network, a cascade heating of the DH water has been chosen. In the first stage, heat is used from slag-flushing water and low-pressure saturated steam. At this step the DH water reaches about 67°C. In the second step absorption heat pumps use the cooling water to further increase the DH water to 75°C. Additionally, as a third step absorption heat pumps are used in substations to decrease the return flow to 30°C.

A general difficulty in this case is the varying load of the DH network, which is even out of operation in the summer months. A reasonable amount of heat can therefore not be used in summer. Nevertheless, the two steel plants could in the case of complete finalization of the project supply 2.35 PJ of heat to the town close by.

Low temperature excess heat

The integration of excess heat into DH systems has large potential in cities. Especially low temperature sources between 20-40°C are available in many places as two examples will show in this chapter.

In contrast to the excess heat from large plants or facilities, the European Project ReUseHeat[5] has analysed four different cases which use low temperature excess heat in a DH network. Partly, these systems are called Low-Ex (Low-exergy) systems, in which heat pumps are the only heat suppliers.

In **data centres**, the consumed electricity for computing is fully released as heat in the server halls. If air cooling is applied, the air can then be circulated through a heat exchanger to be used as source heat in the evaporator of a heat pump. The thermal energy on the condenser side can be used to lift the temperature in the DH network from the return temperature level to the supply temperature level. A buffer storage can be used to balance peak demands in the DH network or to cover times of no supply from the data centre. A heat supplying backup system is also used in these cases, as the heat pump is usually dimensioned as a base load supplier for the DH network.

In Scandinavian countries, especially in Sweden, a range of large heat pumps >1 MW use **sewage water** as a source to supply heat to the DH network. The majority of the large-scale heat pumps were installed in the 1980's at times of electricity surplus in the grid. Since then, the installed capacity has only decreased little but is now under competition with waste and biomass CHP plants as well as confronted with changing electricity prices and taxes.

The treated sewage water temperatures in Swedish heat pump plants range between 12 and 20°C. Two-stage turbo compressors are commonly used to achieve required temperatures in the DH grid which have on average 86°C in supply flow and 47°C in the return flow (Averfalk, 2017).

Based on the Swedish experience in integrating industrial excess heat in DH networks Lygnerud et. al. (2017) have analysed the connected risks. In order to evaluate a potential business case of integrating industrial excess heat, different **key factors** must be considered:

- Uncertainty for how long the industry will have excess heat
- Changes in costs of heat sources due to changes of e.g. taxes may change
- Distance to the DH grid
- Different perspective on excess heat use by industries and utility operators
- Aim of independent heat supply by industry
- Volatile heat delivery by the industry
- Inability to create an agreement that is beneficial for both parties
- Excess heat sources must have a backup facility for heat supply

[5] https://www.reuseheat.eu/

5.3.6 Power-to-Heat

Power-to-Heat applications convert electric energy into thermal energy. Hence, the technology of Power-to-Heat provides the possibility of interconnecting the electric sector with the heating sector, which is known by the term of sector coupling. Power-to-Heat is deployed in households, businesses or industries. One specific application is the integration in DH systems. Therefore, electric boilers and heat pumps can be used which are described in the following.

Electric boilers are converting electrical energy directly into thermal energy. Possible technologies are electrode boilers or electric flow heater. The technology used in a specific case depends on local conditions and on the individual requirements. Both technologies are suitable for control energy. The investment costs are varying with regards to the requested capacities and necessary peripheral devices.

The main components of electrode boilers are their electrodes. These electrodes are surrounded by water and use its physical properties to generate heating energy. If the electrodes are energised, the ohmic resistance of the water leads to its heating. With an additional heat exchanger this heating energy can be transmitted into the DH system. This separation is necessary because the boiler and the DH system have different special requirements for the water properties. The boiler's capacity can be stage less regulated with the water-level and resulting dipped-depth of the electrodes. The common capacities of electrode boilers are varying between 5 MW and 50 MW (AGFW, 2017). A schematic representation of an electrode boiler is shown in Figure 50.

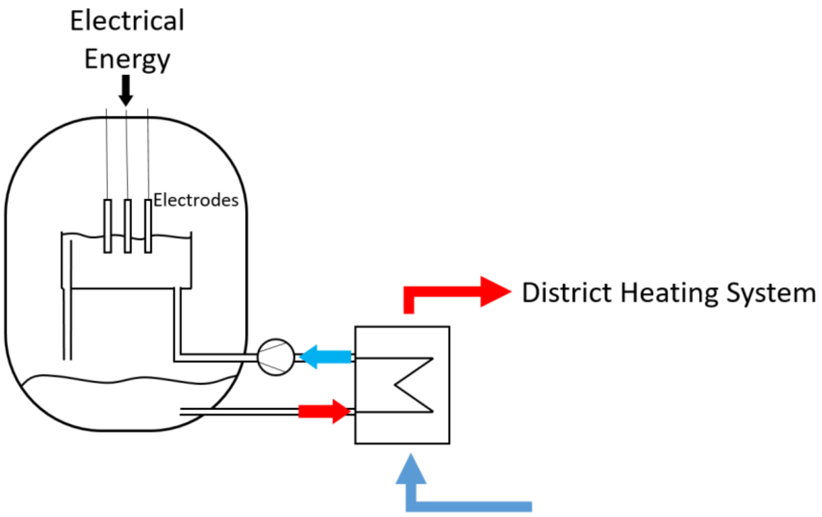

Figure 50: Scheme of an electrode boiler (Source: AGFW)

Figure 51: Electrode boiler of 10 MW and 14.4 m³ capacity of the solar DH plant in Gram, Denmark (Source: D. Rutz)

Electric flow heaters provide the possibility to warm-up the DH water without an additional water circuit. Electric flow heaters consist of one or more heating elements which are dipped in the current of the DH water. Whenever the heating element is energised, it heats up and transmits the heating energy to the flowing water. The regulation of the capacity can be made by regulating the power of the heating element(s). In case of multiple heating elements, the number of operating elements can be adopted. Hence, this technology is stage less adjustable. Common capacities for electric flow heater are between 100 kW and 10 MW (AGFW, 2017). A simplified representation of an electric flow heater is shown in Figure 52.

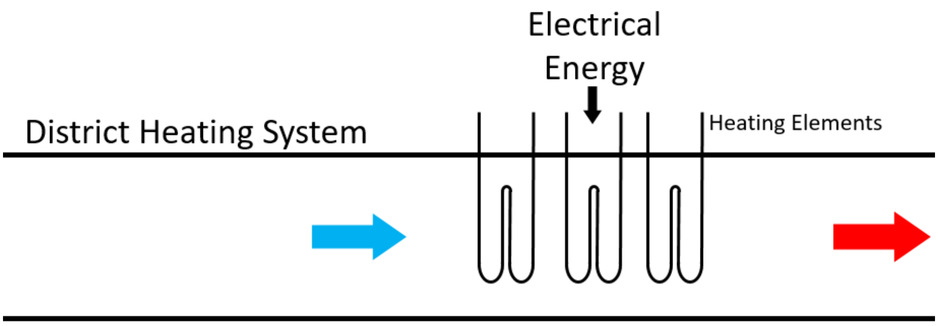

Figure 52: Scheme of an electric flow heater (Source: AGFW)

Figure 53: Electric flow heater (Source: Klöpper-Therm GmbH & Co.KG)

