Delivering the Energy Transition: What Role for District Energy

sustainable energy for everyone

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Table of contents

1 Introduction

The EU has committed itself to drastically reducing the European energy consumption in its climate goals. This requires major improvements in energy efficiency at overall energy system level and a shift towards low carbon energy sources. Heating and cooling represent the EU's biggest energy demand and thus play a primary role in this debate. The EU Strategy on Heating and Cooling, as well as research conducted over the last years, have highlighted the role of District Heating and Cooling (DH&C) networks in achieving the EU's energy transition until 2050.

Potentials can only be tapped and exploited by taking a holistic view of the energy system. The fundamental question throughout is how the corresponding infrastructures can be developed in a smart way to achieve a cost-efficient, sustainable, and climate-friendly energy system.

This strategy paper addresses the following main questions investigating the crucial role that DH&C networks would play in the energy transition towards 2050;

- How does DH&C develop while energy demands in buildings are decreasing?
- What is the role of DH&C in bringing renewable energy sources (RES) to high density city areas and villages?
- How would DH&C solutions support the balance of demand and supply?

2 A look into the energy system of 2050 - Vision

Rapid urban growth as well as mandatory European energy and climate goals oblige us to change our urban energy system from fossil fuels to low/no carbon: By 2050, the EU aims to decarbonise its energy system to at least 80% below the 1990 level. Achieving this will require major improvements in energy efficiency at overall energy system level and a shift towards low carbon energy sources. The energy system needs to build on a cross-sectoral approach and makes use of synergies between the various energy sub-sectors by identifying suitable and cost-effective renewable energy solutions for the future. The energy system of 2050 will be the one that fulfils the requirements from the EU's climate targets:

- that emits low/no carbon in 2050 and as little as possible on the way there. Thus the energy system in 2050 will exploit renewable and recoverable energy sources to the largest extent possible and implement energy technologies that provide the highest efficiency to avoid systems losses.

- that fits to the increasing urbanisation. The energy system of 2050 will utilise technology options that overcome the constraints of dense urban environments without compromising on the health and quality of living.

- that is safe for current and future generations. The transition towards a more secure and sustainable energy system will require careful determination of energy sources and technologies.

- where demand and supply match by fully utilising flexibilities and storage capacities of an integrated energy system. Therefore, towards 2050 a mapping of heat demand density and access to local sources will be available in development plans together with a thorough understanding of energy demand patterns to consider hourly balance.

- which ensures supply at all times (without interruptions/blackouts). Therefore, the energy system of 2050 will ensure a diversity of energy sources and suppliers as well as increased focus to produce energy locally.

- with no or little dependencies on fuel imports to increase energy security. Thus, using local renewable sources will be one of the priorities of the 2050 energy system.

- that is affordable and supports economic prosperity of the EU. The transition that will happen by 2050 will require a large investment into the energy system to install renewable energy generation facilities, modernisation of grids, and improve the energy efficiency of buildings. Therefore, an overall efficiency approach in demand and supply side in parallel is crucial in the transition to the 2050 energy system in all sectors in order to have savings that will pay off the costs of investments, creates jobs, and reduces energy poverty.

The above components of the vision will be achieved by a two-part strategy that would satisfy the future demand through an optimised combination of strong energy efficiency measures and a shift from conventional to low-carbon sources in the supply mix.

It is essential to reduce the demand for energy in all sectors; primarily in buildings, industry, transport, but also in others. Increased energy efficiency is an important and necessary measure for saving energy and mitigating climate change. Therefore, significant end demand savings will be implemented in households, industry, and businesses, considering that economic growth will increase demands in the future.

In order to meet its greenhouse gas (GHG) emission reduction target by 2050, the EU needs to combine energy efficiency measures with the decarbonisation of the energy supply. The future energy system will rely on renewable energy sources such as wind, solar, biomass, and will utilise the recoverable energy. Decarbonising other sectors is as important as decarbonising the energy supply. The increase in the share of renewable and recoverable energy sources together with reshaping transport systems, building and urban design, industrial processes, and agricultural activities to enable cost-effective zero-emissions will create new forms of flexibility by moving away from a "fuel to conversion to end use" approach to an "interconnected approach" in the future energy system where thermal, electricity, industry, and transport sectors are combined and compensate for each other. Innovation will play a key part in this systemic change. In order to rethink our ways of generating and using energy, there will be a need for new technologies, processes, services and business models which will shape the future of our economy and society.

Improvements in energy efficiency and increases in the contribution from renewable energy to supplies are both important and complementary for achieving a sustainable energy future with reductions in GHG emissions and improvements in the security of supply situation. Combinations of these strategies can deliver the required results. In the following sections, the focus will be on how DH&C can add to meet these requirements.

3 Current status and potentials of DH&C

DH&C networks are well-established technology options for providing heat to buildings. Although the level of technology differs, there are around 6,000 DH&C networks established in many cities in Europe. Modern DH&C networks increase system efficiency by combining the end user thermal comfort and a quality match between supply and consumption, trying to satisfy the demand through efficient distribution networks and supply systems based on renewable energy and waste heat.

Up to 2050, the energy system is expected to change significantly. District heating networks hold important potential for major savings (improved energy efficiency in buildings) and to serve as an infrastructure to integrate renewable sources into the energy system especially in densely populated cities.

3.1 Background

About 75% of the population of the EU lives in urban areas, indicating that the majority of the EU's buildings are in high heat density areas.[1] About 70% of the global energy demand and 40 to 50% of the global greenhouse gas emissions occur in cities.[2] The future urban population in the EU will continue to increase and it is estimated that by 2050, 82% of the population will live in urban areas.[3] This indicates that a major part of the EU building stock is in cities.[4]

In the EU 28 in 2014, the final energy consumption summed up around 1,095 Mtoe of which 274 Mtoe (ca. 25%) were consumed in the residential sector, 152 Mtoe (ca 14%) in the commercial and public services, and 255 Mtoe (23%) in the entire industry sector. Total heat final energy consumption made up about 45 Mtoe (ca 4 %), of which 44% is the heat used in residential sector, about 25% is in the commercial and public services sectors, and about 31% is in the industry sector.[5]

To supply the heating needs, district heating plays an important role and can be found in many cities all across Europe. Due to differing urban structures, climatic conditions, societal developments, political decisions, and the state of the general energy market, market penetration levels, and the state of technological advancement are different in different countries. Generally speaking, it can be said that most of the 6,000+ district heating systems can be found in Northern, North Eastern, Eastern, and Central Europa with substantial coverage also in the Northern parts of Southern and South Eastern Europe. Connection shares spread from over 90% in Iceland, and 65+% in Latvia, down to below 5% in the Western and Southern countries.[6] Northern European states with 50+% can be found in the middle, while Eastern and Central European states range from 10-50% connection shares.

In the countries of Northern Europe community schemes have a long tradition where the solution of choice in response to the oil crisis is to increase the resilience and decrease the import dependency of the wider energy system. By today more than 50% of the citizens of the Northern countries in the EU are served by district heating. Efficiency has played a crucial role in this decision. Due to the high penetration, technical progress was continuous and, following the progressive approach of the Northern countries towards more renewable sources, these DH networks are front-runners in decarbonisation.

Community schemes were also introduced quite early in the countries of Central, North Eastern, Eastern, and South Eastern Europe. Germany, Austria and the Northern parts of Italy have substantial penetration shares of DH especially in urban areas. In Central and Eastern Europe,

[1] Eurostat, 2015
[2] Seto et al., 2014
[3] United Nations, 2014
[4] Connolly et al., 2012
[5] International Energy Agency (IEA), 2016b
[6] Euroheat & Power, 2015

including former Eastern Germany, the construction of DH networks was linked to ambitious housing programmes. The Baltic Member States have the highest connection rates in Europe with over 65% of households connected in Latvia. Eastern European states follow with rates between 30-50%, whereas South Eastern countries have experienced pressure due to high rates of disconnection from community schemes currently standing at around 20%. At the end of the cold war, the networks all over Central and Eastern Europe were technically behind the state of the art. Substantial and successful efforts have been made in most countries to refurbish the networks, shifting to more efficient and sustainable heat sources. In particular, the Baltic states and the states of former Eastern Germany have seen progress and massive investments to establish state of the art networks but also countries such as the Czech Republic have made substantial progress. However, in South eastern Europe there was little progress and the disconnection with customers worsened the situation. Nevertheless, all existing networks form strategic assets that can contribute to Europe's decarbonisation. The inefficient networks need to be refurbished and combined with renewable resources in the future.[7]

Other than the Northern European countries, Western Member States responded to the oil crisis with investments in the exploitation of domestic natural gas resources and the extension of nuclear power generation capacities. Accordingly, overall market penetration in the UK and the Netherlands, Belgium and France is quite low. Having said this, DH networks have existed for decades in a number of cities including Paris, Nantes, Ghent, Rotterdam, Amsterdam, London and Glasgow. Under the impression of fading domestic gas resources and facing the challenge of decarbonising the cities, frontrunner municipalities have started extending existing grids and constructing new networks in these countries. National governments have made it a strategic objective to increase the share of DH subsequently. Accordingly, penetration levels have increased with the potential to speed up the extension even more.

In Southern Europe, DH does not play a major role, firstly because of the climate conditions but also because community schemes have no relevant tradition. Nevertheless, networks exist for example in Lisbon, Barcelona and several cities in Greece. Besides the existing potential in urban areas, small DH networks can play an important role in mountainous areas as well as on islands.

Which sources are utilised in DH networks also differs broadly depending on the broader energy system, political choices, and domestically available resources. Whereas overall percentages do not reflect the complexity of local heat planning, they give a hint to general developments. Traditionally, heat recovered from electricity production plays a major role as source for DH. As the combustion of fossil fuels for electricity production decreases, the share of heat recovered from these processes decreases. At the same time heat recovered from RES based Combined Heat and Power (CHP) increases as well as other renewable sources. In 2012, almost 73% of the heat in district heating networks was recovered from electricity production with less than 60% from fossil fuels. Nearly 8%

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[7] Turmes, 2016

of the heat stem from the direct use of renewable sources. Less than 20% of district heating was based on the direct use of fossil fuels, mainly in Eastern Europe or used in peak boilers.[8] A European Commission study came to the conclusion that the fossil fuel input into the CHP plants and heat only boilers together is mainly dominated by gas followed by coal.[9] The overall composition on the country level is inhomogeneous. In 2012, some Eastern Europe countries (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia) above 80% of the heat utilised in district heating was recovered from fossil fuel based electricity production or generated in fossil fuel based heat only boilers. Heat from biomass CHP and heat only boilers plays an important role with significant shares in Sweden (49%), Austria (41%) and Estonia (35%). Iceland has the highest share of geothermal use in DH with 97% followed by increasing shares in France 4% and projects in major cities such as Munich and Den Haag.[10] Recoverable energy sources play a growing role in the production of DH. Denmark, Sweden and Switzerland utilise recovered heat and heat from thermal treatment of waste, as show the following shares respectively: 17%, 19% and 44%.[11] Heat pumps and solar thermal heat play an increasing role.

