D3.1 – REWARDHeat PESTLE analysis

Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks

REWARDHeat

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REWARDHeat

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Abbreviations

CHP Combined heat and power

DC District Cooling

DE Germany

DH District heating

DHC District heating and cooling

DHW Domestic Hot Water

DK Denmark

EED Energy Efficiency Directive

EPDB Energy Performance of Buildings Directive

FR France

GHG Greenhouse gas emissions

HC Heating and cooling

HP Heat pump

HR Croatia

IT Italy

LT Low temperature

LTDH Low temperature district heating

LTDHC Low temperature district heating and cooling

LTH Low temperature heat

NEEAP National Energy Efficiency Action Plan

NECP National Energy and Climate Plan

NL Netherlands

NREAP National Renewable Energy Action Plan

NZEB Nearly zero-energy buildings

PEF Primary energy factor

RED Renewable Energy Directive

RE Renewable Energy

SE Sweden

WH Waste heat

1 Summary

In this deliverable, factors impacting effective replication of Low Temperature (LT) District Heating and Cooling (DHC) networks with Low Temperature Heat (LTH) and Renewable Energy (RE) sources integration are analyzed. A PESTLE (Political, Economic, Social, Technical, Legal and Environmental) analysis is performed for seven European countries, which host one or more REWARDHeat demonstrators.

The PESTLE analysis was performed in a three-step process. The first step was data collection for each of the components included in the PESTLE analysis through literature reviews, interviews with the demo-sites, surveys distributed to and answered by the customers of the existing DH systems and energy systems modelling using the TIMES (The Integrated MARKAL-EFOM System) model generator for understanding the environmental impact long term. The second step was to identify and prioritize key factors identified for each of the PESTLE components. The third step was to rate the identified key factors together with experts from each demo-site country. The key factors were rated either as a barrier (major or minor) or as an opportunity (major or minor).

Overall, the results of the PESTLE analysis show that there are more opportunities than barriers for the replication of LTDHC networks in the investigated countries. Opportunities mainly arise from the ambitious political goal of the EU to become climate-neutral by 2050. The EU goal leads to ambitious national targets for the Heating and Cooling (HC) sectors, which are still greatly dependent on the use of fossil fuels. Positive customers' opinions and the current characteristics of the HC sectors in the investigated countries are also identified as opportunities for the development of LTDHC networks. At the country level, Denmark and Sweden are the countries in which conventional DH networks are well-established and it is in these countries the most opportunities for LTDHC can be found. A tradition of investing in large, centralized heat generation plants could however pose a barrier, and a regime shift is therefore necessary. We show that with the development of LTDHC networks, the cost of heat supply in the investigated HC sectors can decrease, if compared to the development without LTDHC. From the environmental perspective, the development of LTDHC networks and utilization of LTH and RE sources is shown to result in fuel savings and lowered air pollutant emissions in all the demo-site countries, except for Denmark in which insignificant increase in specific primary energy use per unit of generated heat can be expected.

The lack of targeted state-based financial support for developing innovative HC networks is identified as one of the main barriers for the replication of the REWARDHeat solutions in most of the countries. The likely reason for this is deemed to be a lack of awareness and understanding about the LTDHC concept among politicians and decision makers. Hence, more knowledge needs to be generated about the concept, for example through demonstration projects such as REWARDHeat. Another main barrier is that LTDHC is currently only suitable for a small share of the building stock, mainly new or refurbished buildings. Table 1 shows overview of the PESTLE analysis results for each of the investigated countries. The values "3" and "4" on the green background represent opportunities (minor and major, respectively) and the values "1" and "2" represent barriers (major and minor, respectively).

Table 1 – Overview of the PESTLE analysis outputs. The coloring scheme: Major opportunity (dark green), minor opportunity (light green), major barrier (dark red), minor barrier (light red).

Topic	Key factors	DK	HR	DE	FR	IT	SE	NL
Political	National targets	4	3	4	3	3	2	3
	State-based financial support	2	2	2	4	2	1	1
	Predictability	4	3	2	3	3	2	3
Economic	HC Supply	4	4	1	3	3	3	4
	Profitability of DHC	4	3	3	3	1	3	2
	Price of DHC	4	2	3	2	3	3	3
	Specific cost of heat supply	3	3	3	3	4	4	4
Social	Customers' opinion about DHC	4	3	4	3	3	4	3
	Customers' awareness about DHC	2	3	2	1	3	4	3
	Customers' cost expectancy	4	3	3	2	4	2	2
Technical	Technical maturity/establishment	4	2	2	3	1	4	2
	Replicability/standardization	4	3	2	4	3	3	3
	Building stock suitability	2	1	1	2	2	4	1
Legal	Permissions	4	2	2	2	2	4	3
	DHC market legislation	2	2	2	3	3	4	1
	Buildings/construction	4	2	3	4	4	3	4
Environmental	Specific primary energy use	2	4	3	4	4	4	3
	Accumulated air pollutant emissions	4	3	3	3	3	3	3

The results from the energy system modelling, which served as a basis for analyzing environmental key factors as well as the *Specific cost of heat* economic factor, are also briefly presented in this deliverable and are available on an interactive webpage accessible from the project official website (www.rewardheat.eu).

2 Introduction

The REWARDHeat project demonstrates a new generation of Low Temperature District Heating and Cooling (LTDHC) networks, which will be able to recover LTH and RE sources available within the urban context. The development of the REWARDHeat solutions is being piloted at eight demonstration sites around Europe where either third generation DH networks are being retrofitted or new networks are being constructed. The sources of excess heat considered in this work are: Industrial excess heat, data centers, service sector buildings, metro stations, Sewage water treatment systems (further explained Annex 17 – TIMES model).

In this deliverable, *D3.1 REWARDHeat PESTLE Analysis,* barriers and opportunities of LTDHC networks with LTH and RE sources integration are analysed using the PESTLE analysis. The PESTLE analysis is applied to each of the focal countries (DE, HR, DK, SE, NL, FR, and IT) in order to assess factors impacting effective replicability of the REWARDHeat solutions. The political section assesses political interest and support for the REWARDHeat solutions. The economic section assesses the market situation and potential in the countries. The social factor relates to the opinion of customers towards the technology from a social acceptance perspective. In the technical section, focus is on the level of maturity and possibility for scaling-up the REWARDHeat solutions in the respective markets. The legal section identifies the framework affecting DHC projects. The environmental analysis provides inputs on the environmental impacts of LTDH networks on the heating sectors of the investigated countries, as compared to the impact of conventional DH networks.