Heat pumps can be distinguished in compression heat pumps, absorption heat pumps and adsorption heat pumps. For the application related to power-to-heat, compression heat pumps are more suitable and are the commonly used technology for DH. (AGFW, 2017)

Compression heat pumps are using thermal energy on a low temperature level from other sources like air, geothermal energy, water or excess heat, and provide this energy on a higher temperature level for further applications. This provided energy is called useful energy. The transformation of electric energy happens indirectly by powering the system's compressor. The working principle shown in Figure 54. The compressor pumps the heating fluid which is responsible for the heat transport, in a closed circuit. The chosen working fluid depends on the selected heat source and temperature levels. The heat transmission is realized with two heat exchangers, one for absorbing the thermal energy from the ambience and one for transmitting the thermal energy to the DH system. (AGFW, 2017; Wesselak et al., 2013)

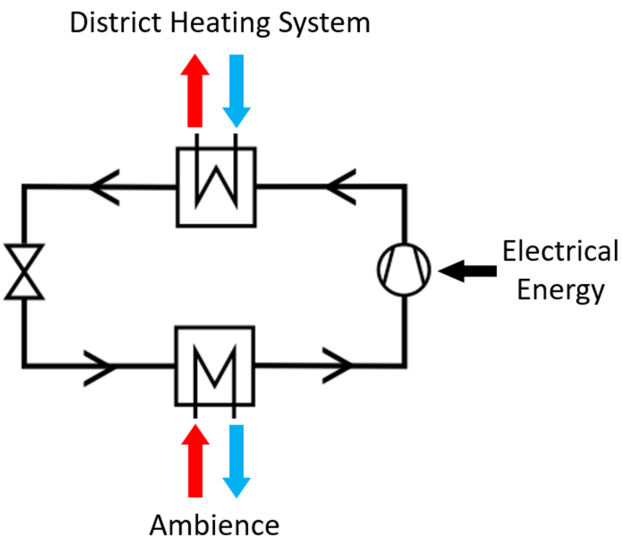

Figure 54: Working principle of compressor heat pumps (based on AGFW, 2017)

For the **scope of applications** between the two technologies (electric boilers and heat pumps), an important difference is needed to be mentioned. Electric boilers in DH are used to stabilise the power grid and provide controlling power ranges. If an excess of electric energy exists in the power grid, the electric boilers can be switched on to consume the excess electric energy, transform it into thermal energy and thereby, balance the power grid. An advantage is on one hand, the revenue which is generated by providing controlling power ranges. And on the other hand, due to fluctuating electricity prices, this heat generation can be more cost effective than others.

On the contrary, heat pumps are used to cover basic heat demands. Heat pumps' efficiency is defined by the coefficient of performance (COP), which means the provided useful thermal energy divided by the consumed electrical energy (see equation below, based on AGFW, 2017).

$$COP = \frac{|\dot{Q}_{use}|}{P_{electrical}}$$

Since the used heat sources (air, geothermal energy, water and surplus heat) are estimated as freely available, their consumption is not considered in the efficiency calculation. Hence, it is possible to have efficiency values higher than one. Usually, the use of freely available heat is considered as cost-free, which means they are not considered in the calculation of operating costs either. Therefore, the heat generation by heat pumps can be very energy-efficient and cost-efficient. This advantage can even increase, if cooling down the heat source is a further benefit for other systems or processes. This means for example, that the waste heat of chillers could be used as low-temperature heat source for the heat pump.

The main barriers against the implementation of heat pumps in DH systems are their high investment costs, and the dependence of their profitability to the local electricity price. The investment costs are internationally fairly steady, while electricity prices are very different depending on the national or local power markets. Due to the generally high investment costs, heat pumps are often used only to cover the basic heat demand, but not peak loads which need to be covered by other heat generators. Heat pumps are also technically unsuitable as a stand-alone technology in DH systems covering total heat demands.

5.3.7 Integration of heat storage technologies

The load in DH networks is constantly varying. Throughout a single day load peaks appear and the load in DH systems varies also between summer and winter. At the same time, the costs for heat production are not the same at all times. Thermal energy storages (TES) can be applied to shift production or consumption peaks and to operate certain production facilities when it is most economical.

Short-term thermal energy storage

Conventional short-term storages are **non-pressurized tank storages** that operate with atmospheric pressure. The tanks are well insulated and are normally used to perform peak shifting. The temperatures are slightly below 100°C in such storages. In some cases, old oil tanks have been refurbished to use them as thermal energy storages for DH systems.

Pressurized storages can hold temperatures above 100°C. This may be required to meet consumer needs or to allow accumulating energy at higher temperature levels from e.g. power to heat facilities. Pressurized storages can hold more energy in the same water volume compared to non-pressurized storages due to the higher temperature. Due to the higher pressure levels, stricter security measures are required compared to non-pressurized storages. This results also in higher construction and maintenance costs.

Figure 55: Non-pressurized thermal storage of the DH system in Zagreb (Source: www.pogledaj.to)

In 2015, the first German two zone thermal storage was taken into operation in Nürnberg. The technology was invented by Dr. Hedbäck and was then patented by Bilfinger VAM. It is based on an upper water zone that is separated by a flexible layer from the lower zone. The weight of the upper zone creates pressure on the lower zone which allows to keep water in the lower zone with temperatures above 100°C. The water temperature in the upper zone is accordingly lower.

The advantages are a higher storage capacity at the same volume compared to normal non-pressurized storages and at the same time lower expenses for security measures as it is the case with pressurized tank storages.

Large-scale underground thermal energy storage

Four main concepts for large-scale underground TES have been developed and demonstrated in the last decades as depicted in Figure 56. Each of these concepts has different capabilities with respect to storage capacity, storage efficiency, possible capacity rates for charging and discharging, requirements on local ground conditions and on system boundary conditions (e.g. temperature levels).

The most suitable TES concept for a specific project has always to be found by a technical-economical assessment for the specific boundary conditions. In the following subsections the TES concepts are briefly introduced.