[8] Euroheat & Power, 2015
[9] European Commission (EC), 2016
[10] European Commission (EC), 2016
[11] European Commission (EC), 2016

3.2 Potentials and trends

Currently, the approach towards DH&C networks is undergoing a big change which will support unlocking its potential. This does not only encompass economic and environmental aspects, but also considers its ability to be integrated into the network of numerous systems as an integral part of smart city infrastructures (such as transport, waste, electricity, sanitation, sewage treatment, buildings).[12] Increasing urban densification and the change of local policies towards compact city planning, together with the local conditions, environmental and economic requirements, and political priorities that differ from country to country, DH&C networks can significantly grow or be refurbished. Examples for a significant growth are found in Finland (where DH demand increased from 5 TWh in 1970 to ca. 35 TWh in 2015 (market share: ca. 50%) with further growth potential by 2025.[13] Also in Sweden, the district heating market has continuously been growing since the 1970s[14] and the market is now mature, with limited growth potential in a largely saturated market.[15] The Baltic States (e.g. Estonia) have traditionally developed DH systems. Hungary, for example, saw a shrinking DH market in the past but a significant growth is expected with the integration of renewable sources into heating networks (according to their National Renewable Energy Action Plans).[16]

The evolution of DH&C technology has gone through three generations already. The two key changes from one generation to the next have been (1) increased energy efficiency through the reduction of temperature levels in the networks and (2) increasing reliance on renewable and residual heat. The fourth generation which is emerging is a low temperature system that reduces the supply temperature down to the required level by the consumer and is based on supply from a wide range of low carbon and locally available resources. This enables a quality match between supply and demand and helps to ensure the compatibility of DH with a more energy efficient and low carbon building stock.[17]

[12] United Nations Environment Programme (UNEP), 2015; own assumptions
[13] Finnish Energy, 2016
[14] Myringer, 2015
[15] International Energy Agency (IEA), 2016a
[16] Szabó et al., 2015
[17] Dalla Rosa et al., 2014; United Nations Environment Programme (UNEP), 2015

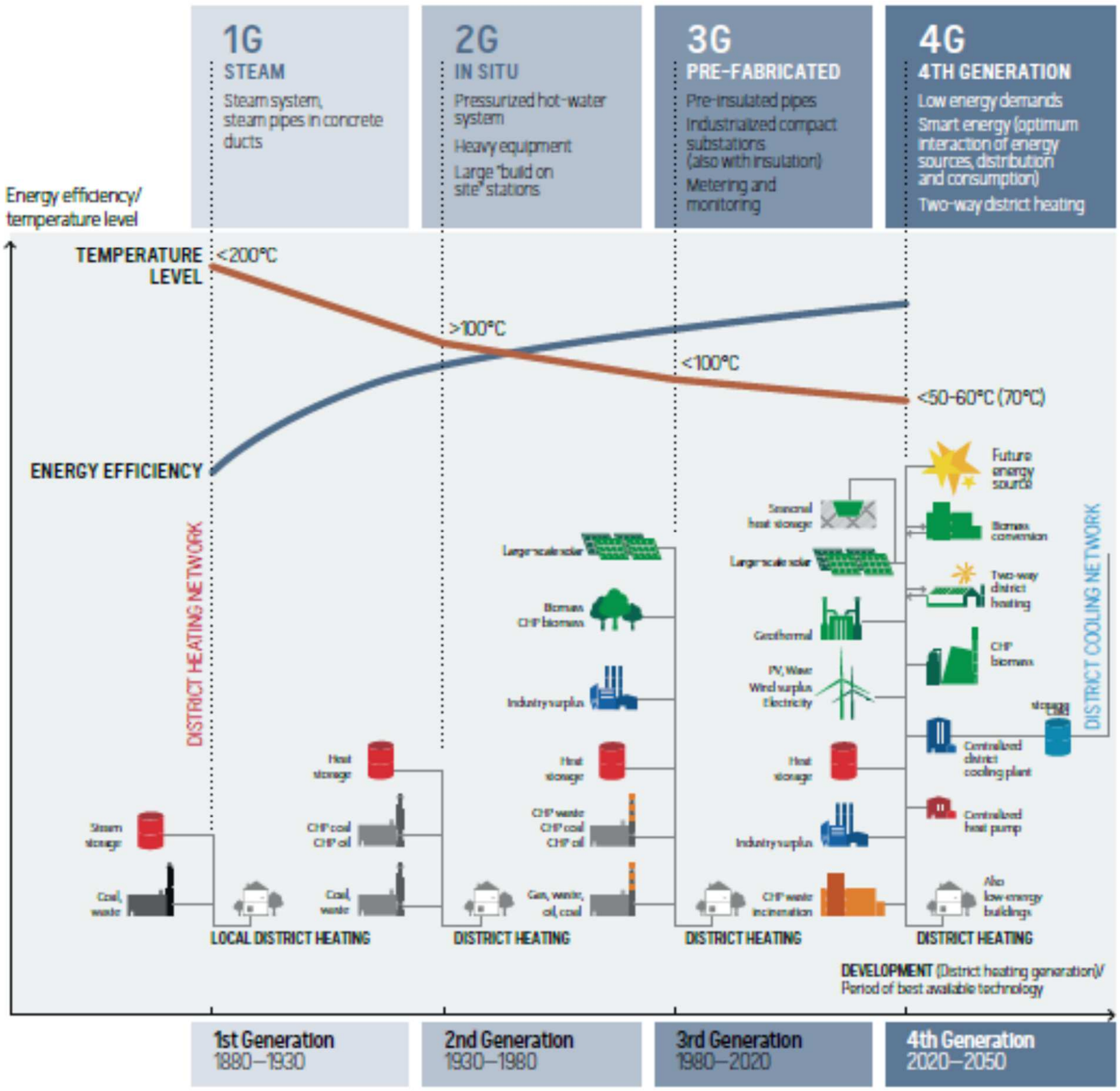

Figure 1: Illustration of the concept of 4th Generation District Heating in comparison to previous three generations[18]

Modern district heating networks can improve efficiencies to a large extent. Modern urban heat planning focuses on demand and resource availability and combines all parts: the end user's thermal comfort and a quality match between supply and consumption, trying to satisfy the demand through

[18] Lund et al., 2014

efficient distribution networks and supply systems based on renewable energy and waste heat. From an economic perspective, this makes the combination of district heating and energy-efficient buildings also feasible.[19]

The potential of the DH&C networks mainly depends on the availability of the heat sources (e.g. geothermal potential, surplus heat from industry) and the applicability conditions (e.g. requirements on baseload or peak load supply). As outlined in previous section, the heat sources for district heating are traditionally cogenerated heat and biomass. There is an increasing use of geothermal potential, solar thermal, heat from thermal treatment of waste and low-temperature heat sources in cities followed by less and less fossil fuels for boilers.[20] A clear trend was observed overall in EU28; the continuous growth of renewable heat and heat based on thermal processing of waste between 2007-2012 was 43% and 17%, respectively. The share of heat from renewable sources and heat based on thermal processing of waste has reached a total share of approximately 20% in 2012.[21] The increasing growth of renewable and recoverable energy sources in the district heat supply provides comparative results to the share of renewable sources in the energy mix (approximately 23% in 2013).[22]

The Heat Roadmap Europe study analysed the potential of available heat sources when considering the 2050 electricity mix. Based on this, the study calculates the annual amount of heat delivered to district heating networks to the residential and commercial sector in EU27. A potential mapping in the study shows that with the exception of heat recovered from thermal treatment of waste, each source has a higher potential than needed to cover the modelled demand (assuming a market penetration of heating and cooling networks at 50% level). The study scenario indicates that the share of fossil fuels would be limited to 1540 PJ/year) which includes substantial parts from CHP for electricity production form natural gas. The study also shows that this share could be replaced by the other resources. Large scale heat pumps are expected to have a major share in the 2050 district heating system (1875 PJ/year) followed by biomass (810 PJ/year) as well as heat from thermal treatment of waste (585 PJ/year) and industrial excess heat (385 PJ/year over the potential of 2710 PJ/year). Geothermal could be utilised to a large extent, even close to its full potential by 2050 (370 PJ/year over the potential of 430 PJ/year). Solar thermal is expected to have a substantial increase in the share, however has still limited extension considering its large potential (355 PJ/year over the potential of 1260 PJ/year).[23]

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[19] Dalla Rosa et al., 2014; United Nations Environment Programme (UNEP), 2015
[20] United Nations Environment Programme (UNEP), 2015
[21] Szabó et al., 2015
[22] Eurostat, 2016
[23] Connolly et al., 2013

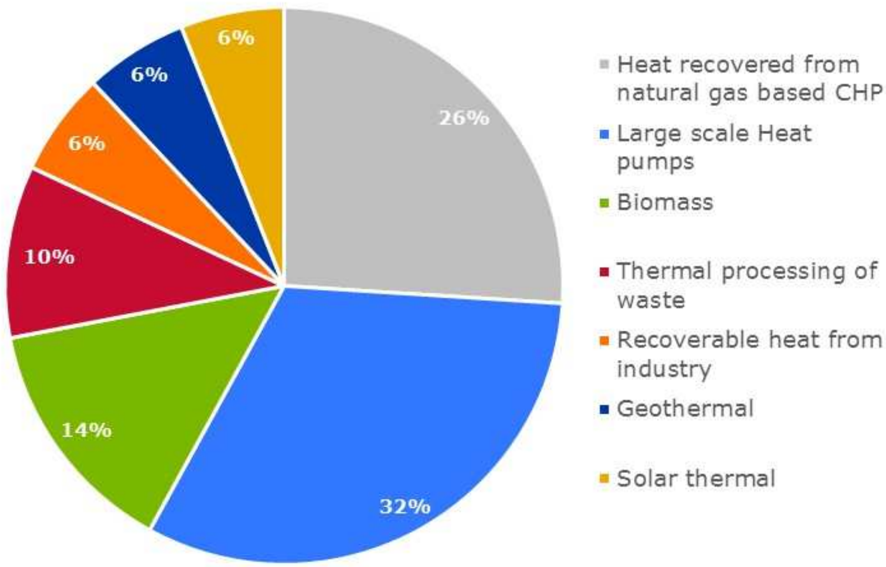

Figure 2: Main strategic heat sources for DH&C by 2050 according to European Heat Roadmap scenario with DH&C market share of 50%[24]

There are regulatory and policy instruments aiming to stimulate the deployment of renewable based district heating in Europe. Most EU member states had set targets for renewable district heating in their National Renewable Energy Action Plans (NREAPs). Sweden, Denmark, Finland, Slovakia, Austria, and the Baltic states are the countries that have overachieved their interim targets in 2012. These leading countries achieved their interim targets despite their DH systems showing high deployment of RES already. The rest of the countries are lagging behind their targets, even though many of them - Hungary, Romania, France, and the Netherlands - were also quite ambitious to increase their RES based DH shares up till 2020.[25] The following figure shows the targets of member states regarding RES district heating utilisation.