The deliverable is part of the Work Package 3 (WP3) of the REWARDHeat project. In WP3, the objective is to facilitate investments in LTDHC networks resorting to LTH and RE sources. The PESTLE analysis is input to other deliverables in WP3 relating to bankability, business models and investments.

The report consists of six sections. The Summary, Introduction and Methodology sections briefly introduce the reader to the REWARDHeat project in general and to this Deliverable (D3.1) in particular. The Methodology section also describes the applied PESTLE analysis. The PESTLE analysis results section presents the results of the performed PESTLE analysis, which was based on the collected country-specific materials, several workshops and the results of the modelling. The E analysis is performed using the results from the energy systems modelling, which are selectively presented in the TIMES section. The final section of the main report is Conclusions. In the Annexes, the reader can find further information on the HC sector of the EU, materials collected and analysed for the PESTLE analysis conducted for each of the countries, inputs and assumptions included in the applied TIMES model.

2.1 Background

To achieve the objectives of the Paris Agreement to limit the increase in global temperature below 1.5 - 2°C, major improvements in energy efficiency and integration of RE sources are required. This has been translated into the 2030 objectives of the Energy Union (EU) to reduce the total GHG emissions with at least 40 %, compared to 1990 values, to have the share of renewable energy in the total energy consumption of at least 32 % and to get improved energy efficiency of at least 32.5 % (Union, 2021). The EU also has the ambition of being the first climate-neutral continent by 2050.

HC represents approximately 50 % of the final energy consumed in the EU and about 75 % of the total final energy use in buildings, therefore it is crucial to identify and utilize the potential of energy savings (Fleiter et al., 2017). According to 2018 numbers from Eurostat, the share of RE sources in the energy generated in the EU (27) is only 21.1 % (Eurostat, 2020a).

A number of studies have concluded that DHC networks should play an important role in the future sustainable energy system (Connolly et al., 2014, Lund et al., 2010, Münster et al., 2012, Rezaie and Rosen, 2012, Brand and Svendsen, 2013). However, the same studies underline that existing DH networks must undergo a change: to be converted into LTDH networks, which will interact with low-energy buildings while also become an integrated part of smart energy systems. The utilization of LTDH networks reduces transportation losses in pipelines and can increase the overall efficiency of heat generation and delivery in DH networks (Schmidt et al., 2017).

DHC networks are a key solution to decarbonize urban areas cost-effectively by incorporating RE and LTH sources that cannot be accessed on a building level. Their importance will be even more pronounced considering that the level of urbanization in the EU is expected to increase from 75 % in 2020 to approximately 84 % 2050 (Mathiesen et al., 2019).

The results of a study on the long-term system impacts of utilizing four LTH sources (data centers, metro stations, sewage systems and service sector buildings) at a city/urban level showed that utilization of the LTH sources can contribute to an increase in competitiveness of DH, when compared to individual heating (Sandvall et al., 2021). The study was based on a TIMES energy system model applied to the heating sector of a city. The study also shows that the impact on primary energy use is reduced, when utilizing LTH sources. The main cause of this reduction is that health sources replace fuel use for heat generation. A similar study was conducted to investigate the effects of utilizing the same LTH sources at a national scale s (Nielsen et al., 2020). The analysis showed that the feasibility of LTH sources can be challenged by large amounts of low-cost conventional heat sources such as geothermal and solar thermal energy production.

The PESTLE methodology applied in this deliverable has been applied in other H2020 projects targeting the heating sector. For example, in the SunHorizon project (IVL Swedish Environmental Research Institute, 2019), barriers and opportunities for solar appliances and HPs in Germany, Spain, Belgium and Latvia were assessed. In the SOWHAT project, the PESTLE analysis was applied to identify barriers and opportunities for waste heat and cold recovery from industries in Belgium, Italy, Portugal, Romania, Spain, Sweden and the United Kingdom (Klugman et al., 2020). The impact, positive or negative, for each of the PESTLE components on DHC networks with RE sources was analyzed in the WEDISTRICT project for Poland, Spain, Romania and Sweden (R2M, 2020). The focus of the PESTLE analysis in this deliverable is on LTDHC networks and is a good complement to previous PESTLE research of the heating sector, also adding more countries to the analysis.

2.2 Purpose & research questions

The purpose of the PESTLE analysis is to analyze the factors impacting effective replication of LTDHC networks with LTH and RE sources integration in the demonstration countries (DE, HR, DK, SE, NL, FR, and IT). As a result of the analysis, each of the chosen key factors will be identified either as a barrier (minor or major) or an opportunity (minor or major) for each of the considered countries. In short, a research question can be formulated as follows:

- What are the main barriers and opportunities for the REWARDHeat solutions in Denmark, Croatia, Germany, France, Italy, Sweden and Netherlands?

Apart from assessing factors as barriers or opportunities for the replication of REWARDHeat solutions, this task (Task 3.1) aims to analyze the effects of different environmental policies and investments in LTDH networks with LTH and RE sources on the primary energy use and air pollutant emissions of the heating sectors of the demonstration countries. The analysis will also touch upon the cost-optimal utilization of LTH sources in the DH networks, the shares of DH and the costs of heat supply in the countries' HC sectors.

2.2.1 Contribution by partner

IVL has been the responsible partner for the deliverable. The task has been highly collaborative between the partners in the REWARDHeat project, and many have been involved in the PESTLE analysis. The contributions to the sections of the PESTLE analysis are listed below and IVL would like to officially thank all the partners for their contributions.

The survey conducted for the social section of this deliverable and for the data collection to deliverable 3.2 (*Customers' perspective on REWARDHeat solutions*) was translated to the local language by Albertslund, UNIZAG, HAWK, EDF, RINA-C, IVL and Mijnwater. Responses for the survey was collected by Albertslund, UNIZAG, Wärme Hamburg, EDF and Dalkia, A2A, Arvalla, Indepro and IVL and Mijnwater.

EHP, RINA-C, HFT, UNIZAG, EDF, Albertslund and IVL provided information about the legal frameworks in the respective countries by filling out a template developed by IVL.