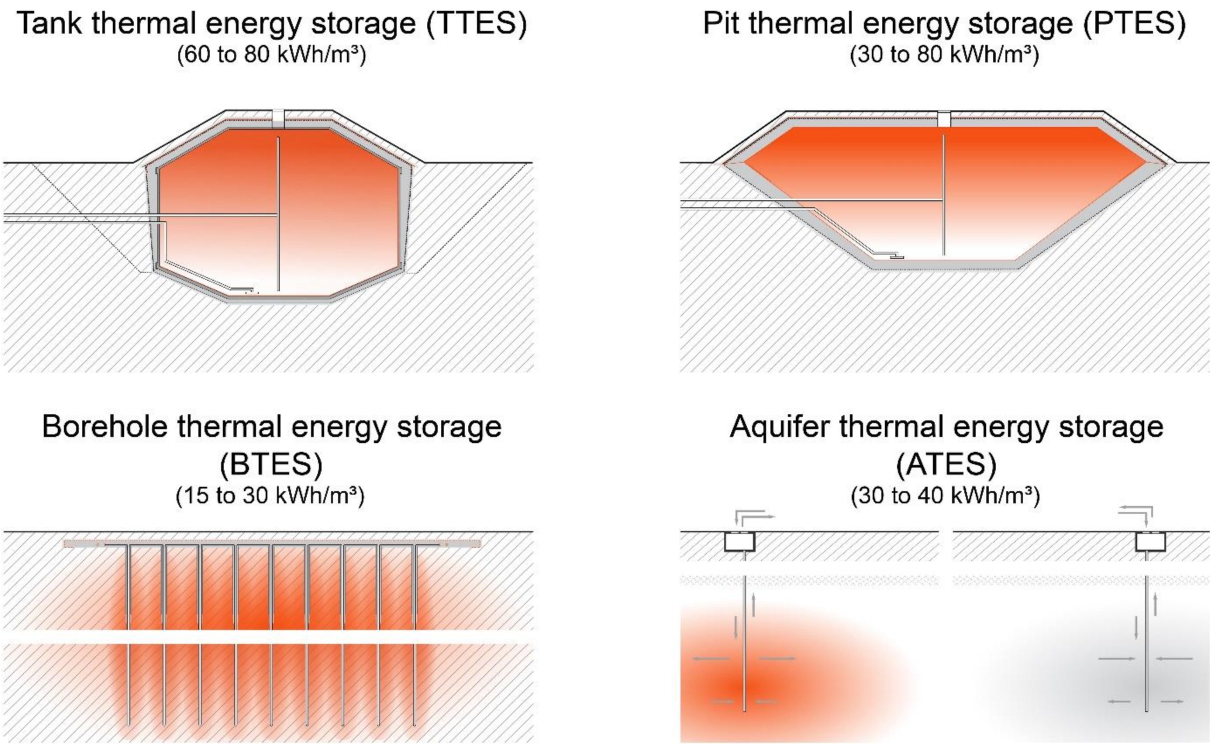

Figure 56: Overview of available underground thermal energy storage concepts (Sources: Solites)

Tank thermal energy storages have a structure made of concrete, steel or fibre reinforced plastics (sandwich elements). Concrete tanks are built utilizing in-situ concrete or prefabricated concrete elements. An additional liner (polymer, stainless steel) is normally mounted on the inside surface of the tank to ensure water and vapor diffusion tightness of the construction. The insulation is mounted on the outside of the tank.

Figure 57: Tank thermal energy storage with 5,700 m³ of water volume built from prefabricated concrete elements in Munich, Germany (in construction and finalized, Sources: Solites)

Pit thermal energy storages are built without static constructions by means of mounting a liner with or without insulation material in an excavation pit. The design of the lid depends on the storage medium and geometry. In the case of using water along with gravel, soil or sand as storage medium the lid may be constructed with a liner and insulation material, often identical to the walls. The lid construction of a water filled PTES requires major effort and is the most expensive part of the thermal energy storage. Typically, it is not supported by a construction underneath but floats on top of the water. Temperatures in the storage are normally limited by the liner material to 80 – 90°C. Pit thermal energy storages are entirely buried. In large PTES the soil dug from the ground is used to create banks which make the storage somewhat higher than the ground level.

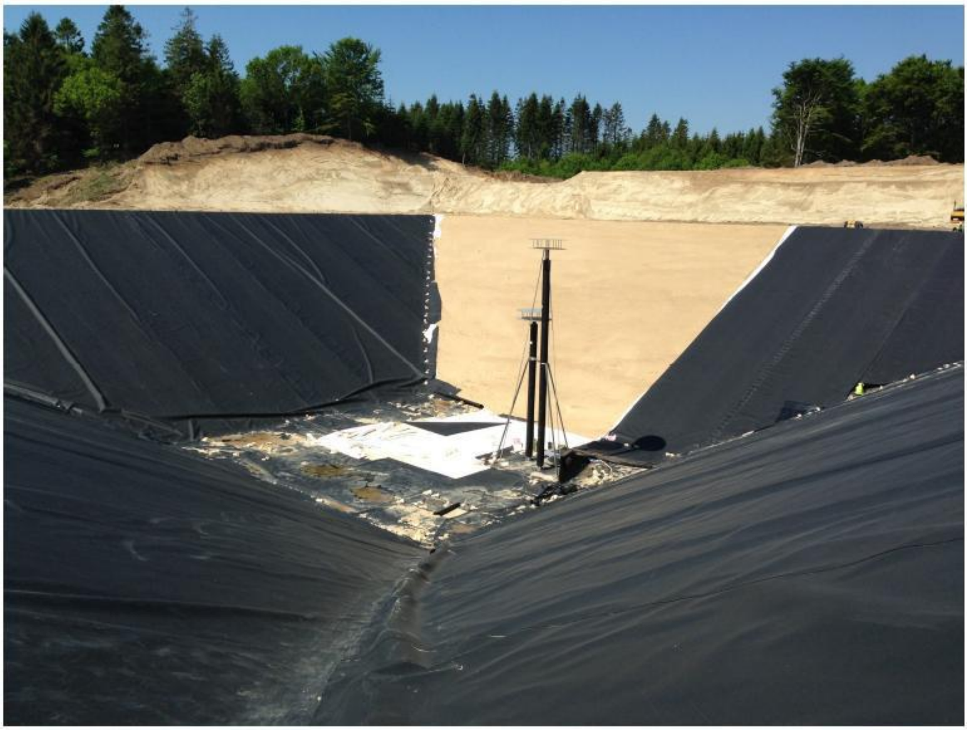

Figure 58: Construction of the SUNSTORE 3 pit thermal energy storage in Dronninglund (Dronninglund Fjernvarme)

In a **borehole thermal energy storage**, the underground geology is used as storage material. There is no exactly separated storage volume. Suitable geological formations are rock or water-saturated soils with negligible natural groundwater flow. Heat is charged or discharged by vertical borehole heat exchangers which are installed into boreholes with a depth of typically 30 to 100 m below ground surface. Borehole heat exchangers can be single- or double-U-pipes or concentric pipes mostly made of synthetic materials.

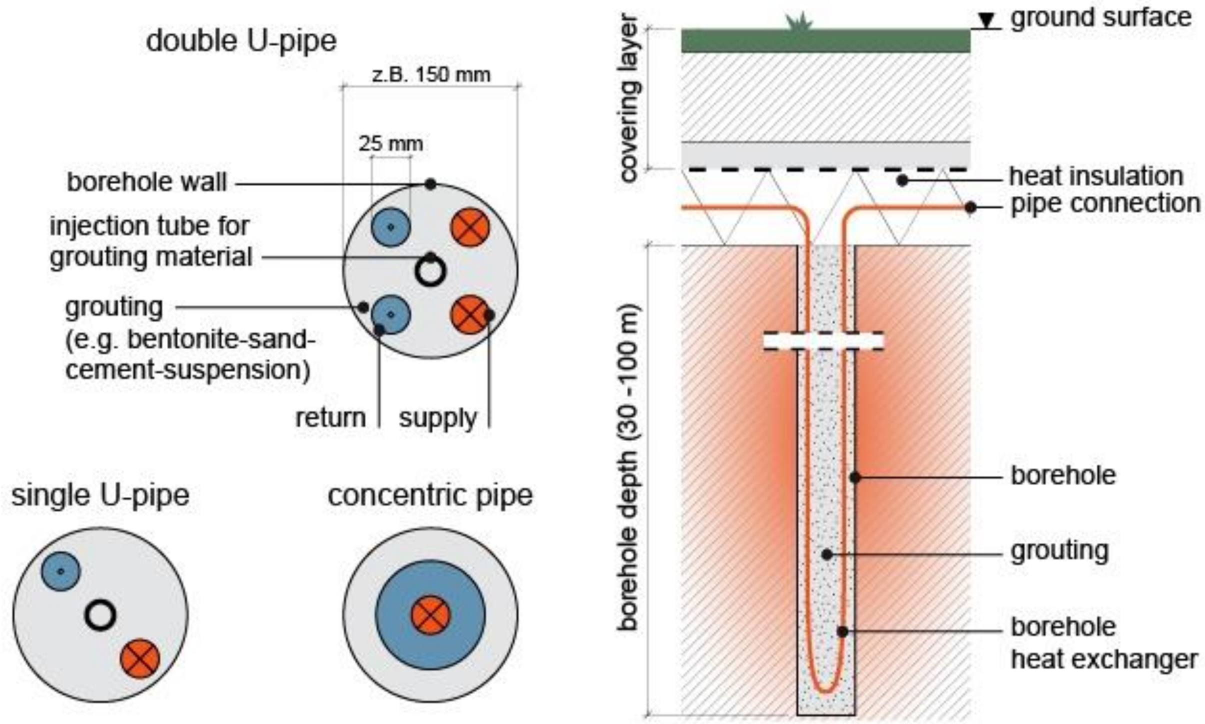

Figure 59: Common types and vertical section of borehole heat exchangers (Source: Solites)