[24] Connolly et al., 2013
[25] Szabó et al., 2015

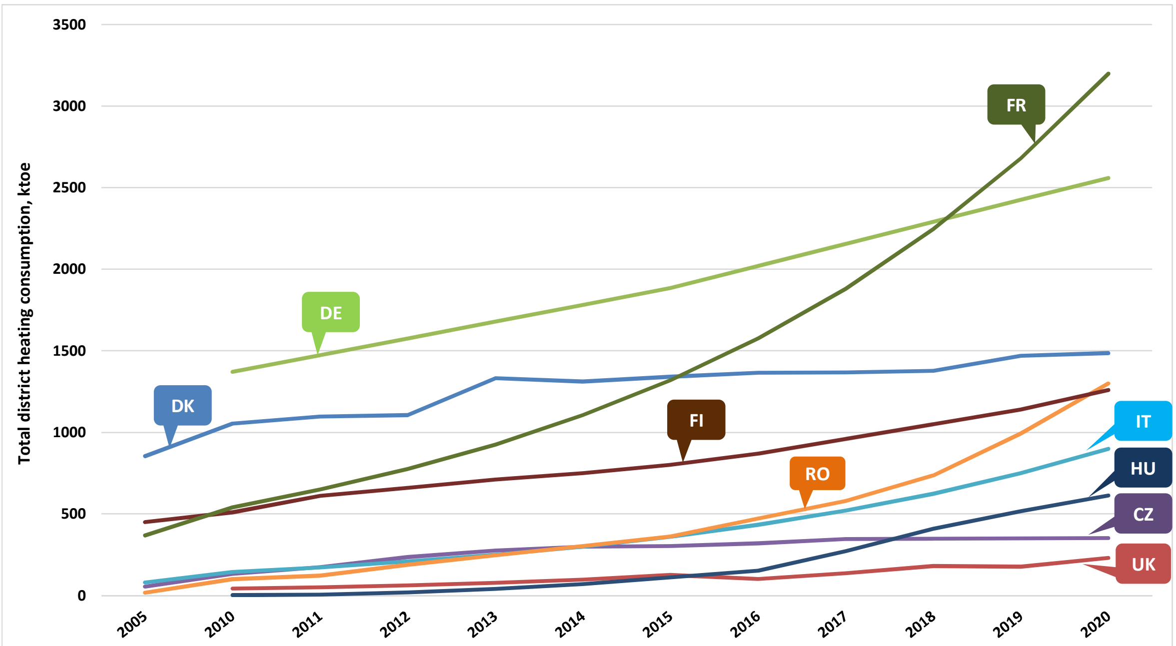

Figure 3: National targets for increasing RES in DH for different EU member states, updated figure[26]

[26] Szabó et al., 2015

District Cooling

Cooling is a matter as complex as heating and cooling demands are diverse. The cooling sector comprises cooling in industrial processes, i.e. industrial chilling, from very high temperatures as for example in metallurgic industries, over the whole food chain, data centres, space cooling in domestic and service buildings down to deep temperature refrigeration below -60°C. The energy demand for cooling in the EU is estimated to be 5% of the total energy demand.[27] Cooling demands are expected to increase worldwide due to various reasons. In Europe it is mainly due to the technological progress (e.g. more data centres), climate change, increased comfort demands, and side-effects of further urbanisation, e.g. heat islands effects.

Nowadays, cooling is mainly produced by electricity-driven compression chillers – it is literally hidden in the electricity bill. The use of F-gases as refrigerants in vast numbers of individual, rarely controlled and often poorly maintained installations leads to significant impacts on the climate. With the current electricity mix still relying on fossil fuels to a large extent refrigeration and air conditioning accounts for 7 % to 10 % of the global greenhouse gas emissions, almost 3 times more than shipping and aviation combined.[28] Space cooling demands are at only 16% of the potential needs[29] and are expected to rise 70% of the overall heating demand by 2050.[30] Therefore, it is expected that even with increasing shares of RES in the electricity grid a drastic change is required to be able to meet the EU climate goals and prevent furthermore severe grid issues.

District Cooling has a great potential to help overcoming current and future problems of the cooling sector while providing multiple benefits. It can be based on natural cooling from the sea water, the efficient use of electricity in large heat pumps, or recoverable heat from various sources in absorption and adsorption chillers. The Rescue project showed that decision-makers opted for District Cooling, not just for ecological or economic reasons but also to overcome heat island effects, guarantee the health of citizens and to improve the appearance of their cities. Despite these positive effects, market penetration of District Cooling is very low only covering 1-2% of space cooling in Europe with a substantial potential in urban areas. There are only single grids in Eastern Europe, with the majority of grids located in Northern, Western and Central Europe. Sweden, with 50 networks, has the highest number of grids but the biggest ones are located in Helsinki and Paris. Other major cities such as Copenhagen, Berlin, Vienna, Barcelona and Lisbon follow.

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[27] European Commission (EC), 2016
[28] Prof. Toby Peters, University of Birmingham at Stakeholder Round Table on Cooling in Brussels 12th April 2016
[29] Stratego, 2015a
[30] Stratego, 2015b

District cooling has an even higher potential in combination with efficient buildings as lower individual loads balance the higher flow rate and allow for the connection of more buildings. At the same time, it offers benefits to both – the heating and the electricity sector. For the latter, District Cooling allows using available electricity in an efficient manner by aggregating and balancing different demands. The use of storage installations helps shifting peak demands but also allows for the utilisation of abundant renewable electricity in peak production times. Linked to District Heating it allows using recoverable heat also in summer months when heat demands are low but can also provide thermal energy to the heating grids when used to recover heat from buildings or processes.

To promote the most promising solutions regarding financial and environmental aspects a whole system level should be considered. As surely the benefits and the cost of an optimized whole system consideration will differ, adequate policies will be required to insure that the increasing cooling demand of the EU will be covered in an environmentally-friendly way at minimum costs for the European society and maximum benefits for the European industry.

3.3 Heat demand in 2050

Various studies at national and international level been conducted in order to outline scenarios for heat demand towards 2050. Table 1 provides an overview to present the results and inputs used to reach these scenarios. The scenarios considering heat demand reductions estimate savings in the range of 40 – 50%. The scenarios considering final energy savings estimate savings in the range of 36 - 54%. The latter estimation is only related to the final energy for space heating. The figures from the Renovation Tracks study seem to provide higher estimates in the reduction of space heating compared to the Heat Roadmap study at first glance. This is due to the different parameters used to report the reductions (specific heat demand in Heat Roadmap study, final energy use for space heating in Renovation Tracks study) and differing accounting principles.[31] Once those differences are considered in detail, the Heat Roadmap Europe and the Renovation tracks study prescribe the same level of savings for space heating; both conclude that although moderation of heat demand is expected the remaining need will still be significant and will need to be met in a manner consistent with the EU's long-term decarbonisation and energy security ambitions.

Table 1 Scenarios from the countries and Heat Roadmap

Country	Level of reduction (accomplished)	RE included	Scenario description	Time horizon
Denmark[32]	Net heating demand in total is projected to be 40 TWh for existing buildings and 5 TWH in new buildings in 2050	Yes	Focus on provision of efficient and flexible district heating with cost-effective use of renewable resources	2010-2050
The UK[33]	Around 50% in space heating demand (from 36,1 Mtoe in 2007 to 19,1 Mtoe in 2050)	Yes	Increased electricity generation; servicing additional transport and heat, with large quantities of conversion loss, mostly as waste heat from centralised fossil-fuelled power stations	2007-2050
Germany[34]	- Energy efficiency scenario with final energy reduction of 54% (whereas 64% for space heating and 17% for hot water) - Renewable energy scenario with final energy reduction of 36% (whereas	Yes	Reducing Germany´s primary non-renewable energy demand by 80% and having a climate neutral building stock by 2050 are both political targets. Therefore, energy efficiency as well as utilisation of renewable energies within the building sector have to be increased. The scenarios highlight	2008-2050

[31] The Renovation tacks study reports final energy savings for space heating and not demand savings. Final energy for space heating refers to the delivered energy that is used for space heating. Final energy savings include savings that are achieved through a change in technologies (e.g. from a gas boiler to a heat pump). The final energy saving when replacing a boiler with a heat pump in this example gives a reduction of about 73% (considering that heat pump has coefficient of performance (COP) 3 and oil boiler has efficiency of 90%). This means although the space heating demand has not been changed, final energy savings are calculated for heating. The heat demand in the Heat roadmap Europe mostly refers to space heating and hot water. The figures in the Renovation tracks study refer to space heating only. This also impacts the final results since energy demand for hot water is expected to increase in the future.

[32] Dyrelund, 2010

[33] Spiers et al., 2010

[34] BMWi Bundesministerium für Wirtschaft und Energie, 2015

Country	Level of reduction (accomplished)	RE included	Scenario description	Time horizon
	43% for space heating and 13% for hot water)		two extreme cases of meeting the targets, by either exploiting the maximum potential of energy efficiency and a low use of renewable energies in the building sector or vice versa. In a way, the scenarios can be seen as borders to a corridor in which the actual development will take place.	
Czech Republic	40% in total heat demand (share of 40% district heating of the overall heating supply)	Yes	All values are calculations from the STRATEGO project. It compares a "Business-As-Usual-Scenario" to a "Heat-Roadmap-Scenario", in which energy efficiency measures for the heating sector are taken into account.[35]	2010-2050
Croatia	40% in total heat demand (share of 40% district heating of the overall heating supply)	Yes		
Italy	30% in total heat demand (share of 60% district heating of the overall heating supply)	Yes		
Romania	50% in total heat demand (share of 40% district heating of the overall heating supply)	Yes		
Heat Roadmap study[36]	51% in specific heat demand between 2015 and 2050	No	An alternative future energy system scenario for the EU, which contains energy efficiency measures on both the demand and the supply side (i.e. by using district heating) of the energy system	2015-2050
Renovation tracks[37]*	Reduction of final energy use for space heating: Track 1: 32 % Track 2: 58 % Track 3: 80 %	Yes	Track 1: Shallow renovation, low contribution from renewable energy Track 2: Shallow renovation, and high use of renewable energy Track 3: Deep renovation and high use of renewable energy	2012-2050

[35] Stratego, 2015b
[36] Connolly et al., 2013
[37] EURIMA, 2012

Key Note

Extensive evidence suggests that energy-intensive urbanisation that heavily relies on fossil fuels has resulted in rising greenhouse gas emissions. The energy demand of buildings is dominated by space heating and cooling. Representing about 40% of global buildings energy use, space heating, and cooling continues to be a critical area of needed action in the buildings sector, especially in cities.

The heat delivery services need to be adopted to enable a greater share of renewable and recoverable heat energy sources into an integrated urban energy system. Already with the modern district heating networks, the low-carbon energy for heat demand is increasingly supplied by biomass, geothermal, recoverable heat from industry and thermal processing of waste options all over Europe. The DH&C networks can be the main driver to increase the diversity of energy sources and local heat generation.

Significantly increasing the rate of renovating Europe's aging building stock and providing high energy efficiency in new building is key to meeting EU climate targets. During and after the energy transition, a decrease in heat demand is expected, however it will remain significant within the overall energy demand. Thus, the heating sector has an important role to play towards a low carbon economy. Currently, district heating networks hold important potentials to be combined with major savings (improved energy efficiency in buildings) and to serve as an infrastructure to integrate renewable sources into the energy system. Therefore, national and local policy needs to address and pave the path for a low carbon efficient heat sector.

4 Position of DH&C in 2050 energy system

The European Union aims for a reduction of greenhouse gas emissions of the building sector of 88% - 91% by 2050 compared to the 1990 levels.[38] The transition from the current fossil fuel dominated system to a low-carbon energy system of the future means substantial changes in the energy system paradigm. Major improvements will be required in the energy efficiency of building side and at overall energy system level together with increasing shares of low-carbon energy sources in the supply mix. Especially in dense urban areas, district heating infrastructures have an important role to play in meeting the challenges of increased energy efficiency at system level together with providing a shift towards low-carbon energy sources.

One of the main pillars of decarbonising the energy system is the transformation of the building stock into high energy efficient standards. As presented in chapter 3.3., during and after the energy transition, a decrease in heat demand is expected, however it will remain to be significant within the overall energy demand. For district heating networks it is necessary to adapt the heat production to interact with energy efficient buildings in the future. Several projects already benefit from the applications with energy efficient buildings connected to district heating networks.

As the second pillar to reach the decarbonisation of the heat delivery, the services need to be adopted to enable a greater share of renewable and recoverable heat energy sources into an integrated urban energy system. The value of such potential is especially large in cities where it is of utmost importance to use local resources despite the space limitations of dense urban areas. The strategic importance of DH&C networks is their potential to aggregate the heat demand of multiple consumers to a scale and thus utilise renewable and recoverable energy sources to an extent which would not be possible at individual building level. Therefore, district heat networks have a further role to play in the decarbonisation of the heat sector with the heat being increasingly supplied by geothermal and solar thermal sources together with fully exploiting the local recoverable heat sources from industry and thermal processing of waste.