Albertslund, EDF, Tehnokom, UNIZAG, Wärme Hamburg, A2A, Mijnwater, Indepro, Arvalla, Danfoss and Thermaflex were interviewed by IVL on the technical aspects of the technology. EHPA together with its partner associations in the respective countries assisted with data collection on HPs for the technical sections.

For the TIMES model, RINA in Italy, University of Zagreb in Croatia, University of Applied Sciences and Arts (HAWK) in Germany, and EDF in France provided data related to existing DH systems in the respective countries. In addition, Aalborg University assisted with data related to hourly heating demand curves in all the case countries.

Participants in the workshops; Albertslund and AAU (Denmark), UNIZAG and Regional energy agency of North-West Croatia (Croatia), HAWK and HFT (Germany), EDF (France), EURAC and RINA-C (Italy), E.ON and IVL (Sweden), Mijnwater and EHP (Netherlands). Additional review to get utility perspective Wärme Hamburg (Germany) and A2A (Italy).

3 Methodology

The Section describes the method used for gathering information for each of the PESTLE components as well as the method applied to analyze and aggregate the collected data.

3.1 PESTLE Analysis

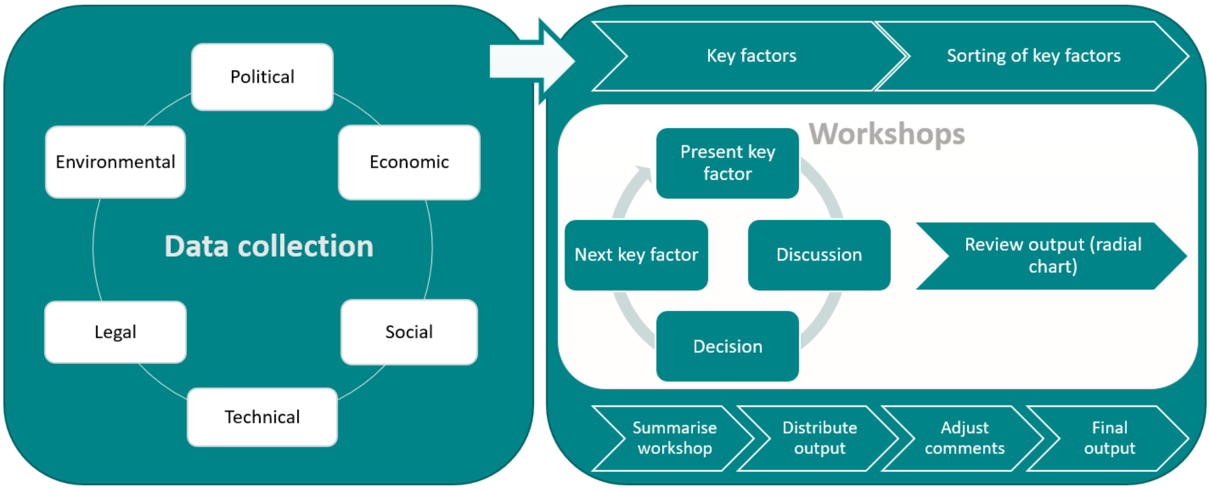


Figure 1 – Overview of the method used for the PESTLE analysis

The PESTLE analysis framework is a business tool used to analyze and monitor the factors that may have a profound impact on a product, service or organization on a market. PESTLE is an acronym for Political, Economic, Social, Technical, Legal and Environmental and covers many aspects of the prevailing setting on a market. The content of the PESTLE analysis framework was proposed by IVL at an early stage in the project and discussed with the other partners in WP3. The PESTLE analysis is performed by first collecting data for each of the PESTLE components and then performing the analysis as described below and visualized in Figure 1.

The analysis of the collected information was conducted in a two-step approach:

- sorting out key factors
- assigning a score to key factors
-

1. Sorting out key factors

The purpose of this step was to sort out the key factors generally important for the industry. To do this, the collected material was summarized into bullet-points, with one bullet-point representing one factor (Bhushan and Banu, 2019). The bullet-points were then collected into a list, which was pre-sorted based on the team's experience and knowledge of the area. This was followed by a final sorting together with experts. The experts used a simplified ranking for this: (UNICEF, 2015):

'++' - for very important factors
'+' - for factors with some importance
'0' - for unimportant factors

Using this ranking, less relevant factors were excluded from the analysis, while the important factors were assigned a score - see step (2) below. The list of the sorted key factors is available in Annex 16. The key factors chosen for the step (2) are indicated in the respective subsections 3.2-3.7.

2. Assigning a score to key factors

In this step, the key factors identified under step (1) were put into a country context and assigned a score. During the workshops held for each country (7 workshops in total), a decision on whether a certain factor is a barrier or an opportunity for a country was made via consensus discussions (Jurevicius, 2014, Parra-Lopez et al.). Prior to the workshops, participants received information collected for each of the countries as preparatory material. This also served as a quality control of the material included in the Annexes of this report.

The barriers and opportunity were then assigned a score, using the following scores (EPM, 2018);

1 = major barrier
2 = minor barrier
3 = minor opportunity
4 = major opportunity

Visualization of the scores was done by displaying the scores in radial charts during the workshops. After the workshops, summaries of the discussions were written and distributed to the participants for review before going into the deliverable. Representatives from a utility company in Germany and Italy were not present in the respective workshops. The workshop summaries were distributed to utility companies in Germany and Italy after the workshops to ensure the utility perspective was included.

At the time of conducting the workshops, the results from the modelling for the environmental section were not yet finalized. The assessment of the environmental key factors was, therefore, done by the IVL experts based on the modelled data. A separate workshop with invited WP leaders for other work packages in the project was conducted, during which the results of the optimization modelling serving as a basis for the analysis of the environmental key factors were presented and discussed.

3.1.1 Limitations

Information gathered in a PESTLE analysis can quickly become outdated. A new political party can change the direction of the political agenda and new legislation can render the results obsolete. Data for the political, economic and legal section are especially vulnerable against the PESTLE limitations. Data for those sections were collected during spring 2020. The social section is based on interviews with a limited number of customers in connection to the REWARDHeat demonstration sites. The results in the social section are hence not likely to be representative for the general population. The environmental section is based on the results of the energy systems optimization model, the description of which together with the input data can be found in Annex 17 – TIMES model.