Aquifer thermal energy storages are water-filled bodies below ground comprised of permeable sand, gravel, sandstone or limestone layers with high hydraulic conductivity. Aquifers are suitable for thermal energy storage if impervious layers exist above and below and natural groundwater flow is negligible. In this case, two wells (or several groups of wells) are drilled into the aquifer layer and serve for extraction and injection of groundwater. During charging of heat, cold groundwater is extracted from the cold well, heated up either by a heat source or a cooling application and injected into the warm well. For discharging the flow direction is reversed: warm water is extracted from the warm well, cooled down by the heat sink and injected into the cold well. Because of the different flow directions both wells are equipped with pumps, production pipes and injection pipes.

Specific aspects

The most common purposes of TES in DH systems are:

- Buffer storage for short-term heat storage or peak shifting
- Long-term or seasonal storage of e.g. solar thermal or surplus heat
- Energy management of multiple heat producers such as CHP, solar thermal, heat pumps, and industrial surplus heat
- Cold storage of e.g. ambient cold (air, surface water) or evaporator cold from heat pumps

A deliberated integration into the overall energy supply system is essential for an efficient operation of a large-scale TES. This includes a suitable hydraulic system layout as well as a careful design of not only the storage, but also other system components like additional heat or cold producers, DH network, heat transfer substations up to the point of building installations. In particular, the process control system must be configured to ensure the storage services achieve greatest benefit, depending upon specific project objectives such as maximization of renewable energy share or CHP electricity production.

Storage temperature levels, quality of stratification and return temperatures of the heating network strongly influence the efficiency of a TES. Those parameters not only depend on the storage, but also to a large extent on the connected energy system. Hence, during storage design an accurate prediction of the entire system characteristics is needed. Operation temperatures of the storage throughout the year and charging and discharging power rates must be predicted, along with the DH network return temperatures, as they have a key role for the performances of the storage. Together with the maximum charging temperatures, they define the usable temperature difference and accordingly the thermal capacity of a TES. For some storage concepts, additional components such as short-term buffer tanks or heat pumps can also be economically reasonable supplements.

5.3.8 Retrofitting with renewable energies – finding the right mix

Renewable energy sources can provide a CO_2 neutral and sustainable source of heat. However, their integration and control within a heat network lead to specific challenges. Traditionally, heat networks include a source of heat, a distribution network and an end user of the heat. Modern networks need to be smarter with more integrated heat sources of different sizes, temperature profiles and locations in the network. Control of supply and demand needs to be smarter and more integrated to meet the requirements of the heat consumers whilst making maximum use of intermittent renewable energy sources. A heat network which considers these factors may look something like Figure 60.

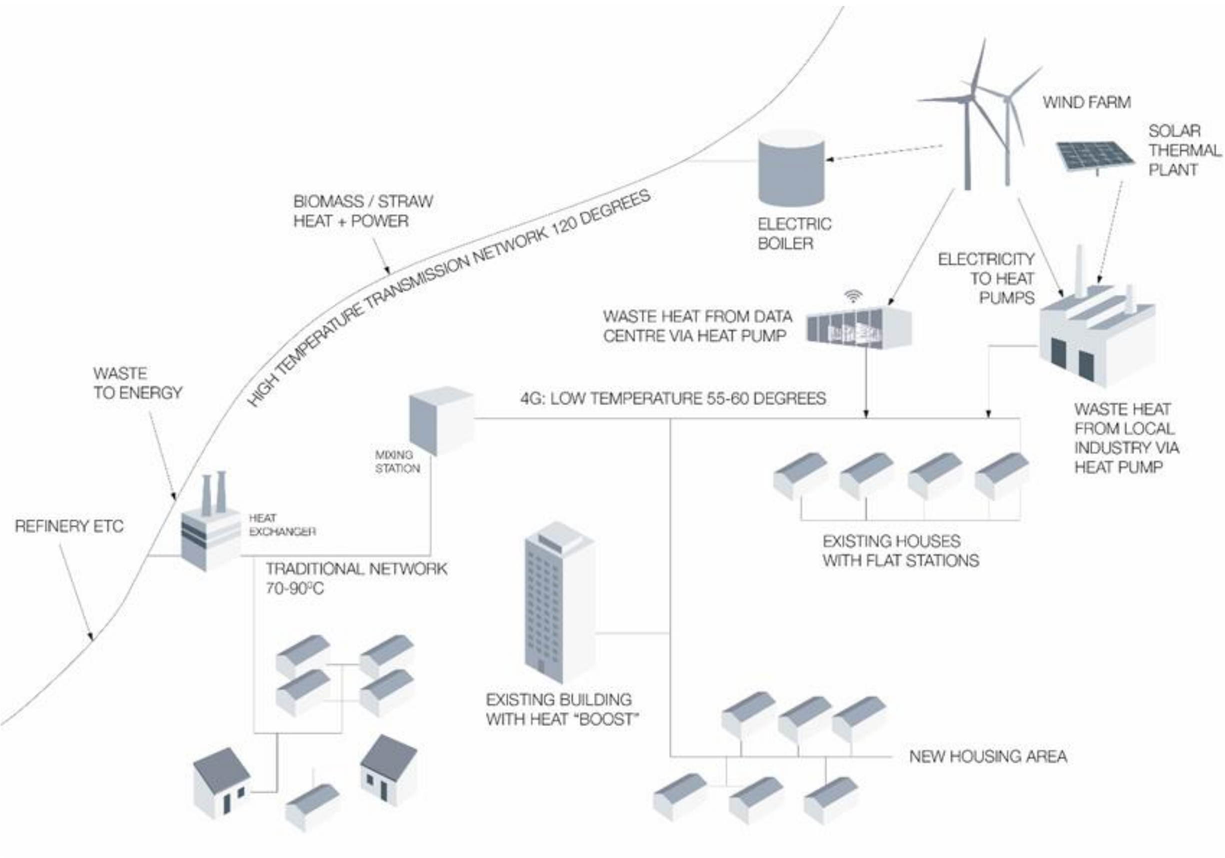

Figure 60: DH with variable heat sources (Source: COWI)

Base heat load should be supplied by a reliable and controllable source of heat output. Usually a waste to energy plant runs continuously and cannot be shut down easily, it is therefore a likely candidate for the base load. Likewise, high temperature waste heat from heavy industry, such as a refinery, is a continuous source of heat at a high temperature. Biomass boilers and CHP are more flexible (although not able to start up at a moment's notice) and can be used to increase supply when it is required. Unlike waste to energy, biomass fuel can be stored and used as needed.