The future energy systems will have undergone a substantial change with increased share of RES. The efficient conversion of different energy forms, as well as the storage and transport of energy carriers, has great potential to increase flexibility and stability within the energy system. Adequacy for heat systems with high penetration of renewable and recoverable heat sources towards 2050 will require greater emphasis on ensuring sufficient flexibility and storage capacities as they will create an increasing value to the system integrations. DH&C is a promising means for integrating renewable energy sources and providing flexibilities when coupling heat and power market.

[38] European Commission (EC), 2011

Improvements in energy efficiency and increases in the contribution from renewable energy to supplies are both important and complementary for achieving a sustainable energy future with reductions in GHG emissions. It has strategic importance to move forward with a national and local policy that evaluates the individual local conditions, that can harness the local low-carbon energy sources, to map the potentials of utilising low-carbon heating and cooling in buildings, and determine the technologies that exploit them in their full potential. DH&C networks provide promising solutions, for the utilisation of different energy sources and bring the different parts of the energy system together in an integrated therefore more efficient system.

4.1 Energy efficient buildings and DH&C

To reach policy goals on energy and climate, it is essential for the future sustainable energy system to reduce the energy demand substantially. Significant end demand savings have to be implemented until 2050 in households, industry, and businesses, considering that economic growth will increase demands in the future. Therefore, for district heating it is necessary to adapt to an energy system with less heat demand in the future.

4.1.1 The need for change

Buildings are responsible for a large part of the global energy demand. Approximately 40% of energy end-use in the developed world takes place in buildings. Of all energy used in buildings, energy for space heating represents the greatest demand. Significantly increasing the rate of renovating Europe’s aging building stock and providing high energy efficiency in new building is key to meeting EU climate targets. Accordingly, decreased heat demand in future is expected, however it will remain significant within overall energy demand.

High savings on individual building scale is technically possible and has primary importance to be utilised where possible. However, there are also natural limits to the demand side efficiency measures before supply side measures prove more cost- and carbon-effective, particularly in the case of high density urban areas or historic buildings. To achieve the maximum benefits, there is a need to evaluate the relevant cross-over points between demand and supply side investments. The role of district heating is significant to utilise this potential benefits. Together with the change in demand and transition to energy system of 2050, DH&C networks also need to adopt and further develop to decrease grid losses, exploit synergies, and thereby increase the efficiencies of low-temperature production units in the system. Several projects already benefit from the applications with energy efficient buildings connected to district heating networks. These examples illustrate and show the way to increase the synergies between energy efficient buildings and modern DH&C network services.

4.1.2 Case studies in combining DH&C with energy efficient buildings

Numerous case studies show applications of DH&C networks with low heat demand from space heating realised in Austria, Belgium, Denmark, Germany, and Italy. The intention of this chapter is to show how district heating is combined with high energy efficient buildings, discuss the potentials of district energy development and identify common key success factors.

The methodology applied is a combination of questionnaires (1st Phase) and interviews (2nd Phase). The questionnaires aimed at analysing where and how district heating and cooling are combined with high energy efficiency on the demand side (i.e. reduced heat demand per building). The interviews aimed at understanding the factors that contributed to the success of the projects. Based on the outcome of the questionnaires, we selected interview partners for an in depth analysis and validation of first insights. The interviews were primarily realised with respondents to the questionnaire. Additionally, three companies/associations were contacted for interviews. The interviews with the respondents of the questionnaire aimed at analysing in depth how the decision making process in the case studies affected the implementation. Based on this analysis, we developed possible key success factors. The interviews with companies and associations that did not respond to the questionnaire had the target to; a) get a wider perspective (especially from an association's point of view), and b) validating the first conclusions about key success factors.

The questionnaires and interviews have grouped projects in terms of type of buildings and existence of DH network. Four types of projects were identified:

a. (deep) renovation of buildings with continued connection to a DH&C network;
b. connection of (deep) renovated buildings to a) a new or b) an existing/extended DH&C network;
c. combined (deep) renovation of buildings and connection to a) a new or b) an existing/extended DH&C network;
d. new energy efficient buildings connected to a) a new or b) an existing/extended DH&C network.

The results are based on nine specific case studies that were considered and examined. Additionally, further interviews were conducted with experts that are experienced in similar projects. General experiences from the sector were collected from other research projects or through the work of the DHC+ Technology Platform. These were used to verify and clarify specific findings.

Each of the case studies present the application of DH solutions in a diverse set of local conditions and specific needs. Examples of integration of new energy efficient buildings to the DH network are case studies 1, 2, 4, 6, and 8. Examples of projects where renovated buildings are connected to DH networks are case studies 3, 4, 5, 7, and 9. Several commonalities were identified for the successful integration of energy efficient buildings concept with DH networks and are presented in the following chapter. Specific details on the process of project realisation, achieved results, and important factors from case studies are as follows.

Case study -1: Antwerp, Belgium. Nieuw-Zuid is a newly built neighbourhood in Antwerp, consisting of 287,000 m² residential floor space, 54,000 m² office space, and 21,000 m² schools and sport infrastructure. The project is an example for new energy efficient buildings that are connected to a new DH&C network.[39]

The case study shows the successful integration of very low energy buildings to a newly developed DH network. In the newly built area, most of the buildings reach passive house standards (space heating demand 15kWh/m^{2}a., domestic hot water demand 15kWh/m^{2}a.). After full development in 2033, Nieuw-Zuid will have an estimated heat demand of 10600 MWh/a, and a peak demand of 6.8 MW supplied by 30 substations. The project also shows the strength of the DH provided by its versatility in the supply mix which can be designed and changed according to long term plans of the region. In this start-up phase, gas boilers will supply the heat to the newly developed area. The ambition on the long run is to make use of excess heat from industry (from the nearby chemical plant) and to consider the waste incinerator for generation of heat. The current gas boilers will become peak boilers after the planned transition to low carbon sources.

Case study-2: Salzburg, Austria. Salzburg is part of the Concerto Project "Green Solar Cities" (Partner city was Valby-Copenhagen), where the whole city district Lehen was renewed. The Stadtwerk Lehen was the lead project with 287 new apartments, a kindergarten, a student dormitory and a seminar centre, but the renovation of 285 apartments was also realised. The project is an example for both the connection of (deep) renovated buildings as well as new energy efficient buildings to a new DH&C network.[40]

The project is a good example of exploiting the local sources in the optimum way for new and renovated buildings by integration of DH. The aim of the demonstration project was to test how large scale thermal solar energy could be integrated in a district heated area; to decrease the energy demand combined with the increase of renewable energies in an urban area. For this area a micro net was built; heating central with a with 200.000 litre water puffer tank. The heat of 2,000 m² thermal solar collectors is fed to the water tank and optimised with an integrated 150kW Solar-Heat pump. The additional heat comes from the local district heating net form the city of Salzburg (50% energy from industrial waste heat and biomass). The micro-net in the Stadtwerk Lehen area runs with temperatures of 60 Cº and maximum 35 Cº back by the local energy supplier The apartments are totally social supported apartments for rent, the building projects achieved to supply heat within the economic borders for social housing. The project shows the importance of involvement of several stakeholders including city authorities, tenant (running via a social forum with an Info Point to inform tenants) and housing associations.

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[39] *Communication via "District heating and cooling strategy" – questionnaire*. Project: Nieuw-Zuid Antwerpen. VITO – EnergyVille.

[40] *Communication via "District heating and cooling strategy" – questionnaire.* Project: Lehen, Salzburg. Salzburger Institut für Raumordnung & Wohnen (SIR).

Case study-3: Germany. Within the district, 231 buildings are renovated and a solar-thermal plant will be installed. The project is an example for a combination of (deep) renovation of buildings that are connected to an existing/extended DH network.

The heat demand of the renovated buildings was reduced by half, as well as a connection to a solar thermal plant was installed. The main drivers were environmental compatibility, sustainability, and security of supply for the regional development.

Case study-4: Copenhagen, Denmark. When Danish legislation was adjusted, it became possible for companies owned by a municipality to supply cooling. This case study does not refer to a single project and within this framework examples are found for a) (deep) renovation of buildings with continued connection to a DH&C network, b) connection of (deep) renovated buildings to an existing/extended DH&C network, c) combined (deep) renovation of buildings and connection to new and existing/extended DH&C network, and finally d) new energy efficient buildings connected to new and existing/extended DH&C network. District cooling is supplied when building owners demand it, it is operated at a competitive market without any subsidies.[41]

The case study is an example of well-established district cooling network with existing and new energy efficient building since buildings must meet 2020-regulations. Often district cooling is the only method that can support these high standards. Moreover, it was mentioned that often decision makers demand district cooling simply because of the preference of the convenience and the absence of maintenance on a local system. Seawater is used all year around for cooling. In the summer electrically driven compressors are used to meet peak load. The application shows importance of interest of the municipality as DC is a part of Copenhagen's ambition of being carbon neutral in 2025.

Case study-5: Torino, Italy. Torino is one of two demonstrator cities of the EU´s District Information Modelling and Management for Energy Reduction[42] (FP7), which aims to provide and manage real-time data of the buildings and the district energy distribution network. This project is an example for the renovation of buildings with a continued connection to a DH&C network.[43]

This is an example where building renovation is combined with optimal network management in a dense city landscape where the choice was driven mainly by the economic concerns. Currently, it is performed at a city quarter level with 105 buildings being renovated. In the future, the project is planned to be extended to the entire city.

Case study-6: Copenhagen, Denmark. Nordhavn is one of Scandinavia's largest city development districts. Over the next 30-40 years it will develop into a district with 40,000 residents and 40,000

[41] *Communication via "District heating and cooling strategy" – questionnaire*. Project: Copenhagen. HOFOR Fjernkøling.
[42] DIMMER Consortium, 2015
[43] *Communication via "District heating and cooling strategy" – questionnaire*. Project: Turin. Politecnico di Torino.

jobs. This project is an example for new energy efficient buildings being connected to new and existing/extended DH&C network.[44]

The district heating network is designed and planned by HOFOR (Denmark's largest utility company) for a maximum 70 °C flow temperature and is planned to be running by 2020. The project demonstrates low temperature district heating providing to low energy new buildings, fuel-shift, various short term storage solutions and other flexibility services for the power sector, as part of the future integrated energy system. For the region, a business case for individual heat pumps was carried out as a part of the project proposal, but was found to expensive, and technically to complicated, compared to district heating. The municipality of Copenhagen approved the project proposal showing that district heating is the best overall societal business case

Case study-7: Linz, Austria. The city of Linz is developing a whole new city district called "Grüne Mitte" with 800 apartments, 50 apartments with assisted living and a kindergarten and also a housing area with another 450 apartments and a kindergarten ("Lange Allee"). This project is an example for new and energy efficient buildings being connected to a new DH&C network.[45]

The heating demand of the individual buildings vary between 10 - 30 kWh/m² a, with a total heat demand of 2.5 MW supplied by 10 exchange stations. The heat supply mix includes a gas CHP plant with 60%; biomass CHP plant with 20%; and waste incineration plant (CHP) 20%. The DH was preferred over the heat pump option as DH operator has provided a combination of competitive offer for the district heating connection fee, an attractive heating price and high level of service.

Case study-8: Munich, Germany. Freiham-North is a newly built district in Munich. In a first stage an area of 850.000 m² is developed to provide homes for about 10,000 people in the future. This project is an example for new and energy efficient buildings being connected to a new DH&C network.[46]

The case study is an example for application of low temperature district heating grid using renewable heat in new building quarter. As an alternative to natural gas, the supply mix includes geothermal heat and CHP plant, also using heat from return pipe system for low temperature district heating grid in Freiham-North. The application has potential of extension as low temperature district heating grids can also be realised in other new building quarters of Munich in the future. District heating in Munich shall be transformed to a renewable system until 2040 using particularly geothermal heat with a focus on environmental performance and security of supply.