3.2 Political

The main sources of information for the political factors were the integrated National Energy and Climate Plans (NECP) that all member states have submitted to the European Commission. The NECP outline the national plans for energy and climate strategies for the period 2021-2030. The NECP were reviewed to identify the long-term goals of the respective countries and the stated interests in DHC networks to achieve targets in the HC sectors. Other energy and climate policy documents were reviewed on national levels to go more in depth on the available financial supports for the REWARDHeat solutions. Partners in the REWARDHeat project have been involved to fill the gaps in information on financial support.

The chosen for the scoring (step 2) in the PESTLE analysis political key factors are:

- National targets
- State-based financial support
- Predictability

3.3 Economic

For the economic factors, the extensive work of Heat Roadmap Europe on supply and demand of HC in the EU countries was utilized. For some of the countries, in depth country analysis featuring future demand for HC is available and has been summarised in this deliverable. The information about DH in the respective countries was gathered mainly from governmental agencies (such as the equivalent of the energy agency) and was complemented by input from partners in the REWARDHeat project. The potential for LTH and RE sources integration has been assessed in previous EU projects and the information is summarised in this deliverable. The information from the EU projects is supplemented with scientific articles and governmental sources where necessary and available.

In addition to the analysis based on extensive literature review, computer-based optimization modelling was also used for the assessment of the *Specific Cost of Heat Supply* economic factor (see below). Further information on the applied modelling can be found in the Environmental Section 3.7 and in the Annex 17.

The chosen for the scoring (step 2) in the PESTLE analysis economic key factors are:

- HC supply
- Profitability of DHC
- Price of DHC
- Specific cost of heat supply

3.4 Social

The aim of the social factors in the PESTLE analysis is to understand customers' opinion on DHC, and especially on LTDHC networks with integrated LTH and RE sources The information was collected by means of online questionnaires answered by customers connected to, or foreseen to be connected to, the REWARDHeat demonstration sites. The topics covered in the surveys were:

awareness about LTDHC, availability of information on LTDHC, aspects of trust and environmental considerations. These are the topics that have been found to drive social acceptance towards innovative technologies in previous studies (Hofman, 2015). 10 interviews per demo site were foreseen. 5 interviews with professional customers, defined as a customer that signs the contract with the DH company (a building owner or a building operator), and 5 interviews with end-users/residents, defined as people who would experience the service provided by a DH network. The online questionnaires also serve as the data collection method for the Task 3.2 *Customers' perspective on REWARDHeat solutions.* An in-depth methodology for developing and distributing the survey is available in that deliverable.

The chosen for the scoring (step 2) in the PESTLE analysis social key factors are:

- Customers' opinion of DHN
- Customers' awareness of technology
- Customers' cost expectancy

3.5 Technical

The information serving as a basis for technical factors was gathered with the help of several interviews. The interviewees were the demo site responsible partners in the 7 countries as well as internationally active DHC equipment manufacturers and installers within the 7 demonstration site countries. For two countries, complementing interviews were held with a further national partner or with another partner as deputy (see further below in text). The interviews were prepared, carried-out and documented by IVL. The contributors participating in the interviews were Albertslund, EDF (deputy participator for Dalkia), Tehnokom, UNIZAG, Wärme Hamburg, A2A, Mijnwater, Indepro, Arvalla, Danfoss and Thermaflex.

The material gathered from the interviews was processed and assembled to the reported format by IVL to preliminary drafts. These drafts were reviewed by each contributing partner, while also any need for further complementing input were fulfilled, and then edited to the final state in accordance to the contributors' reviews.

The texts encompass the national level of maturity of the DHC technology, the availability of technical components, installers and operators on the market, replicability opportunities of DHC solutions and further technical prerequisites within the countries. The technical section on heat pumps was compiled using the information gathered by EHPA by sending out an interview sheet to partner associations in the respective countries.

The chosen for the scoring (step 2) in the PESTLE analysis technical key factors are:

- Technical maturity/establishment
- Replicability/standardization
- Building stock suitability

3.6 Legal

The legal sections were developed through a questionnaire template completed by one or several of the REWARDHeat partners relevant to the subject. The information requested in the template was descriptions of the main legal considerations and issues impacting the development and opportunities for DHC solutions and systems at a national scale.

The contributors comprised mainly the DHC research-oriented partners of the project but partially also the demo site responsible partners. The partners providing the fulfilled template information were EHP, RINA-C, HFT, UNIZAG, EDF and Albertslund. The fulfilled template information was further processed and edited to the reported format by IVL. After the editing, the report sections were reviewed by the contributors and any need for further complementing input was fulfilled. After that, the sections were edited to the final state in accordance to the contributors' reviews. The texts encompass the main national legal frameworks impacting retrofitting of buildings, energy production and distribution in relation to DHC.

As a background to the national legal prerequisites, the EU 2030 Climate and Energy Framework and EU directives that have an important impact on the legal framework with obligation to be integrated into national legislation are described in Chapter 8.1.

The chosen for the scoring (step 2) in the PESTLE analysis legal key factors are:

- Permissions
- DHC market legislation
- Buildings/construction

3.7 Environmental

The environmental sections are based on the case study approach, using dynamic and quantitative energy system modelling for scenario analyses, in which different policy and technology assumptions are contrasted. In the study, the well-established TIMES (The Integrated MARKAL-EFOM System) energy system modelling framework is used for the analysis (Etsap, M. Gargiulo, 2009). The developed model includes descriptions of the heating sectors of the seven case study countries and accounts for the interactions between the heating sectors and the respective electricity and fuel supply systems. The model allows to study how an optimized usage of LTH and RE sources in LTDH networks would impact the heating sectors of the demo site countries, as compared to the effects of conventional DH on the heating sectors. More detailed description of the developed and applied model along with the model inputs, scenarios and performed sensitivity analysis can be found in Annex 17.

The method and the results were presented to selected partners in the REWARDHeat project before publication. At least one representative attended from each of the demonstrator countries. The session served both as a quality assurance (assumptions and results were discussed) and as dissemination of project results within the project.