Renewables such as wind and solar are by their nature, fluctuating resources. These must be integrated as directly as possible when they are available, with thermal storage integrated within the network to provide maximum utilisation.

A network like this requires sophisticated control to ensure that the parts are working together and not against each other. For example, the network needs to know that there is supply available from a solar thermal plant or a heat pump and adjust the heat drawn from the high temperature sources.

Mapping out the options and achieving the optimal solution can be a complicated process. Networks are typically built up over time, with additions and improvements made periodically to the existing network. Software packages which facilitate the modelling of different solutions can be valuable to assess the optimal mix of heat supply technologies for a particular area given local constraints.

One such software package is **EnergyPro**, which can be used to build up a model of the heat supply options and their interrelations. Using EnergyPro the operational parameters of the heat supply can be optimised. Figure 61 shows a screen shot from EnergyPro for the operation of a network for a small Danish town where there is a solar thermal heat source as well as gas CHP and boilers. The first graph shows the hourly solar radiation for the location, which is used to calculate the heat production from the solar collectors. The second graph shows hourly electricity prices. The third graph shows the heat demand and the production of the various heat generators. The fourth shows electricity generation and the fifth shows the hourly status of the thermal store.

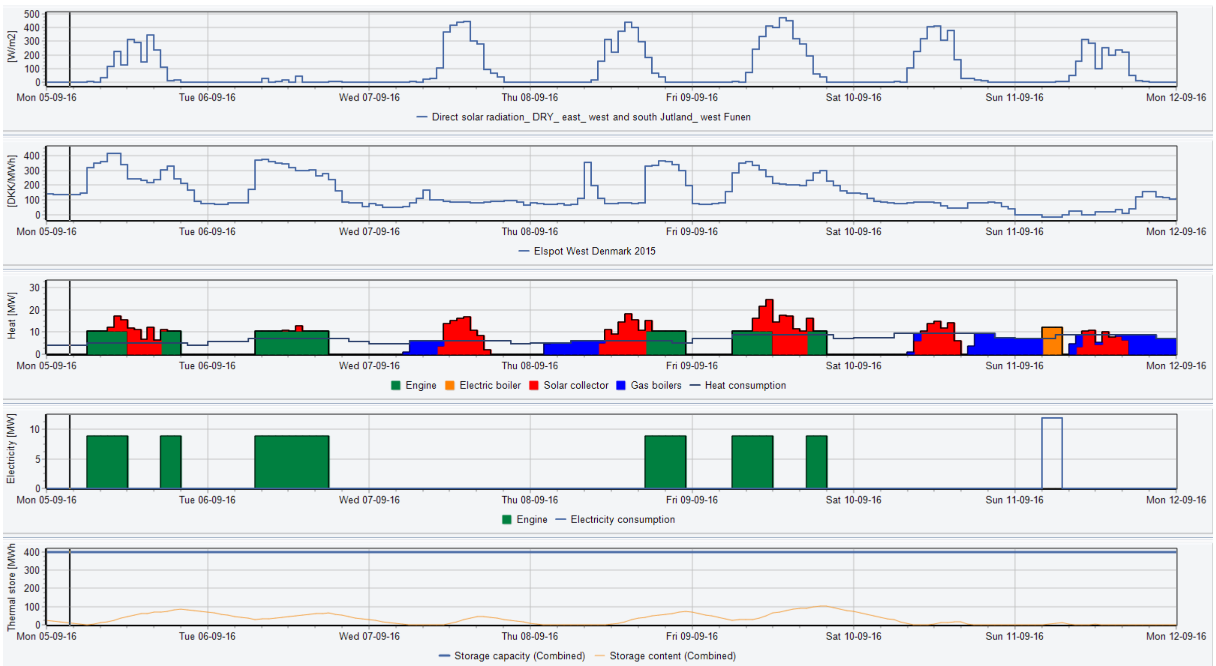

Figure 61: EnergyPro Model (EMD international A/S)

Another example is **Optit's solution for energy production optimization** (Upgrade DH 2018c), which is already embedded in the everyday operating process of several DH systems in Italy. This tool allows for optimization of the asset scheduling in order to maximise the operating margin, on a short-term and long-term basis.

Thermodynamic modelling using a software package such as **TERMIS** can be a useful method of assessing the technical impacts of changes of heat source and supply specifically on the

DH network itself. This modelling considers the size and operational parameters of a new heat source together with its physical location on the network. The model can be used to assess how the entire network will operate with the proposed changes. For example, the following questions can be answered:

- Are the pipes large enough to transport heat from the generation point to the connected loads on the network?
- Are there any points where additional pumps should be installed to maintain pressure on the network?

Figure 62 shows an existing network where a new generation plant is to be added. It is immediately obvious from the output that, although the location could potentially suit the addition of a heat generation plant, a large part of the network should be upgraded if a heat input of the specified size is to be added at that point.

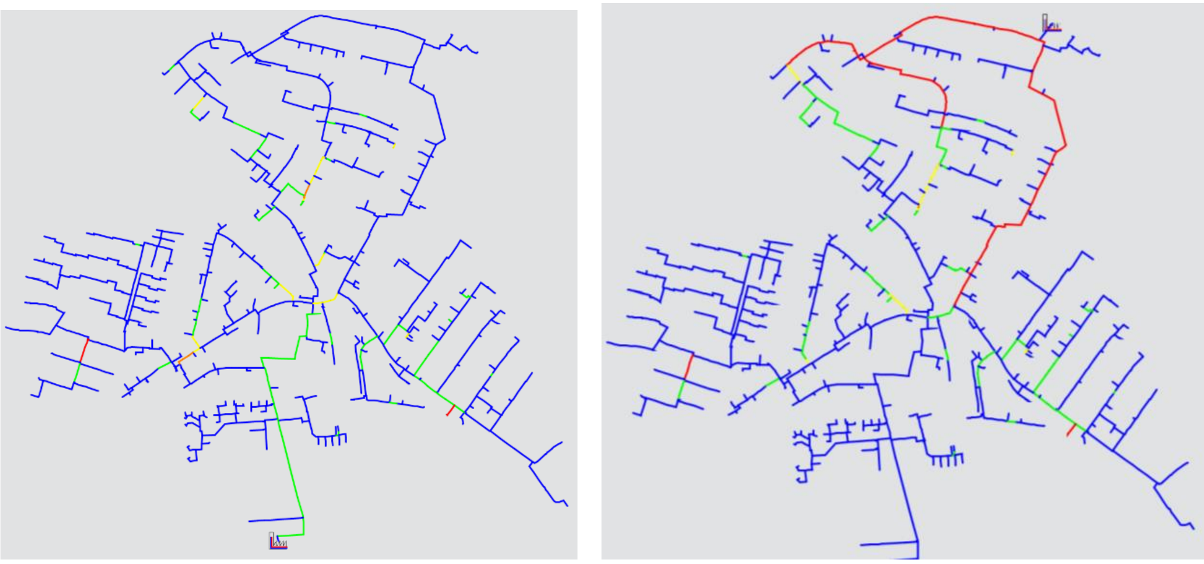

Figure 62: TERMIS screenshots for addition of a new generation plant (Source: COWI)

5.4 Technical data monitoring, control and digitalisation

The efficient operation of DH is based on the complex interaction of different heat generators with different consumers. In future energy systems, not only more different heat sources may be used in a single system, but also additional services may be provided, such as the interaction with the power grid. The integration of SDH may require dedicated storages. All this will increase the complexity of whole system.