Case study-9: Bolzano, Italy. Bolzano is one of two demonstrator cities for the EU's Smart Initiative of Cities Fully Committed to Invest in Advanced Large–Scaled Energy Solutions Project

[44] *Communication via "District heating and cooling strategy" – questionnaire*. Project: Nordhavn, Copenhagen. HOFOR.
[45] *Communication via "District heating and cooling strategy" – questionnaire*. Project: "Grüne Mitte" and "Lange Allee", Linz. Linz AG.
[46] *Communication via "District heating and cooling strategy" – questionnaire.* Project: Freiham-North, Munich. SWM Infrastruktur GmbH.

(FP7), which aims to deploy integrated and scalable energy solutions in mid-sized European cities.[47] It focuses on optimising the heating and cooling network with 36,000 m² of living space being currently renovated. This is an example for a (deep) renovation of buildings with a continued connection to a DH&C network.[48]

Within the project a substantial heat demand reduction is foreseen by 2018; the space heating demand will be reduced to 20kWh/m^{2}a. from 178 kWh/m^{2}a. By the existing DH network an incinerator provides the base thermal energy to the network, while a backup system composed by 2 methane engines responds to the energy demand peaks. The project is a part of a larger plan for DHC extension and deep renovation of the social housing building stock in the district

The following table presents important aspects for success of presented projects. The summary is based on the analysis of the questionnaires and in depth interviews with respondents of the questionnaires.

[47] Sinfonia, 2016
[48] *Communication via "District heating and cooling strategy" – questionnaire. Project: Bolzano. EURAC Research, ALPERIA SPA.*

Table 2 Summary of different projects and their most important aspects

Q	Initiator	Solutions and Processes	Decision of building owner side	Tenants	Role of the city	Embedded in campaign	Reason for final choice	Connection security in the future
1	Former city council		No involvement, decision was made by the project developer	No Involvement	Very important; ordered feasibility studies and took decisions on energy standards. Also decided for DH instead of gas network and did PR and communication part	Newly built neighbourhood	Environmental performance and local supply; missing alternative as gas was not supplied in the area	No alternative for district heating as gas is not supplied
2	Partner initiative (local authorities, DH&C utility, institute and association)	All partners signed a quality agreement; the steering group guaranteed information and cooperation	Housing association for residential and local authorities for public buildings	Involvement via forums	Led the design of the masterplan and the steering group. Also responsible for the renovation part	Concerto project "green solar cities"	Decrease energy demand combined with increase of RE in an urban area; social housing project, so costs for future tenants were limited	Energy Demand is not a problem as it´s a new built area and demand was known during planning phase; monitoring showed that demand is higher than calculated, which corresponds to experiences from other new built areas where people have room temperatures above 20°C and do not save energy.
3	City asked DH&C utility to develop DH&C concept	Extension of conventional network by solar thermal supported DH	The building owner himself	Involvement via public relations work and the building owners	Ordered the design of a concept and installed an energetic quarter management within the framework of a whole city concept	Climate protection project of the city within the scope of the European Energy award	Energy policy and ecological reasons; main drivers were environmental compatibility, sustainability and security of supply	Intensive and individual communication process with the building owners, which was carried out by the DH&C utility, supported by the energetic quarter management
4	DH&C utility proposed concept to the local authorities	After adjustment of Danish legislation municipality owned companies were allowed to supply cold	Differs, in some cases the building owner, in others the building manager or technician	Full involvement; all that was build was done by tenants	Outlined DH as part of the 2025 carbon neutral strategy	No, only depended on number of contacts	Environmental performance was main driver from the supply and price from the demand side	Cost effective solutions, which ensure a viable business that can be expanded in well planned steps
5	Local authorities	Optimal management of the network	Direct involvement of condominiums	Direct involvement of condominiums	Member of the advisory board and owner of one of the considered buildings	Yes, currently performed at quarter level,	Lowest cost	

Q	Initiator	Solutions and Processes	Decision of building owner side	Tenants	Role of the city	Embedded in campaign	Reason for final choice	Connection security in the future
						planned to extend to whole city		
6	DH&C utility proposed concept to the local authorities within the framework of a comparative study	Low temperature DH with max. flow temperature of 70°; Option for DC if demand is sufficient for positive business case	Bound by project proposal / legislation	No involvement	Approved project proposal and has target of being carbon neutral in 2025	Whole new city area	Best socio-economic solution	Competitiveness of district heating via new, greener and more cost-effective providers of energy into the system
7	Partner initiative (local authorities, stakeholder of buildings, DH&C utility)	Competitive offer for the DH connection fee on the one hand and attractive heating price and high service level on the other hand	The building owner himself (most of them are non-profit making housing corporations)	No involvement; buildings were newly constructed buildings	Had a general city planning function	Was part of general city planning	Competitive price and good level of service	Long term heating contracts (10 years)
8	DH&C utility	Low temperature DH grid using geothermal heat, CHP and heat from return pipe system	Buildings will be built as from 2017. A district heating grid will be installed in the total area to supply all buildings there	No involvement; buildings were newly constructed buildings	Developed DH solution along with the local DH utility	Yes	Environmental performance and security of supply were important factors followed by economic concerns	DH customers in Munich rarely change to other heating solutions
9	Director of the building owner	The building was already connected to the DH network	Director of the building owner	No involvement	Provided building permits for the deep renovation construction process	Yes, was part of a larger plan for DH&C extension and deep renovation of the social housing building stock in the district	Environmental performance and local supply	Affordable and advantageous tariffs for the clients

4.1.3 Key success factors and the decision making process

The case studies show that clear environmental and energy policy targets in the decision making process is one of the strongest drivers in projects where DH networks are combined with energy efficient buildings. In some cases, the final solution to implement a DH network was a part of a longer planning process that developed over time and was adapted together with the stakeholders.

The questionnaire and interview responses show that several factors contribute to different grades of the success. The exact mix of success factors depend directly on the type of project and the stakeholders involved. One of the most important factors is the strong involvement of the city authorities which supports the implementation of the project, even more, if the project is a part of demonstration campaign. Apart from economic reasons, the choice for the implementation of a DH project is driven by environmental, energy policy as well as the security of supply.

Although success factors are specific to each project, there are several common factors that help successful combination of DH&C networks with energy efficient buildings. The following section describes the most important factors for success:

- **Regulatory framework:** Several projects have been executed in cities where there are positive framework conditions such as a supportive regulatory framework, ambitious climate targets or campaigns support the implementation of DH projects. Examples are Copenhagen, that has climate targets (carbon neutral in 2050) or Linz that gives preference to DH solutions in certain areas. In contrast, negative framework conditions such as subsidies of fuel prices, misregulated heat prices, or promoting individual solutions such as e.g. gas boilers distort the markets and represent a barrier to extension of DH.
    - Case study-7. In this case study, the city decided to use a former freight train station to build a new city quarter. The city has set positive and functioning framework conditions for DH network (such as preference areas for DH) and thus enables the implementation of this project. In Linz already 70% of the city network is a low temperature network. The city itself sees DH as an important future technology.
    - Case study-4 and 6: Copenhagen has very ambitious climate targets (climate neutral in 2050). In some cases, the new buildings must meet 2020 regulations and this is often only possible with district cooling which is the only method that can support these high standards.

- **Strong city involvement**. A strong involvement of the local authorities supports the implementation of such a project and even more, if the project is executed within the framework of a campaign. The city provides infrastructure and services and thus is in the position to design low-carbon pathways including a district energy strategy considering societal, environmental and economic benefits. In every case study, cities play a major role, however to a different extent - from primary role to accompanying the implementation phase with public relations and communications:

  - Case study-1: the role of the city is driven by its ambitions with respect to DH. In this case the city executed feasibility studies, took the decision about the energy standards and about the heating technology (DHC instead of a gas network). In the later phase of the project, the city was involved in public relations and communication work.
  - Case study-2. In this case, the city was also involved in the initial phase. City of Salzburg was leading the design of a master plan and the architect competition in the starting phase. For the whole project time the city of Salzburg was leading the steering group. The old houses of the quarter (Strubergassensiedlung) beside the new built area are owned by the city, so the city of Salzburg was responsible for the renovation part.
  - Case study-3. In this case, the city was the initiator of the project. In the framework of the city agenda, it charged the realisation of a (quarter related) concept and installed an energy quarter management.
  - Case study-4. In this case, the municipality is interested in activities that reduce CO_2 emission and makes the infrastructure second to none. DC is a part of Copenhagen's ambition of being carbon neutral in 2025.
  - Case study-6. In this case, the municipality of Copenhagen approved the project proposal showing that district heating is the best overall societal business case. The municipality is interested in activities that reduce CO2 emissions and makes the energy infrastructure second to none. HOFOR is a major contributor to the City of Copenhagen's ambition of being carbon neutral in 2025.
  - Case study-8. In this case the city, together with the Stadtwerke München, developed this district heating solution with very high energy efficiency in the past.
- **Changing the perspective.** Successful projects pay attention to changing requirements and priorities of stakeholders and customers. The focus is shifted away from selling heat (being the heat generator) to the distribution of heat and related services. This seems to be key and it affects the business models. Successful projects/companies understand future developments (e.g. decreasing heat demand) and are able to adapt their strategies accordingly. Instead of focusing on the supply side, the focus shifts to the demand side including high engagements with the customers.
- **Steering committee/working groups**. Case study-2 showed an important element that contributes to success: the steering committee and working groups. The steering committee organise, canalise and work with the different stakeholder groups and oversee implementation (e.g. with members from different stakeholders, such as energy supplier, housing association, city council and citizens/consumers). Case study 2 shows that the steering committee facilitates good and transparent information and cooperation during the project phase (using a monitoring report).
- **Written agreement on how to measure success and quality.** It seems that a form of quality agreement, where basic agreements are laid down such as how to measure success or agreements on desired level of quality contributes to a successful project. Case study 2 used this measure in the development phase to let all partners to align expectations and create solutions based on the important facts.

- **Participation of highly innovative people.** Successful projects have in common that highly innovative people are involved from the initial phase to think out of the box and bring in creative ideas and solutions. E.g. case study-2 the involvement of highly innovative people during the planning process was key and changed the initial project idea. Based on the evaluation of the economic and ecological effects possible technological solutions were evaluated. In this process the first project idea (use an existing 90° net) was adapted and it was decided to use a (newly built) micro net with solar contribution (with 60°) and to also use the overheat in the summer in existing apartments that have been renovated in parallel. In particular, the idea to use the large scale solar thermal plant and integrated solar heat pump was pushed by individual innovative people and would not have been implemented without them.
- **Context in which the project is executed (e.g. innovation project).** Being part of a campaign/innovation project (e.g. a demonstration project) is very positive and creates a certain positive dynamic. This does not mean that not being part of a project represents necessarily a barrier and directly impacts the ambition. However; it may have an impact on the nature of innovation of a project. Often in projects without any funding, the first cut back of costs occurs for the innovative ideas of the project. A positive context supports the project to be executed with flanking measures, such as e.g. steering and monitoring or working groups. Most of the case studies were embedded in larger city projects that aimed at building (whole) new quarters or city areas (case study 1, 6), extending ongoing projects (case study 5) or at renovating/extending or creating a new district heating net (case study 8 and 9). Other case studies were embedded in external projects such as the Concerto Project "Green Solar Cities" (case study 2) or the climate protection project of the city of Chemnitz in the Framework of European Energy Award (case study 3).
- **Involvement of stakeholders:** In case tenants are affected by regional development plans it is key to secure their involvement at an early stage. Case study 2 involved the tenants via a social forum that ran an info point, also evening events and discussion forums were organised. Other instruments that are used are public relations and involvement via the building owners (e.g. in case study 3).