The chosen for the scoring (step 2) in the PESTLE analysis legal key factors are:

- Specific primary energy use
- Accumulated air pollutant emissions

The assessment of whether a key factor is a barrier or an opportunity was performed by comparing modelling results for two development scenarios: 1) with conventional DH, 2) with LTDH and utilization of LTH sources (scenarios are further explained in Annex 17). The assessment of whether a key factor will be identified as a barrier or as an opportunity can be explained by taking *Specific primary energy use* as an example. If the *Specific primary energy use* is lower in the scenario with LTDH and utilization of LTH sources than in the scenario with conventional DH, then the key factor is assumed to be an opportunity. If the energy use increases – a barrier. The judgement on whether a key factor is a major or a minor opportunity (barrier) was made based on the extent to which the value of a key factor is different in one scenario compared to another. E.g., if the value of *Specific primary energy use* decreases in the scenario with LTDH and utilization of LTH sources more than by 50%, compared to the scenario with conventional DH, then the key factor is assumed to be a major opportunity. If it decreases by less than 50% – minor opportunity.

4 PESTLE analysis results

4.1 Summary

The scores from the workshops for all the key factors in all the countries have been summarized in Table 2. The overview provides information on which key factors are found to be barriers or opportunities in the investigated countries.

Table 2 – Overview of the PESTLE analysis output. The coloring scheme: Major opportunity (dark green), minor opportunity (light green), major barrier (dark red), minor barrier (light red).

Topic	Key factors	DK	HR	DE	FR	IT	SE	NL
Political	National targets	4	3	4	3	3	2	3
	State-based financial support	2	2	2	4	2	1	1
	Predictability	4	3	2	3	3	2	3
Economic	HC Supply	4	4	1	3	3	3	4
	Profitability of DHC	4	3	3	3	1	3	2
	Price of DHC	4	2	3	2	3	3	3
	Specific cost of heat supply	3	3	3	3	4	4	4
Social	Customers' opinion about DHC	4	3	4	3	3	4	3
	Customers' awareness about DHC	2	3	2	1	3	4	3
	Customers' cost expectancy	4	3	3	2	4	2	2
Technical	Technical maturity/establishment	4	2	2	3	1	4	2
	Replicability/standardization	4	3	2	4	3	3	3
	Building stock suitability	2	1	1	2	2	4	1
Legal	Permissions	4	2	2	2	2	4	3
	DHC market legislation	2	2	2	3	3	4	1
	Buildings/construction	4	2	3	4	4	3	4
Environmental	Specific primary energy use	2	4	3	4	4	4	3
	Accumulated air pollutant emissions	4	3	3	3	3	3	3

Based on the discussions with the experts in the workshops, only the Customers' opinion about DHC factor was rated as an opportunity for the replication of the REWARDHeat solutions. The ratings, however, were based on the results of the surveys answered by the customers connected to the demo sites. This indicates that customers already connected to DHC are generally positive about the technology and this can be deemed as an opportunity for the development of LTDHC networks. However, the participants of several workshops stated that the opinions of the customers connected to DH networks are not representative of the general populations of the countries and hence, this key factor may easily become a barrier.

The factors based on the applied optimization modelling: *Specific cost of Heat supply, Specific primary energy use* and *Accumulated air pollutant emissions,* are also scored as being opportunities in all the countries, with the only exception of the *Specific primary energy use* factor for Denmark. These key factors were rated as opportunities because they show clear decreases in the heat supply cost, in primary energy use and in air pollutant emissions from the heating sectors of the investigated countries in the future with developed LTDHC networks and utilized LTH and RE sources, as compared to the future with only conventional DHC networks being available.

National targets, *HC Supply*, *Replicability/Standardization*, and *Buildings/construction* were rated as opportunities for 6 out of 7 analyzed countries. The overall political agenda of the EU to transition the energy system towards greener solutions is visible in the national energy and climate plans, which create opportunities for innovative technologies such as REWARDHeat solutions. The translation of the goals into policies will decide how much of an opportunity the targets are for the REWARDHeat solutions. LTDHC needs to be more explicitly encouraged and it is believed that the knowledge level of politicians needs to increase for this to happen. HC sectors of several countries are still strongly dependent on fossil fuels and the necessity to phase out those types of fuel creates an opportunity for LTDHC in those countries (*HC supply* factor). *Standardization* is seen as something necessary for LTDHC and many aspects of the solutions are believed to be possible to standardize. Demonstration of concepts based on locally available heat sources and distribution of the acquired knowledge can drive *replicability* and faster scale-up. The *Buildings/construction* aspect focuses on the energy performance requirements for buildings. Energy performance requirements either favor DHC (supplied with recovered or renewable energy) or are technology-neutral, i.e., tend not to favor any heating technology. However, in Croatia, for example, the NZEB regulations are mainly a barrier as they do not suggest DH as an alternative and the primary energy factor for DH is comparatively high.

State-based financial support and *Building stock suitability* are assessed as barriers in 6 countries. Targeted financial support towards LTDHC solutions is deemed necessary in many countries for the development to take-off and this is not available today. Financial support often favors competing heating solutions, such as individual heat supply options (e.g. HPs) and building level RE sources. In France, the targeted financial support is available and assessed as an opportunity. New and retrofitted buildings are suited for LTDHC, but these buildings constitute a small share of the national building stocks. Slow refurbishment rates and unwillingness of the building owners to invest in new or adapt the existing hydronic systems also contribute as barriers to the replication of the REWARDHeat solutions. Only in Sweden, it is assessed that the building stock is an opportunity for LTDHC.

Table 3 – The shares of opportunities and barriers in the respective countries

Country analysis	DK	HR	DE	FR	IT	SE	NL
Share of opportunities	72%	61%	50%	72%	72%	78%	67%
Share of barriers	28%	39%	50%	28%	28%	22%	33%

Table 3 shows the shares of opportunities and barriers identified for each of the 7 countries. Denmark and Sweden have the largest shares of opportunities. This is mainly because these countries already have DH networks as a well-established and reliable heating solution. *Customers' opinion about DHC, Technical maturity/establishment,* and *Permissions* are assessed to be major opportunities in both Denmark and Sweden, and this is again because of the extensive history of DH networks in these countries. Germany has the largest share of barriers. The *HC Supply* is considered a barrier because the dependency on gas is thought to create a threshold and producing hydrogen to keep utilizing the gas grid is seen as an option. In Germany, as well as in all other countries except Sweden, the *Building stock suitability* is considered a barrier since most buildings are old, not adapted to centralized heating and have low refurbishment rates.