Technical data **monitoring** is a wide-ranging term with different application fields which could help to handle the complexity of future energy systems. The general target of monitoring seems to be simple “to achieve the state of optimal operation”. However, “the optimum” is specific for each system and can inter alia be affected by economical, energetic or environmental factors. Even though the goals may be different, it can nevertheless be assumed that, without **digitalisation** (supporting monitoring and control), future heat supply systems can hardly be operated.

To handle the number of available data, it is an important step to analyse the data by so-called **performance-indicators**, which will give the operator a quick and easy idea of the current status of the system. These indicators can be parameters of the system which are either directly measured or calculated with the measured parameters. Some easy to understand and commonly used parameters are temperature levels (supply and returning pipeline), pressure levels and energy consumptions.

For future systems, it might be necessary to capture the relevant data by installing various **measuring instruments** at different system and network points. Depending on the boundary conditions, on the systems complexity (number of plants, customers, connections, etc.), and on the optimisation targets, different parameters might become more relevant than others. However, the level of automatization will affect the number of necessary measure points and parameters. Ongoing research activities in Germany, by AGFW and the Technische Hochschule Rosenheim, aims to identify the most relevant parameters and Key-Performance-Indicators for an energetic data monitoring within the project NEMO[6].

Table 5 presents the requirements to measurement data acquisition and recording, that were applied for the energetic monitoring of six DH systems in content of the project Mona (Bücker et al., 2015). The addressed parameters were highly rated for a successful energetic monitoring. The mentioned requirements are classified in the affected component and the estimated significance.

Table 5: Requirements to measurement data acquisition and recording for a complete energetic monitoring (based on Bücker et al., 2015)

Component	Required measuring instrument	Importance
Generation	Heat meter	Necessary
	Mass flow meter	Important
	Electric meter	Preferable
Thermal storage	Temperature sensor (4 times)	Necessary
Network	Heat meter	Necessary
	Differential pressure sensor	Necessary
Network pump	Electric meter or status detection	Important
Boiler house	Electric meter	Necessary
	Ambience temperature sensor	Preferable
Consumer	Heat meter	Important

With the **digitalisation**, it is possible to measure much more parameters and to automatically analyse them, which can lead to more efficient impacts of upgrading measures. With the collection of more and better data, unused upgrading potentials can be found by calculating more key-performance-indicators. However, the benefits need to justify the efforts of data collection, thus a good benefit/effort ratio needs to be identified.

The necessary **measuring frequency** of the above mentioned Mona project was found to be sufficient with round about 15 minutes (Bücker et al., 2015). In that case it provides enough details to show up dynamic effects, without generate unmanageable data volume. Influenced by changing requirements and the continuous evolution of data processing tools, this period will most likely shorten continuously.

It is impossible to give a complete overview on **existing software tools** supporting the data monitoring in general. Some software tools are described in “Best practice instruments and tools for diagnosing and retrofitting of district heating” (Upgrade DH, 2018c).

An example for such a software tool is **Monisoft** developed by the Karlsruher Institut für Technologie (KIT) and updated by the Technical University of Applied Sciences in Rosenheim, Germany. Depending on internal requirements and expertise the used software tool to collect and prepare the data for the monitoring can vary. Figure 63 shows the visual presentation of the data.

[6] https://www.agfw.de/nemo/

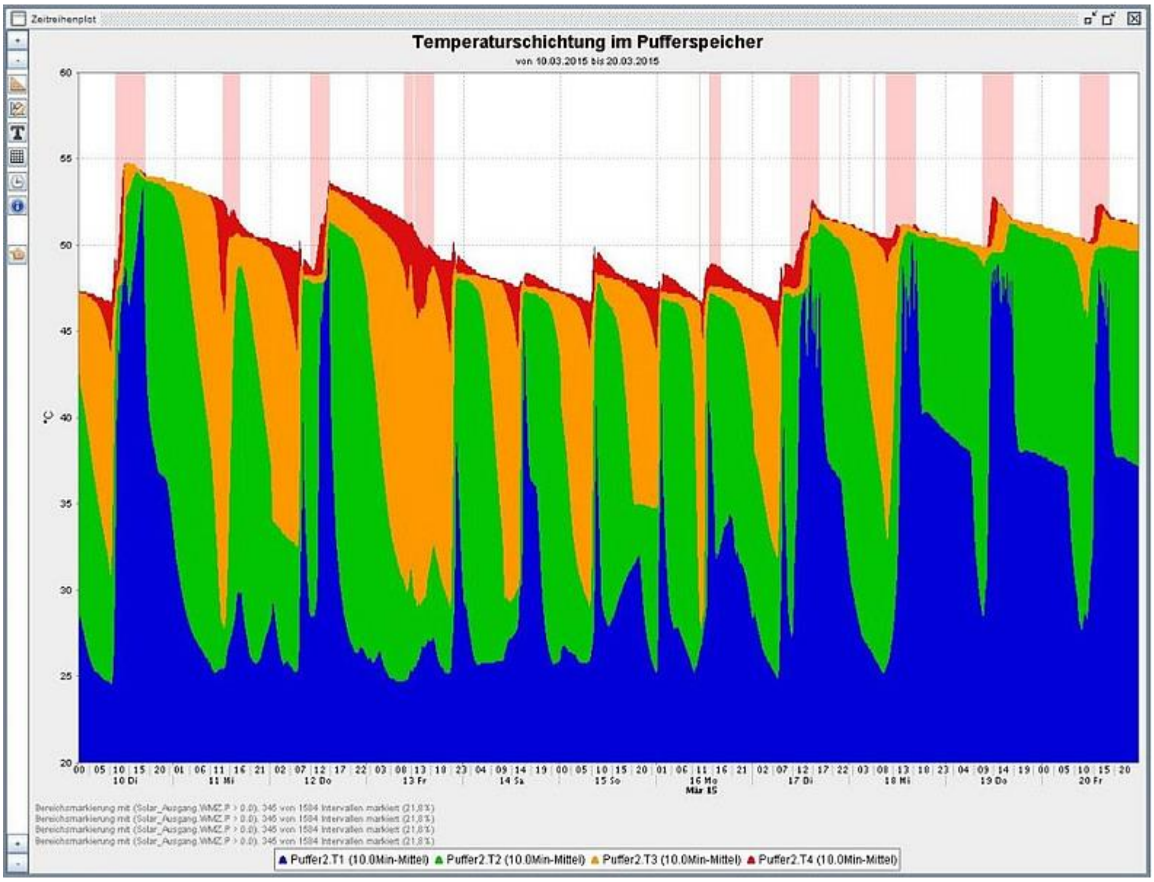

Figure 63: Temperature layer of a thermal storage monitored by Monisoft (Source: Hochschule Rosenheim)

For the evaluation of the data, different software tools or instruments can be used. In the following example, the evaluation of monitored primary energy data of six anonymized DH systems (A, B, C, D, E, and F) are presented. The calculation of the primary energy factors is based on the methodology of (AGFW FW 309, 2018). Figure 64 shows the graphical presentation (the negative values are caused by the calculation methodology of AGFW FW 309, 2018, negative annual values are set to zero).