Key Note

There are already examples showing the successful integration of low heat demand buildings with DH&C networks. The examples show how measures for energy saving on the one hand, and new district heating loads, on the other hand, can shift these limits. The case study-1 (Antwerp), case study-3 (Germany) show that the decreasing demand to the level of passive house standards can be coupled with DH networks through applying fuel switch and integration of low carbon heat sources gradually (long term planning). The technologies and sources that are playing an increasing role such as solar thermal DH networks are exploited in case study 2, 3 and heat from thermal processing of waste in case study 7 and 9 show how DH networks can help to bring renewable energy into the energy efficient cities of 2050 to achieve targets outlined in section 3.3.

The findings based on case study 7 (Linz) point to the crucial role that DH suppliers play in creating solutions in a changing market by paying attention to changing requirements and priorities of stakeholders and customers. Moving away from merely being heat suppliers to heat service providers and exploiting the new dynamics of a changing market, integrating technologies for network management as in case study-5 creates new business cases that provides additional potential for DH networks.

The evidence from the case studies highlighted in this section is clear: successful integration of energy efficient buildings and DH&C networks is possible. It does not need highly innovative technical solutions. Rather it requires effective use of targeted local policies to systematically address barriers and allow for full realisation of the potential of DH&C within an overall energy planning that considers social and environmental factors in addition to economic concerns.

4.2 Energy sources for DH&C in 2050

The 2050 energy system will be the one that emits low/no carbon. On the way to 2050, the energy system has to emit as little as possible with no or little dependencies on fuel imports and using technology options that overcome the constraints of dense urban environments without compromising on the health and quality of living.

4.2.1 Increasing the share of low carbon energy in cities

Clearly, the pathway to reach the 2050 climate targets requires a significant deviation from the current heating market in the EU, which is now dominated by individual fossil fuels boilers. It has strategic importance to move to no/low carbon technologies. Beside the use of renewable electricity in heat pumps it is required to move to local low-carbon and renewable energy sources, to map the potentials of utilising low-exergy heating and cooling in buildings and determine the technologies that exploit them in their full potential. The value of such potential is especially large in cities where it is of utmost importance to make use of local resources despite the space limitations of dense urban areas. DH&C networks provide significant flexibility when it comes to the choice of heat source. The strategic importance of DH&C networks is their potential to aggregate the heat demand of multiple consumers to a scale and thus utilise renewable and recoverable energy sources to an extend which would not be possible at individual building level.

4.2.2 Renewable sources

- Geothermal energy

There are more than 240 geothermal District Heating plants in Europe. Currently, the share of utilised geothermal resources that are suitable for direct use, is limited to less than 0.001%, far lower than the full potential.[49]

Geothermal energy has a wide spread utilisation in district heating in France, Hungary, Germany and Italy. The way to utilise geothermal potentials in district heating is various and depends on the local conditions. In Coulommiers, Paris, the geothermal district heating supplies heat and sanitary hot water to around 3000 housing units. In Hungary, Morahalom, a geothermal cascade system was developed to reduce dependency on natural gas. Within the project a new district heating system was established to supply renewable heat (mainly) to public buildings. The GHG emissions are now reduced by 80%. In South of Munich, Unterhaching, the geothermal power plant was integrated in an already established community. The project showed economic advantages via combined use of geothermal sources supplying both heat and electricity. Local district heating networks prove to be a key element in the scheme. Ferrara, Northern Italy, uses the geothermal source in an integrated system for district heating and cooling. There are several EU countries where geothermal district heating systems are gaining increased development, as it is the case in Poland, Slovakia, Romania, the Netherlands, UK, Ireland and Denmark. The Podhale region in Poland had high air pollution, which was successfully tackled by the utilisation of geothermal district heating connected to around 1600 buildings. The district heating in Limburg, South Netherlands, uses the water from the mines for heating and cooling the buildings after the municipality of Heerlen conducted a study on the potential of this geothermal resource. The expansion of the district heat network in Heerlen continues, as a result of positive outcomes achieved by the innovative demand-supply system.[50]

The experience shows that geothermal energy provides a stable, renewable and favourable supply of baseload heat. Being an energy source with very low CO_2 emissions, geothermal district heating has the advantage to be used in large extended in available locations towards 2050. It is estimated that geothermal district heat systems can provide heat to 26% of the EU27 population in major cities like Munich, Berlin, Aalborg, Groningen, Amsterdam, Rotterdam, Paris, Strasbourg, Madrid, Barcelona, Budapest and Bratislava.[51]

- Solar thermal systems

There is large potential for increasing the use of solar thermal for heating and cooling needs. Long-term experience is available from various demonstration projects in Sweden, Denmark, Germany,

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[49] Connolly et al., 2013
[50] European Geothermal Energy Council, 2016
[51] Connolly et al., 2013

Austria. The largest solar thermal district heating projects in each these forerunner countries have a capacity of 75250 kW_{th}. The full potential of the solar thermal sources in DH&C networks are still to be reached.

Large scale solar thermal solutions require accessibility to relatively large land areas for collector fields and storages. Additionally, solar thermal energy sources need to overcome seasonal challenges in order to be utilised as heating options. Usually there are other (almost readily available) heat resources in city areas (e.g. recoverable industry heat, waste incineration, geothermal etc.) which can be utilised frequently than solar thermal. In Denmark, where the largest applications of the solar thermal are found, the solar thermal district heating systems are mostly located at places with relatively low heat demands. The district heating grid in town of Denmark called Marstal demonstrates integration of solar energy (and biomass) into to heating grid within the European Project Sunstore4.[52] Whereas it seems like solar thermal heat is more cost-effective in small district heating systems, there are cases where it is utilised in in large cities. The Austrian district heating network of Graz is with over 15.000 m^2 of solar power already a pioneer for solar thermal in large city district heating. The total heat delivery of the district heating grid of Graz is about 1.050 GWh/year and has a solar thermal fraction of about 0.5 % which was extended in 2014 by another 1,4 MW. Currently three big solar thermal installations feed into the district heating network of Graz with a solar yield of approximately 4,290 MWh/a.[53]

The Solar District Heating platform currently lists 163 European large-scale solar heating plants with a nominal capacity higher than 700 kW_{th}.[54] The majority of them do not have any integrated storage system other than the district network itself. The key to boosting the contribution of solar thermal will be continuing to develop low-cost, highly efficient compact thermal storage technologies. This will allow more solar energy to be captured in summer and stored for use in the winter. Although there are schemes that have implemented this approach, it has not yet widespread use for commercial applications.

- Bioenergy

Biomass is currently used as a dominant energy source in many European district heating systems. The Swedish district heating sector is an example where use of biomass in DH was adopted very early compared to other MS and today it is heavily reliant on biomass. This led to a significant increase in the share of renewable heat in the supply mix.

Global use of bioenergy is expected to grow in the future due to climate targets and the possibility to use biomass in several sectors (e.g. production of transportation fuels (e.g. aviation, shipping and heavy duty trucks), for industrial heat (steel furnaces) and for the production of materials and

[52] Sunstore4, 2016
[53] SDHplus, 2015
[54] Solites, 2016

chemicals) to meet these targets. According to the IEA New Policies Scenario, the heat and power production are expected to continue to be the largest uses of solid biomass, thanks to the mature and widely practised combustion technology.[55] Liquid biofuels for transport are also expected to increase significantly. Research focuses on providing more cost-effective conversion technologies to enable higher blends and pure application of biofuels into the transport sector. The liquid biomass can be produced from solid biomass as well as biofuel crops, depending on the most optimal logistic choice.

The future availability of biomass as a source for heating via DH&C networks will first of all depend on the local availability of the forestry and agricultural products, since it could be economically attractive to tap into any local biomass if that is abundant. Furthermore, biomass could come from abroad, which could be attractive depending on logistical routes, costs and policy measures.

Additional potentials exist where biomass produce combinations of different energy carriers, such as heat, steam, electricity, automotive fuel and cooling. Increasing use of biomass in other sectors will generate secondary heat losses that should be recovered in the district heating systems. District heating systems will have further potential by focusing on exploiting the recoverable heat potential from new transformation processes based on biomass.

The scenario study carried out by Ecofys for WWF (The Energy Report) in 2011, foresees that by 2050, (in global scale) 13% of heat used in buildings will come from biomass.[56] A significant proportion of the bioenergy needs in the Ecofys scenario can be derived from products that would otherwise go to waste. These include some plant residues from agriculture and food processing; sawdust and residues from forestry and wood processing and manure. The expected potential share of biomass in district heating from the Heat roadmap Europe study (section 3.2) of 14% also supports the results of Ecofys scenario in WWF The Energy Report. The report also emphasises that towards the energy system of 2050 it is important to ensure biomass will be available from established forestry as part of sustainable forest sources without threatening food and water supplies or biodiversity, or increasing atmospheric carbon.

Biogas remains to be another sustainable source for heat supply. Efficient utilisation of heat from biogas plants in Europe is still to be achieved.[57] Applications exist all over Europe, in Austria, Croatia, Czech Republic, Denmark, Germany, Italy, Latvia, Poland and Romania. The examples present the successful use of local potentials. For example, in Peckelsheim, Germany the school centre and sports hall are supplied with recovered heat from CHP biogas plant. In Odense, Denmark the large share of thermal energy from the Fangel biogas plant is used in the heating network of the nearby city to heat approximately 600 single family houses.[58]

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[55] International Energy Agency (IEA), 2013
[56] WWF et al., 2011
[57] Ramanauskaite et al., 2012
[58] Mergner et al., 2012

Overall, a large global potential for biomass in DH&C can be developed without conflicting with biodiversity or food security. This requires more widespread sustainable forest management, significant improvements in agricultural production, and in the food market.

4.2.3 Recoverable sources

- Recoverable heat from industry

Largest surplus heat source industrial sub-sectors are the petroleum refining industry, followed by chemical, primary metals (iron and steel), non-metallic minerals, fabricated metals and pulp and paper industries. If these high volumes of fairly high quality surplus heat are not recovered for reuse, the heat will dissipate into the atmosphere. In general, the least expensive option for utilising surplus heat is to reuse this energy in a thermal process. Although the exact potential is not known, the total annual excess heat volume is estimated to be around 2.7 EJ for EU27, if generated from the major industrial plants that are located near urban areas from pre-mentioned industrial sub sectors. Currently, only 3% of the direct available industrial excess heat was recycled into district heating systems.[59]

In the future, other industry sectors can be integrated into low temperature DH&C networks for the surplus heat they produce. The question is rather ensuring the long term availability of the manufacturing premises for the DH&C network and bring about a co-operation platform between players where the use of industrial recoverable heat is understood in the light of a broader system perspective. Such integration between industry and energy network can be sustained via long-term regional planning where local authorities play an important role.

The heating supply in the German Ruhr and Lower Rhine (Niederrhein) regions is secured for more than 50 years by the district heating network. By combining these two networks, the planned "Western Grid" ("Westverbund") will become the biggest district heating network in Europe. The combination of the two networks will supply around three billion kWh/a of climate-friendly heating to almost half a million homes with a supply network of over 1,400 km by creating a flexible regional system of heating supply.[60] The district heating is predominantly generated through CHP, Thermal processing of waste, and increasingly from industrial recoverable heat.[61]

- Low temperature waste heat from metro stations, waste water, data centres

Urban environments host several systems that are intertwined. Each of these use some form of energy to function and produce waste, either as materials or surplus heat. Similar to their capacity to utilise the energy potential of municipal waste in the cities, DH&C networks can use several other excess heat potentials from other systems. The surplus heat produced by public transport networks and data centres can be funnelled into the network, eliminating waste, lowering carbon emissions and fuel consumption.