Denmark has the largest share of major opportunities (67%). Aspects that could still improve are: 1) financial support, which is currently encouraging individual HPs, 2) awareness of the technology (storytelling), 3) refurbishment rates of the existing building stock, and 4) improved market legislation to guarantee demand within selected planning zones.

4.2 Denmark

Figure 2 shows the overview of the identified barriers and opportunities for the replication of the *REWARDHeat* solutions in Denmark.

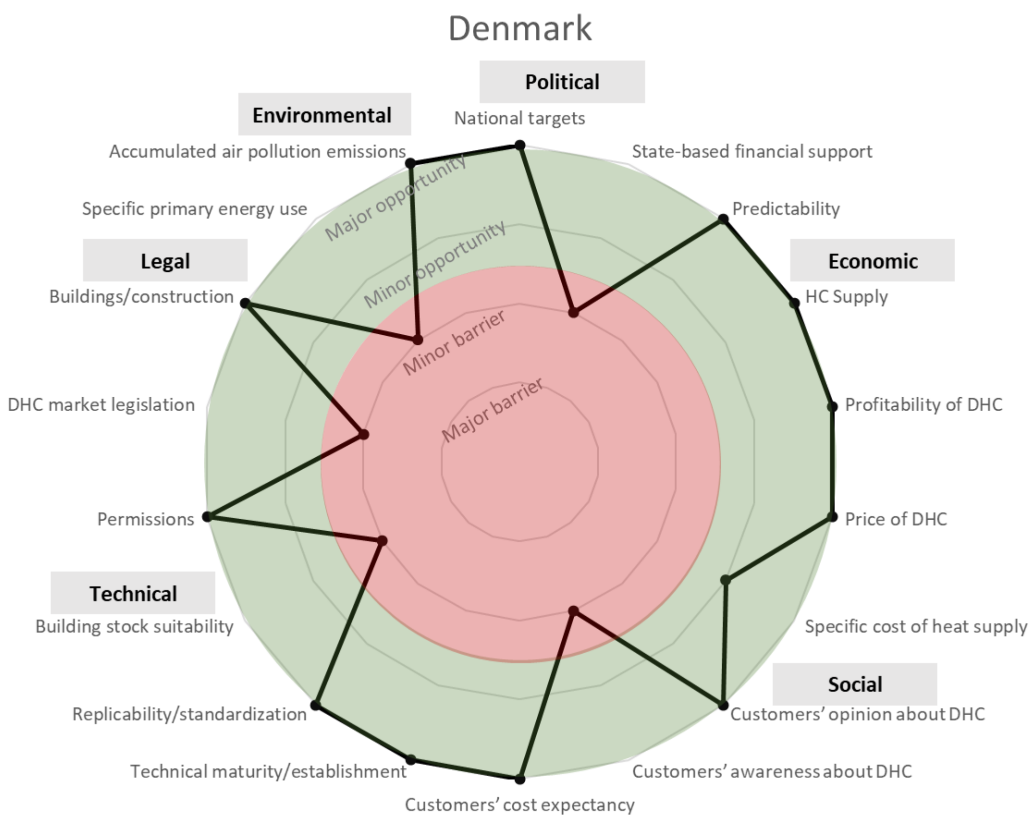


Figure 2 – Overview of the barriers and opportunities for the REWARDHeat solutions in Denmark.

4.2.1 Political

National targets – major opportunity

The national targets are ambitious and forward-looking. No specific targets aimed at DHC are in place, but DH is acknowledged as an important part of the strategy to meet the national targets.

State-based financial support – minor barrier

There is no direct support for DHC. However, DH in Denmark is non-profit and there is access to investment capital through KommuneKredit. Funding is available for solar thermal. The support for individual HPs right now is a barrier for new DHC networks.

Predictability – major opportunity

There is a long tradition of broad political agreement in Denmark making the predictability of the overall framework good. Taxes on various sources in the HC sector can be a little bit less predictable.

4.2.2 Economic

HC Supply - major opportunity

DHC networks have the capacity to support a high penetration of variable renewables in the power grid through large-scale HPs, CHP plants and thermal storage solutions. In phasing out natural gas, it is an advantage that buildings already have hydronic systems in place and that customers are used to centralized heat supply.

Profitability of DHC – major opportunity

DH networks are non-profit in Denmark, which is seen as an opportunity. Customers are less suspicious about pricing and often are the owners of the systems.

Price of DHC - major opportunity

All DHC networks in Denmark are different and so is the price and what is included in it. For a customer, the price of DHC, in general, is competitive against other supply options.

Specific cost of heat supply – minor opportunity

The modelling results show that the specific cost of heat supply (in MEUR per PJ of heat) in Denmark averaged over the period 2020-2050 is estimated to be lower if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 9 for country details and Annex 17 for modelling details).

4.2.3 Social

For all the responses in the social section the scores have been allocated based on the results of a survey performed with 8 customers connected to the demo site in Albertslund. The experts in the workshops would like to highlight that this is not necessarily representative for the Danish population.

Customers' opinion about DHC - major opportunity

Customers in Albertslund are generally positive towards DHC and this is seen as an opportunity. The experts who participated in the workshop also expressed their opinions that people normally pay little attention to the heating solutions as long as they function properly.

Customers' awareness about DHC – minor barrier

Customers should become more aware of the DHC solution as otherwise new buildings might choose another supply option (such as a HP). In Albertslunds customers know about LTDHC networks but this is not representative. DHC as a concept has a more complicated storytelling than wind power or HPs.

Customers' cost expectancy - major opportunity

It is an opportunity that customers think that the cost will be the same or decrease when transitioning from a conventional DH to a LTDH with LTH and RE sources.

4.2.4 Technical

Technical maturity/establishment – major opportunity

DH is well-established in Denmark, LTDHC networks also exist and there are cases of both solar thermal and geothermal energy utilization. Denmark has good players in the market researching new technologies to develop DHC.

Replication/standardization- major opportunity

The DH market in Denmark is non-competitive, which encourages knowledge-sharing and contributes as an opportunity to the replication of the REWARDHeat solutions. The Danish District Heating Association, and the association's yearly congress, are examples of good forums to spread knowledge.