A closer look at the DH system C shows significantly higher values in May which was in this case related to the shutdown of the biomass boiler during this time. A potential upgrading measure is to minimize the downtime of the biomass boiler to generate a lower primary energy factor.

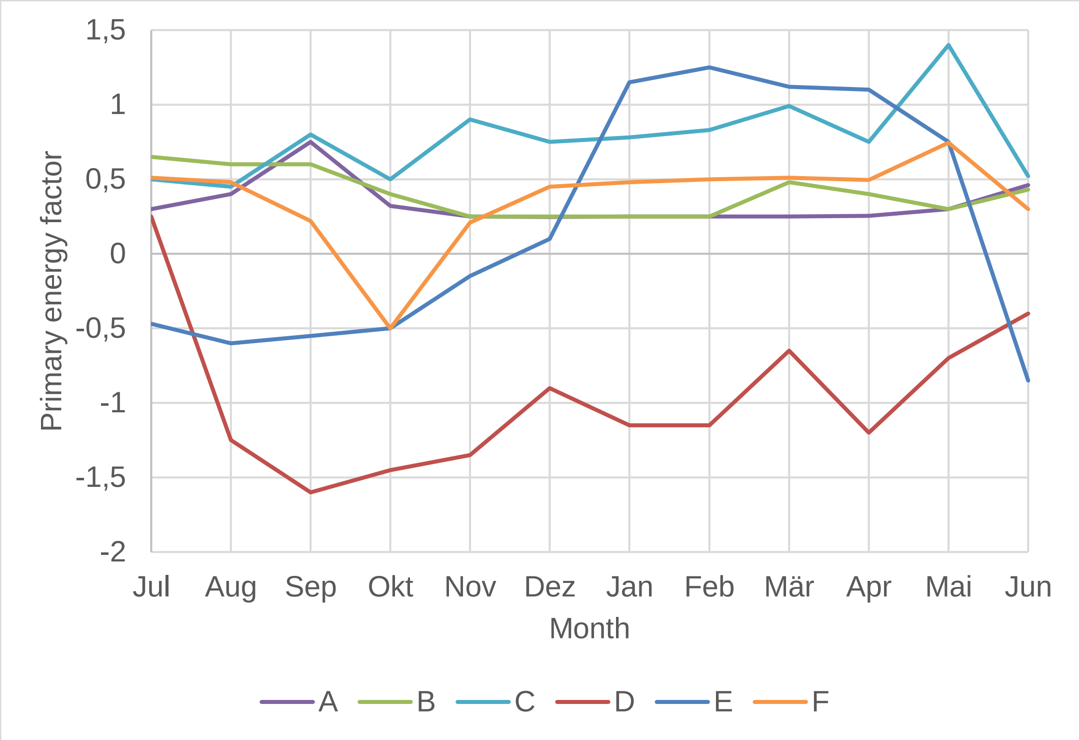

Figure 64: Primary energy factor of DH systems A, B, C, D, E and F (own graph, based on Bücker et al., 2015)

5.5 Demand-response options

The definition of Demand-Response (DR) is frequently discussed in the energy sector, usually in the electrical energy context. It is also often used synonymously to Demand Side Management (DSM). According to Forschungsstelle für Energiewirtschaft e.V (2019), a suitable definition is (translated into English): Demand Response is a short-term and predictable change in consumer load in response to price signals in the market or due to the activation by contractual agreements on providing certain capacities. These market prices or capacity agreements are triggered by unplanned, irregular or extreme energy events.

For DH systems, the **change of the load** will be able to reduce consumption peaks. These occur when many consumers need heat at the same time. This happens for example when many connected private houses request domestic hot water in the morning/afternoon e.g. for showering, or when the night-time heating reduction turned off at the same time. For these peaks of heat demand, most DH systems have some peak-load boilers, working only for a few hours a year. The problem is that they cause substantial costs and usually use fossil fuels (heating oil, natural gas) for this short-term delivery. That is the reason why there are many optimisation approaches to lower/ avoid these peak loads as for example to apply accurate load prediction (Faber et al., 2018) or to integrate (buffer-) storages.

As discussed in chapter 5.3.6, the integration of power-to-heat using peak power during sunny (PV) and windy (wind energy) days can be also considered as DR. In that case, the approaches of sector coupling become relevant for the whole energy sector by using excess electrical power as source for DH (power to heat) or for production of gas (power to gas), that could either be used for electricity or heat production or with CHP (combined heat and power) for both.

However, the demand response options for DH with direct changes of consumer loads are also investigated in research activities on a European level like in the STORM Project[7]. In this

[7] https://storm-dhc.eu/

project, the developed STORM controller (innovative DH & Cooling network controller), based on machine learning and applied artificial intelligence, should be able to increase the use of waste heat and renewable energy sources and boost energy efficiency at district level (Johansson et al., 2018).

Glossary and Abbreviations

The Glossary and Abbreviations list describes and defines various specific or common expressions, terms and words, which are used in this handbook. A major aim of this list is to facilitate translations of the handbook into national languages. Several expressions are adapted from Wikipedia and from Rutz et al. (2017).

a: see Year

Absorption: process in which atoms, molecules, or ions enter some bulk phase (gas, liquid, or solid material). This is a different process from adsorption, since molecules undergoing absorption are taken up by the volume, not by the surface (as in the case for adsorption).

Adsorption: the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a solid surface

Anaerobic digestion: Also called digestion or fermentation: A microbiological process of decomposition of organic matter, in the complete absence of oxygen, carried out by the concerted action of a wide range of micro-organisms. Anaerobic digestion (AD) has two main end products: biogas (a gas consisting of a mixture of methane, carbon dioxide and other gases and trace elements) and digestate (the digested substrate). The AD process is common to many natural environments and it is applied today to produce biogas in airproof reactor tanks, commonly named digesters.

ATES: Aquifer thermal energy storage

Barrel of oil equivalent (boe): The amount of energy contained in a barrel of crude oil, i.e. approx. 6.1 GJ, equivalent to 1,700 kWh. A "petroleum barrel" is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 litters); about 7.2 barrels are equivalent to one tonne of oil (metric).

Biogas: Gas resulting from anaerobic digestion consisting of mainly methane and carbon dioxide, but also of hydrogen sulphide, water and smaller fractions of other compounds

Biomethane: Upgraded biogas to natural gas quality with CH_4 content >95%

BTES: Borehole thermal energy storage

Capacity: The maximum power that a machine or system can produce or carry safely (the maximum instantaneous output of a resource under specific conditions). The capacity of generating equipment is generally expressed in kilowatts or megawatts.

CAPEX: capital expenditure

Carbon dioxide: CO_2 is a naturally occurring chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It is a gas at standard temperature and pressure and exists in Earth's atmosphere in this state, as a trace gas at a concentration of 0.039% by volume.

CHP: Combined heat and power: (Syn. Co-generation): The sequential production of electricity and useful thermal energy from a common fuel source. Reject heat from industrial processes can be used to power an electric generator (bottoming cycle). Conversely, surplus heat from an electric generating plant can be used for industrial processes, or space and water heating purposes (topping cycle).

Circuit water: see heat transport medium

CO_2: see Carbon dioxide

Coefficient of performance (COP): The coefficient of performance or COP (sometimes CP), of a heat pump is the ratio of the change in heat at the "output" (the heat reservoir of interest) to the supplied work. The COP was created to compare heat pumps according to their energy efficiency.