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[59] Connolly et al., 2013
[60] Gesamtverband Steinkohle e.V., 2015
[61] Expo Fortschrittsmotor Klimaschutz GmbH, 2016

In undergrounds, shafts that extract air have the potential to recover heat. One way would be to take the air directly to the potential user, which would mean the recipient would need to be close to the shaft and, given the shaft size, their building designed with this in mind. A pragmatic example exists on the Paris Metro where heat exchangers were installed into station passages to transfer heat to a district heating system in a housing development, which did not require significant construction due to its physical proximity to the metro station.

An alternative is to install a heat exchanger in the airshaft to remove heat from the air, for example through water, which then could be piped to a user. This second option is more flexible and allows for more control, and is similar to the system to be used in the project to supply heat from the Underground to the Bunhill Estate heat and power network in Islington, London.[62]

Another source in cities are data centre facilities with high demand for mechanical and electrical systems and a high potential to create surplus heat. Temperatures in most data centre hot aisles range from 27 to 46 Cº, still fairly low temperatures for some heat recovery strategies. But currently the facilities which capture and reuse this heat is increasing. Towards 2050 it will become more important to reuse the locally available low-temperature heat via 4th generation DH&C technology.

The surplus heat from supermarkets, which is not used to heat the supermarket, can be a source of heat when channelled into the district heating network. The Danish supermarket chain SuperBrugsen in Høruphav is equipped with an innovative CO_2 refrigeration system, which is able to cool the food and additionally provide the store with a constant source of heating. This innovative technology saves energy, which can be used to supply 16 standard homes of 130 m^2 living close by every year. By using the surplus heat from the refrigeration system, the supermarket chain saves more than 31,000 USD/a on gas for heating and also reduces its CO_2 emissions by 34%, which would otherwise have been lost. The innovative pilot project is carried out by the Danish HVAC giant Danfoss and is applied in 20 SuperBrugsen grocery stores.[63]

- Recoverable heat from thermal waste processing

Waste incineration provides two benefits simultaneously. As a primary benefit, it substantially reduces the amount of waste that would go into landfill. Currently waste-to-energy is the main method of waste disposal in Europe. As a secondary benefit, incineration of waste allows for production of electricity and heat through burning (otherwise unused) waste in combustion chambers. Combustion technology is already advanced to minimise the emissions during the combustion process. Thus waste incineration contributes to reducing GHG emissions when replace fossil-fuel based capacity as well substantially reducing the amount of waste that would go into landfill.

[62] Couvée, 2016
[63] Danfoss A/S, 2015

The Circular Economy package adopted by European Commission provides revised legislations on waste with clear targets for long-term waste management and recycling. This includes a common EU target for recycling 65% of municipal waste and 75% of packaging waste by 2030, together with a binding target to reduce landfill to a maximum of 10% of municipal waste by 2030. Once total waste amount decreases via higher reuse and recycling rates, recovering its energy content is still the most viable option both for environmental and economic perspectives. The European Commission acknowledges that "Waste to energy' can therefore play a role and create synergies with EU energy and climate policy, but guided by the principles of the EU waste hierarchy."[64]

[64] EC (2015)

4.2.4 Fossil fuels

- Fossil fuel boilers

Considering that fossil fuel use is the primary driver of climate change, the share of fossil fuel will decrease and ultimately totally phase out in the energy mix of 2050. According to Eurostat statistics production of derived heat from coal continued its long term decreasing trend: since 1990 it decreased by 56% and reached a record low in 2014. While natural gas significantly increased and peaked in 2005, it decreased by 24% by 2014.[65] This trend is expected to continue while natural gas fired plants keep their market longer than coal due to their flexibility and role of "on demand" supply for the electricity grid. A potential practice is to replace fossil fuels with a CHP source or some other form of low carbon heat such as industrial heat, only retaining them for back up or peak demand.

- Cogeneration

The thermodynamically efficient use of fossil fuels in energy conversion processes to minimise overall losses is an important aspect for reducing CO_2 emissions. CHP units, enable higher overall efficiencies (around 60-85% depending on the power to heat ratio) than traditional power plants due to the simultaneous electricity and heat production. Therefore, CHP technology has been a driving force behind District Heating due to this advantage of increased efficiency by producing electricity in combination with heat and often provide the baseload for district heating systems.

However, if the electricity system changes to a decarbonised system, the role of CHP will also change. Without carbon capture and storage, the energy source for CHP also needs to switch from fossil fuel (replacing the coal first as mentioned in previous paragraph) to either biogas (see section 4.2.2), biomass or synthetic methane (generated from power, see section 4.3.4). Due to the limitations on the future availability of biomass, the costs of synthetic methane and the competition with other usage (aviation, shipping, freight transport, high temperature industry processes), these sources might be used carefully for the production of electricity and heat. Due to the need for flexibility it will be especially used for peak load generation and also the usage of CHP plants might shift from baseload technology to peak load generation with decreasing operational hours which will have a direct impact in their profitability.

[65] Eurostat, 2016

Key Note

Climate change is a compelling reason for an urgent switch to low carbon energy sources. Decarbonisation will mean a gradual phase out of fossil fuels and an increased share of RE and recoverable heat. Within this pathway the strategic importance of DH&C networks stems from their potential to utilise renewable and recoverable energy sources into the heat network that otherwise will not be exploited in full potential or simply be discarded. DH&C networks provide the possibility to aggregate the heat demand of multiple consumers to a scale that provides economic viability to the use of renewable energy that would not be possible at individual building level.

The developments in the last decade have already shown that shares of renewable energy sources and recoverable heat within the supply mix of District heating systems are increasing in EU. District Heat networks have further role to play in decarbonisation of heat sector with the heat being increasingly supplied by geothermal and solar thermal sources together with fully exploiting the local recoverable heat sources from industry and thermal processing of waste.

It is essential for the future energy system to include methodologies and technologies that optimise the use of the limited biomass resources while also building a bridge between the biomass resource and the need for gas or liquid fuels to supplement the direct use of electricity in the transportation sector. It becomes essential to include temporal distributions and intermittencies of renewable energy sources (in the case of heat networks the solar thermal) in the energy planning.

4.3 DH&C as an integral part of energy system

In order to achieve a reliable and integrated energy system, the energy transition towards 2050 will create new forms of flexibility by moving away from a "fuel to conversion to end use" approach to an "interconnected approach" where thermal, electricity and transport sectors are combined and compensate for each other. Innovation will play a key part in this systemic change. In order to rethink our ways of generating and using energy, there will be a need for new technologies, processes and services, which will shape the future of our economy and society.

4.3.1 The increasing need for integration of energy networks

Developments in energy generation are driven by the GHG emission reduction targets and the implementation of RES policies. These targets and policies result in a high level of RES penetration, in particular intermittent RE sources, such as wind and solar power. The energy systems will grow further in complexity, with the main challenge being the balancing and matching supply and demand. Due to the volatility of renewable energy sources, it is key to use new forms of flexibility options and techniques for balancing and operating system reserves.

In order to support the penetration of RES, reduce GHG emissions and at the same time keep the energy system reliable and cost-efficient, it is required to have a more holistic perspective on the energy infrastructure. This perspective includes an increased integration of energy systems to balance energy demand and supply and optimise the different energy transport and -distribution techniques, such as district heating and gas and electricity grids.

In a future energy system, one of the promising system integration opportunities is the conversion between power and heat together with using thermal storage to buffer intermittent electricity production, converting electricity overcapacity to heat, via power to heat results in a combination of heat with low marginal cost and low GHG emissions for district heating, while at the same time contributing to balancing the electricity system.

4.3.2 Thermal storage

While the intermittent RES gain higher shares in the energy supply mix there will be need for storage of energy. RES have a natural variance in when and how much energy is produced, with intermittent production by wind and solar energy and strong seasonal and daily variance for solar energy production. The energy supply does not necessarily coincide with the demand, especially, the heat demand, which is typically opposite from the supply through solar energy, with higher heat demand in cold and dark winter months and in the morning and evenings.

Today, heat networks are typically supplied from sources with different characteristics. One type of heat source provides a stable supply with relatively low marginal cost, to cover the base heat load in the system. The other source is more flexible and can rapidly increase heat output to cover for the seasonal and daily peaks in heat demand. The latter type of source is mainly fossil fuel based peak load boilers. Providing flexibility to the heat supply and demand by replacing peak-load boilers with renewable sources is one of the challenges in the transition towards a higher share of RES.

By incorporating other technologies, such as heat pumps and thermal storage capacity, DH&C networks can absorb excess electricity generation when needed by the system (see section 4.3.4.). Conversion of electricity to heat combined with thermal storage is a solution for providing this flexibility at low GHG emissions.

Thermal storages are important components of heat production to optimise the performance of the heat network. The operation of the thermal storage is straightforward: it is charged when heat supply is higher than the demand, and discharged when the heat production is below the consumption or when less economic or sustainable sources would have to be switched on to match the increased demand. Thermal storage allows the system operator to (partially) replace other sources of heat and provide a more flexible operation of different sources.

Most commonly thermal storage takes heat from the central heat network and stores it in insulated water tanks or underground reservoirs. There are however also examples of thermal storage in other materials such as high temperature molten salts, phase change materials or in the shell of buildings. Heat storage can be implemented central in the heat grid, but also decentral at the user premises. Additionally, the heat network itself can provide thermal storage capacity by increasing or decreasing the temperature in the system.

To overcome the seasonal variation in heat demand, technologies that can offer very large storage capacity with long time shifting periods at low cost are important. The investment costs for thermal seasonal storage have to be carefully considered. However, examples show cost effectively integrated seasonal storage systems (lower cost per m^3, avoiding space restrictions on-site), where inter-seasonal heat store can improve the economics of a heat network by enabling generated heat in the summer to be used for winter heat load. The concept has been widely used in Scandinavia.[66] To cover the daily variations in demand, storage systems can be much smaller. In many countries examples of this type of storage can be found, typically consisting of a number of well-insulated, above the ground containers.

[66] Gebremedhin and Zinko, 2009

4.3.3 Flexibility via resource diversity

By 2050, sources of recoverable industrial and urban heat, or technologies such as geothermal and solar thermal are expected to have an increased share in the heat energy mix. District heat networks offer the potential of supply heat, especially in dense urban areas, directly to homes and businesses. Through this collective form of heating, scale effects can be utilised that lower both cost of heat and GHG emissions per user. Such a collective heat infrastructure can be sourced by a variety of energy sources, providing a mix of base-load and peak-load sources including fluctuating renewable energy sources, recoverable heat and system integration with electricity and gas grids.

The deployment of renewable and recoverable heat via heat network technologies typically increases the diversity of heat sources in the network. No single resource can provide energy capacity and flexibility requirements economically at once. Having a diverse set of sources creates additional flexibility.

This creates a valuable potential for ensuring that sufficient flexibility resources are ready to enable secure operation under forecast uncertainty both on demand and supply side. On the long term, the DH&C network provides an infrastructure where a succession of heating sources can be installed, operated, and then replaced when they become life expired or obsolete. This flexibility helps create policy and regulation stability thereby helping to protect both the operator and consumers against fluctuations in market conditions and resource availability.

4.3.4 Flexibility via integration of heat networks with electricity grids

Flexibility is the ability of a power system to maintain continuous service when facing fast changes in supply or in demand. Traditionally this flexibility was provided by controlling the supply side. With increasing share of renewables in the fuel mix, additional flexibility is needed due to the inherent intermittent character of renewable energy sources and decreasing role of traditional suppliers that give supply side flexibility. This creates a so-called flexibility gap. Instead of having sufficient resources to meet demand the key challenge in the future is to have enough flexibility to balance demand and supply. Heat networks can play an important role in increasing the energy system flexibility. This can be achieved by storing renewable energy in the form of heat; and enhancing demand-side flexibility in the electricity market by taking away over-capacities in the electricity generation.