Building stock suitability – minor barrier

It is difficult to assess the share of the building stock that is suitable for LTDHC. All new buildings are well-suited. Many older houses were built with an overcapacity of the radiators and more buildings are improving the building envelope making them suitable.

4.2.5 Legal

Permissions - major opportunity

The procedures for planning heating supply are well-established in Denmark and this provides a clear opportunity for the replication of the REWARDHeat solutions. Improvements can still be made in adapting the procedure to LTDHC and increased regional cooperation.

DHC market legislation – minor barrier

In existing areas, planning zones can guarantee a demand for DH but in newly built areas the idea is that market competition should steer the heating and cooling technologies, and buildings can no longer be forced to connect to a centralized supplier.

Buildings/construction - major opportunity

All new buildings are low-energy buildings and the energy requirements are well suited for LTDHC.

4.2.6 Environment

Specific primary energy use – minor barrier

The specific primary energy use of heat supply (in PJ of fuel per PJ of heat) in Denmark in year 2050 is estimated to increase insignificantly if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 9 for country details and Annex 17 for modelling details).

Accumulated air pollutant emissions – major opportunity

The accumulated air pollutant emissions (in kton) attributed to heat supply in Denmark over the period 2020-2050 are estimated to decrease significantly and even result in net negative NOx emissions (accounting for substituted emissions in the electric power sector) if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 9 for country details and Annex 17 for modelling details).

4.3 Croatia

Croatia still has several barriers remaining, especially in the legal section with price regulations and unfavourable NZEB regulations. More financial support is needed for LTDHC to develop and the building stock needs to improve. The existing DH networks are old and inefficient. DH is competing against a low price of natural gas.

Figure 3 shows the overview of the identified barriers and opportunities for the replication of the *REWARDHeat* solutions in Croatia.

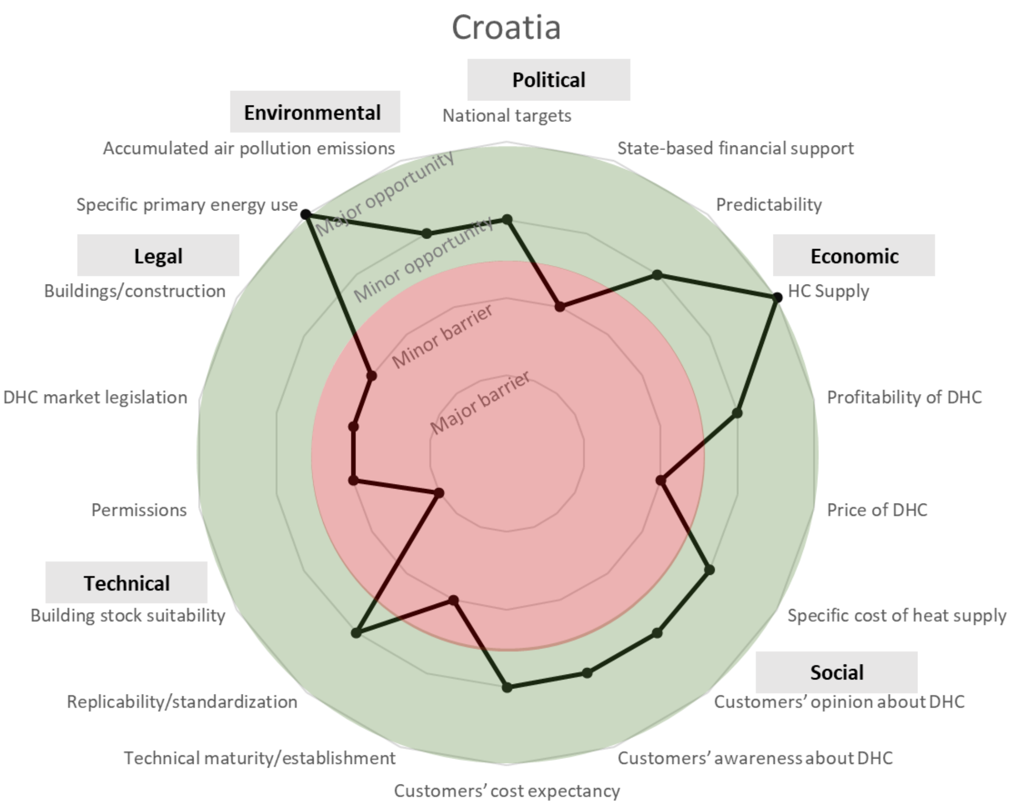


Figure 3 – Overview of the barriers and opportunities for the REWARDHeat solutions in Croatia.

4.3.1 Political

National targets – minor opportunity

National targets can be considered as favorable for DHC solutions but are not very ambitious. Energy efficiency in buildings will increase due to refurbishment targets and NECP regulations. No targets to reduce utilization of natural gas boilers exist. In the NECP, the target for 30% RE sources in multifamily houses means that DH with RE is almost required.

State-based financial support – minor barrier

Some financing is available for refurbishment of DH networks through an EU regional fund but no financial support for investments. Natural gas price for households is below EU average, one of the lowest in the EU. The support needs to be higher for LTDHC to develop.

Predictability – minor opportunity

The predictability of state-based support and regulations is stable, and most DH networks in Croatia are state-owned.

4.3.2 Economic

HC Supply – major opportunity

The HC sector is largely based on fossil fuels, which must be phased out. This is an opportunity for DHC. Currently, natural gas is the main fuel used in densely populated areas and in the long term this must be replaced by DH; there is not enough space for other RE sources-based supply system. The supply of biomass to the HC sector is an issue because it made Croatia reach its RE targets for 2020, but it is traditional biomass and probably not sustainable.

Profitability of DHC – minor opportunity

85-90% of the existing DH networks are owned by the state-owned company HEP. HEP is a large company and profitability of a single branch (HEP DH) is less crucial. For smaller, private companies, profitability is a barrier, especially since the price for heat is state regulated.

Price of DHC – minor barrier

The price of DH is regulated by the Croatian energy regulation agency. The price of natural gas is low, which makes DH a more expensive option in some cases.

Specific cost of heat supply – minor opportunity

The specific cost of heat supply (in MEUR per PJ of heat) in Croatia averaged over the period 2020-2050 is estimated to be lower if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 10 for country details and Annex 17 for modelling details).