Co-generation: see combined heat and power generation (CHP)

Condensing boiler (economizer): Condensing boilers are water heaters with high efficiencies (typically greater than 90%) which are achieved by using the waste heat in the flue gases to pre-heat the cold water entering the boiler. They may be fuelled by gas or oil and are called condensing boilers because the water vapour produced during combustion is condensed into water, which leaves the system via a drain.

Cooling: Cooling is the transfer of thermal energy via thermal radiation, heat conduction or convection thereby changing the temperature from the targeted system from higher temperature levels to lower temperature levels.

COP: see Coefficient of performance

DH: District heating

DHC: District heating and cooling

DHW: Domestic hot water supply

District cooling: District cooling is a system for distributing chilled water from a centralized location for residential and commercial cooling such as air conditioning.

District energy: Combination of district heating and cooling concepts

District heating: According to the EC (2018c), district heating or city heating is the "distribution of heat through a network to one or several buildings using hot water or steam produced centrally, often from co-generation plants, from waste heat from industry, or from dedicated heating systems".

DR: Demand response

Enthalpy: Enthalpy is a measure of the total energy of a thermodynamic system. It includes the internal energy, which is the energy required to create a system, and the amount of energy required to make room for it by displacing its environment and establishing its volume and pressure.

Entropy: Entropy is a measure of how evenly energy is distributed in a system. In a physical system, entropy provides a measure of the amount of energy that cannot be used to do work.

Exergy: In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero. Determining exergy was also the first goal of thermodynamics.

Feedstock: Any input material into a process which is converted to another form or product.

Flat plate collector: Most common solar thermal collector

Flow: Transport medium of a certain quantity and temperature which flows from the heat source to the heat sink.

Fossil fuel: Fossil fuels are formed in millions of years by natural processes such as anaerobic decomposition of dead organisms.

GPS: Global Positioning System – GPS is a global navigation satellite system that provides geolocation and time information to a GPS receiver anywhere on or near the Earth.

Greenhouse gas (GHG): Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapour and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

Grid pipes: DH pipes that distribute the heat to the consumers, who are connected by service pipes.

Heat: Heat is energy transferred from one system to another by thermal interaction. In contrast to work, heat is always accompanied by a transfer of **Exergy**. Heat flow from a high to a low temperature body occurs spontaneously. This flow of energy can be harnessed and partially converted into useful work by means of a heat engine. The second law of thermodynamics prohibits heat flow from a low to a high temperature body, but with the aid of a heat pump external work can be used to transport energy from low to the high temperature. In ordinary language, heat has a diversity of meanings, including temperature. In physics, "heat" is by definition a transfer of energy and is always associated with a process of some kind. "Heat" is used interchangeably with "heat flow" and "heat transfer". Heat transfer can occur in a variety of ways: by conduction, radiation, convection, net mass transfer, friction or viscosity, and by chemical dissipation.

Heat exchanger: Device built for efficient heat transfer from one fluid to another, whether the fluids are separated by a solid wall so that they never mix, or the fluids are directly contacted.

Heating value: the amount of heat released during the combustion of a specified amount of a fuel (biogas, biomethane). There exist a higher and a lower heating value.

Heat transfer efficiency: ratio of the useful heat output and the actual heat produced in the combustion device.

Heat transport fluid: the medium that is used to bring the heat from the heat source to the heat sink. In District heating systems, this is usually water, it is also called circuit water.

Installed capacity: The installed capacity is the total electrical or thermal capacity of energy generation devices.

Kilowatt (kW): A measure of electrical power or heat capacity equal to 1,000 watts.

Kilowatt-hour (kWh): The most commonly-used unit of energy. It means one kilowatt of electricity or heat supplied for one hour.

kW_{el}: electrical power (capacity)

kWh: see Kilowatt-hour

kW_{th}: thermal (heat) capacity

Legionella: Pathogenic group of bacteria which can cause health problems.

Make-up water: make-up water is the water that is needed to refill the lost water, e.g. through leakages, in the DH grid.

Mini-grid: An integrated local generation, transmission and distribution system (for electricity or heat) serving numerous customers.

Natural gas: Natural gas is a fossil hydrocarbon gas mixture consisting primarily of methane, with other hydrocarbons, carbon dioxide, nitrogen and hydrogen sulphide.

ORC: Organic Rankine Cycle

Organic Rankine Cycle: The ORC process is named for its use of an organic, high molecular mass fluid with a liquid-vapour phase change, or boiling point, occurring at a lower temperature than the water-steam phase change. The fluid allows Rankine cycle heat recovery from lower temperature sources such as from biogas plants.

PE: polyethylene

PEHD: high-density polyethylene

PJP: Plastic Jacket Pipes

Power: The amount of work done, or energy transferred per unit of time (definition in physics) as well as electricity from the grid (definition in the energy sector).

Process heat: Heat used in an industry for different internal or external process (e.g. for digester heating).

PTES: Pit thermal energy storage

PUR-foam: cellular polyurethane foam

Return flow: Cooled transport medium of a certain quantity and temperature which flows from the heat sink to the heat source.

SCADA: (Supervisory Control and Data Acquisition) SCADA is a control system that uses computers, networked data communications and graphical user interfaces for technical processes, in this case for DH.

SCOP: Seasonal Coefficient Of Performance

SDH: Solar district heating

Service pipes: DH pipes that connect the consumers, to the grid pipes.

Smart grid: A smart grid is an electrical grid that uses information technologies and other technologies in order to adjust the demand and supply in a most efficient way. Smart grids are measures to improve energy efficiency and with the increase of renewable energies it will be more important to stabilise the grid.

Steam: Steam is the technical term for water vapour, the gaseous phase of water.

Substation: Heat transfer station which connects the DH grid with the heat consumer. It usually includes a heat exchanger.

Surplus heat: See waste heat.

Temperature differential (ΔT): difference of two temperature levels whereas the result is always positive.

TERMIS: TERMIS is an IT tool for mathematical modeling of heating systems. It simulates the operation of the system on the model of district heating network mapped in the program. It retrieves real-time network data, calculates and analyzes current operating conditions. Determines the parameters of the network operation of the moment and at each point of the network.

TES: Thermal energy storage

Transmission pipes: Larger DH pipes that bring heat from the heat source to the DH grid.

Trench length: Single length of the and the return pipes: for example, 100 m trench length means 100 m supply and 100 m of return pipes.

TTES: Cylindrical steel tanks

Vapour: Vapour is a substance in the gas phase at a temperature lower than its critical point. This means that the vapour can be condensed to a liquid or to a solid by increasing its pressure without reducing the temperature. For example, water has a critical temperature of 374°C (647 K), which is the highest temperature at which liquid water can exist. In the atmosphere at ordinary temperatures, therefore, gaseous water (known as water vapour) will condense to liquid if its partial pressure is increased sufficiently. A vapour may co-exist with a liquid (or solid).

Vacuum tube collector: Solar collector consisting of vacuum tubes in which the absorber is placed.

VSD: variable speed driver pumps

Waste heat: Heat from any process, such as from a CHP unit, which is released to the atmosphere and not used. It may be also called surplus heat since “heat” as a type of energy cannot disappear (wasted), according to the law of conservation of energy.

Watt (W): A standard unit of measure (SI System) for the rate at which energy is consumed by equipment or the rate at which energy moves from one location to another. It is also the standard unit of measure for electrical power. The term 'kW' stands for "kilowatt" or 1,000 watts. The term 'MW' stands for "Megawatt" or 1,000,000 watts.

Δ**T**: see temperature differential

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