The simultaneous electricity and heat production in CHP unit proposes proven and mature technology option for linkages between electricity and heat networks. If the electricity system will change to a decarbonised system, also the role of CHP might change, as described in chapter 4.2.4 and the usage of CHP plants might shift from baseload technology to peak load generation to provide capacity and thus flexibility for the electricity as well as heating sector. The main potential in the future will be integration of the increased share of renewable electricity with heat networks. The increasing amount of power generation from weather-dependent renewable sources in EU is expected to lead to a considerable number of hours in which power generation exceeds power demand. This is already experienced in Germany. Conversion of electricity to heat can be done either directly, via power-to-heat or in two steps, via power to synthetic gas and burning the synthetic gas to use as source of heating (and/or electricity).

The simplest power-to-heat technology converts power to heat via direct resistance heating. Power to heat can also be done via heat pumps in buildings, in the heat grid, or in a geothermal energy pump system. The heat pump option offers a greater efficiency, but is more capital expensive and has a longer response time. Through the power-to-heat technology the possibility for interim energy storage in form of gas is removed, yet almost loss free conversion between electricity and heat can be achieved. This approach can replace fuel-based CHP units with electric heaters in periods of high heating demand that coincide with surplus electricity feed-in from RES. Parts of the heat demand is fulfilled via electric heaters and presents a demand to the power market. Additionally, it represents a storage to put temporary overcapacity from renewable energy and reduce carbon emissions by substituting fossil-fuel heat sources.[67]

Power-to-gas technology is a promising path to help solve the challenges regarding electricity and seasonal storage and to regulate grid capacity. To convert power to gas, electricity is used to synthetically produce hydrogen or methane. This is done by splitting water into hydrogen and oxygen via electrolysis. In a second step hydrogen is combined with carbon to create methane. The potential

[67] ECOFYS, 2014

of synthetic gas is not limited to heating. The chemical industry and transport sector uses hydrogen and methane in their processes. Synthetic gas also offers these sectors a valuable, low GHG-emission resource. Similar to power to heat, power to gas is a technology that benefits the excess power or off-peak power generated by wind or solar systems to be used at a later time for load balancing. The potential role is that it may be used as seasonal storage. In Germany e.g. the gas grid has a high storage capacity.

These conversion technologies between electricity, heat and gas are strategically important in the transition to a more sustainable energy system. Collective heating, conversion technologies and renewable energy sources provide the indispensable ingredients in the future integrated energy system. The ability of DH&C networks to use variable power generated from renewable energy sources (such as wind and sun) will have importance towards 2050 where the such renewable energy will be the primary source of energy.

Apart from these flexibility options, DH networks may help to mitigate peak demand electricity loads by providing alternative heating and cooling supply options and thus balance demand peaks. Due to the fact that a variety of energy sources can be used district heating enables to switch heat sources and thus react to price signals and local situations contributing to balance supply and demand. To avoid shortages DH&C can use CHP (including also power-to-gas-to-heat) to support electricity grids in times of shortage.

New business models are needed to support the flexibility and balancing supply and demand and interaction of different energy networks. The interaction is supported by smart solutions in system technology for demand side management and grid management. Smart grids allow for adapting to changing circumstances in supply and demand in the short, medium and long term, and facilitate participation of end-users. In the energy system of 2050, network integrated sensors and smart heat meters would have increased importance to allow for more effective and efficient use of the separate components, supported by overarching energy management, considering:

- New flexibility options in demand and storage require control and communication infrastructure;
- Variable RES control is unavoidable for higher RES shares;
- Changing the market for reducing the flexibility gap;
- Incentives and systems for demand management are needed;
- Extending the market size is a no regret solution.

Key Note

The development of energy-systems with 100% renewable generation emphasises the future importance of district heating. District heating networks linked to the electrical network with renewable power generation is a strategic method of supplying renewable heat for decarbonising energy supplies. Within the energy system with increased RES, linking a district heating network including heat storage to the electrical network has potential to raise the level of viable renewable power generation.

While each of the energy developments could claim to be worthwhile in their own right (e.g. thermal storage, CHP and heat pumps, power-to-heat and power-to-gas options) there are complex relationships between the options and with the operation of the electricity network.

Suitable measures such as flexible generation, energy storage and load management must be found to provide a secure balance between energy demand and supply. DH&C provides important options for a multi-functional energy system which utilises the synergies of different technologies and energy forms by optimising their interactions in operation and to achieve a secure supply.

5 Conclusions

The use of energy is a prerequisite for all economic activities that is primarily focused on urban areas. Current energy system in urban areas are dominantly based of fossil fuels. Today the unsustainable outcomes of current urban economies have gained more attention. This has resulted in a focus on low-carbon energy sources that lead to increased technical progress related to generation and integration of alternative energy sources and decreased costs. Increasing concerns are also addressed in European policy. European policy aims for environmental sustainability, security of supplies and economic competitiveness as its three principle objectives.

The strong environmental commitments and carbon targets mean that deep and cost effective emission reductions must be achieved towards 2050. Within this global aim one main pillar is the transformation of the European energy sector to a competitive low-carbon system. The transition from current fossil fuel dominated system to low carbon energy system of the future means substantial changes in the energy system paradigm. Achieving this will require major improvements in energy efficiency at overall energy system level and a shift towards low carbon energy sources. This will be a national transformation and also a local one, with different solutions for different localities and geographies.

Cities are the main drivers of the global energy demand and its environmental impact. Urban buildings today account for about two-thirds of final energy consumption in the buildings sector. The energy demand of buildings is dominated by space heating and cooling demand. The transformation of heat-generation and heat-use will create new markets and new opportunities. Accelerated deployment of low-carbon technologies could help meet or even improve thermal comfort demand while reducing negative environmental impacts.

The transformation of the building stock into high-energy efficient standards where the demand decreases substantially is a key requirement of a low-carbon energy system. A set of ambitious building renovation options can achieve significant reductions in energy use, on individual building scale. This shows that there are many opportunities likely for heat demand reduction and those must be exploited to full extent where possible. However, the cost effectiveness of these deep renovations and the physical limits to their applicability in cities vary. Even when the full technical potential in building energy efficiency is reached, the remaining heat demand will be substantial in future. Additionally, the building oriented demand reduction, which tends to focus on energy users as individual households or organisations tend to miss the potentials that can be achieved by system efficiency perspective and overall demand balancing approach. A holistic energy planning where reduction of demand not only on building scale but also on building clusters proposes tools to achieve the most optimal results.

A critical approach is required in which the cost effective and most favourable demand reduction measures are implemented while, in parallel, additional efforts are invested in switching to low-carbon heat sources. It has strategic importance to move forward with a national and local policy that evaluates the individual local conditions that can harness the local low-carbon energy sources to map the potentials of utilising low-carbon heating and cooling in buildings, and determine the technologies that exploit them in their full potential.

Through the long term heat planning, the heat delivery services need to be adopted to enable greater share of renewable and recoverable heat energy sources into an integrated urban energy system. DH&C networks prove to be promising solution with their potential to utilise renewable and recoverable energy sources into the heat network that otherwise will simply be discarded. Already with the modern district heating networks, the low-carbon energy for heat demand is increasingly supplied by biomass, geothermal, recoverable heat from industry or heat from thermal processing of waste options all over Europe. Each of these low-carbon energy sources and others such as solar thermal, low temperature waste heat in cities have high potential to provide heat to buildings by expansion of existing DH&C networks and building new networks. Towards the low-carbon energy system, the DH&C networks will be main driver to increase the diversity of energy sources and, through local generation, contributes to the flexibility of the system and its resistance to central shocks together with the advancements in thermal storage technologies.

Delivering heating and cooling through a network offers a system that can grow over time and benefit from interconnections with other networks. DH&C serve as flexible tools to bridge electrical and thermal energy systems, which will play an increasingly important role in achieving integrated, sustainable energy networks in the future, especially considering their ability to utilise power to heat and power to gas to heat options. Such flexibility will have increased value to make the transition to low carbon heat over time with less disruption for consumers and businesses.

Adequacy for heat systems with high penetration of renewable and recoverable heat sources towards 2050 will require greater emphasis on ensuring sufficient flexibility and storage capacities, as they will create an increasing value to the system integrations. EU has already taken steps to realise this. It has released a new strategy on heating and cooling, as part of a wider energy security package. According to the EU's strategy, solutions include creating better links between heating and cooling and electricity networks; creating a more efficient, linked-up system through district heating; generating heat and power at the same time to decrease waste; heat pumps; and switching to renewables, such as solar to generate heat, instead of fossil fuels.

Regulatory mechanisms will be needed to put in place together with policy framework to ensure this integration of energy systems and balancing of supply and demand in a predictable and reliable fashion. Information and communications technologies (ICT) can be deployed to create new intelligent ways of making urban centres more efficient.

Cities are becoming smarter and should take the lead towards a low carbon development. They are well-positioned to enable an integrated approach necessary to advance with both energy efficiency and renewable energy. The development of modern district heating systems in urban areas has a significant potential to contribute to integrated energy solutions and it will play an important role to reach a low carbon economy. To benefit the potential in the highest, the heat supply system would need to have structural change and achieve a significant level of decarbonisation already before 2050. This highlights the importance of starting the transition now and providing the socio-economic and regulatory framework to minimise investments in carbon intensive assets in the next two decades.

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7 Annex

A – Questionnaire

Dear participant,

Thank you for your interest in our questionnaire. This questionnaire is part of the project "District heating and cooling strategy" funded by Euroheat & Power which looks into the role of district heating and cooling (DH&C) in an integrated, sustainable future energy system.
Key elements of the analysis are:

1. DH&C and its position/value within the future integrated energy system
2. Sources of and access to (renewable or recoverable) district heat towards 2050
3. Interaction energy efficiency on demand side and district heating & cooling based on analysis of decision making in best practice examples (building sector)

This questionnaire relates to the 3rd item with the aim to identify where and how district heating and cooling can be combined with high energy efficiency (-> low energy need) on the demand side, by focussing on the decision making process in projects where this combination was successfully implemented.

Please use one questionnaire per project, if you describe more than one example.

1. Your contact data

2. Please indicate name and location of the project

3. Please indicate the type of your project

   ☐ (deep) renovation of buildings with continued connection to a DH&C network;
   ☐ connection of (deep) renovated buildings to a
      ☐ new
      ☐ existing/extended DH&C network;
   ☐ combined (deep) renovation of buildings and connection to
      ☐ new
      ☐ existing/extended DH&C network
   ☐ new energy efficient buildings connected to
      ☐ new
      ☐ existing/extended DH&C network;

4. What standard was achieved on demand side (e.g. 3-Liter or Passive house including information on useful energy demand for space heating, domestic hot water and cooling in kWh/m²a)?

- Additional for renovation projects: what was the energy demand for these energy use types before renovation?

5. What is the average energy density in MW/km² and the size and number of exchange stations?

   - Additional for renovation projects: what was the average energy density before renovation)?

6. What tariff structure is used (price per connection, price per kW, price per kWh)?

   - Additional for renovation projects: what tariff was applicable before renovation (type of supply, price per connection or kW, price per kWh)

7. What is the size of the project (MWh delivered p.a. and number of buildings supplied)?

8. What is the source of supplied DH&C?

9. Who (stakeholder and function level) introduced the idea to combine high EE on demand side with DHC?

10. What solution and process was offered by the DH&C provider?

11. What were other and complementing options for the supply of heat/cold?

12. Who was to decide on the side of the building owners?

13. How were possible tenants involved?

14. What was the role of the city in the process?

15. Was the development part of a concerted campaign, e.g. at city quarter level?

16. What choice was made and why (lowest cost? Environmental performance, security of supply/local supply? Etc.)?

17. How is the required high connection rate secured in the long-term?

18. Is the system designed to be extended in the future?