4.3.3 Social

For all the responses in the social section the scores have been allocated based on the results of a survey performed with 10 customers connected to the demo site in Topusko. The experts in the workshops would like to highlight that this is not representative for the Croatian population.

Customers' opinion about DHC – minor opportunity

The positive opinions of the customers already connected to DH are a minor opportunity. The general opinion towards DHC in Croatia is, however, believed to be more negative as the concept is perceived as old, inefficient and expensive.

Customers' awareness about DHC – minor opportunity

Customers being aware of the technology is seen as an opportunity.

Customers' cost expectancy – minor opportunity

It is seen as an opportunity that customers think transitioning to LTDHC networks would lead to lower energy prices and would drive them to connect.

4.3.4 Technical

Technical maturity/establishment – minor barrier

There is a tradition of DH in Croatia and it is an established and mature technology. The existing infrastructure is old and inefficient, which makes it a barrier.

Replication/standardization– minor opportunity

The overall process of developing LTDHC networks and production of necessary components can be standardized in Croatia. LTH and RE sources, such as geothermal, are available in many places, enabling replicability.

Building stock suitability – major barrier

The building stock today is not suitable for LTDHC and many buildings (e.g. in Zagreb) require a supply temperature in Dh networks of as high as 110 degrees. The refurbished and new buildings are suitable for LTDHC but are still very few.

4.3.5 Legal

Permissions – minor barrier

Establishing new DHC networks is quite a process and obtaining necessary permits can take years. For the HEP company, being state-owned, the process is easier than for smaller developers, since networks are usually either extended or refurbished. It is, however, not more difficult to get an approval for construction of a DHC network than other infrastructural projects.

DHC market legislation – minor barrier

The price regulation in Croatia is complex and is assessed as a barrier.

Buildings/construction – minor barrier

The Primary Energy Factor (PEF) for DH is comparatively high in the NZEB regulations, and the existing DH networks do not qualify for NZEB buildings energy requirements. NZEB is mainly a barrier as it does not suggest DHC as a viable energy supply alternative. In the future this could turn into an opportunity as DHC networks can be very efficient.

4.3.6 Environment

Specific primary energy use – major opportunity

The specific primary energy use of heat supply (in PJ of fuel per PJ of heat) in Croatia in year 2050 is estimated to noticeably decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 10 for country details and Annex 17 for modelling details).

Accumulated air pollutant emissions – minor opportunity

The accumulated air pollutant emissions (in kton) attributed to heat supply in Croatia over the period 2020-2050 are estimated to decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 10 for country details and Annex 17 for modelling details).

4.4 Germany

Germany has the largest share of barriers (50%), especially in the technical section. Awareness of the technology needs to increase, LTDHC networks and HPs are unfamiliar. Targeted financial support is needed (nowadays the focus is on individual solutions) and the framework needs to be more predictable. Generally, only CHP production is encouraged. Building refurbishment rates are low.

Figure 4 shows the overview of the identified barriers and opportunities for the replication of the *REWARDHeat* solutions in Germany.

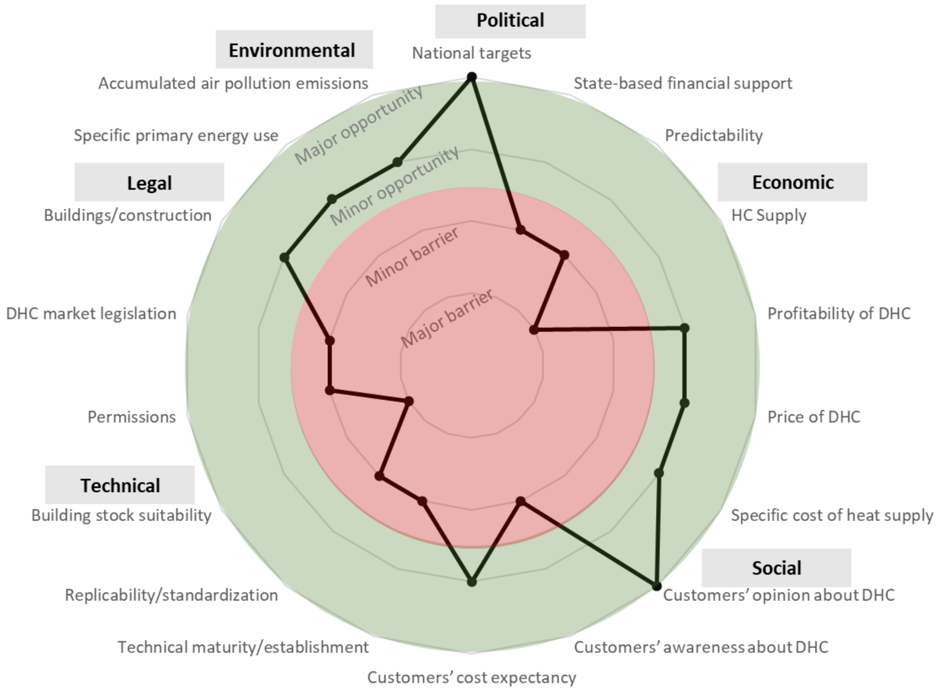


Figure 4 – Overview of the barriers and opportunities for the REWARDHeat solutions in Germany.

4.4.1 Political

National targets – major opportunity

The focus has shifted from renewable electricity to renewable heat. REWARDHeat solutions are aligned with the overall strategy to decarbonize the energy sector. The translation of the strategy into regulation will decide what impact it has.

State-based financial support – minor barrier

The support does not provide enough incentives for LTDHC to develop. The support is mainly aimed at individual heating technologies, e.g., HPs. Integrating solar thermal or geothermal in DHC networks is poorly supported.

Predictability – minor barrier

The overall targets are clear and predictable, but the implementation of policies and financial support is unpredictable. For DHC solutions the support needs to be more stable and long term.

4.4.2 Economic

HC Supply – major barrier

The fact that DH networks currently constitute a small share of the country's HC supply is a barrier. A shift from decentralized to centralized solutions is necessary. Even though fossil fuels need to be phased out, there is a strong dependency on natural gas, which is a barrier. Producing hydrogen and continue utilizing the gas grid is seen as an option.

Profitability of DHC – minor opportunity

From a utility company's perspective, profitability of DHC solutions is greater than of the individual solutions (especially given CO2 taxes). From an investor's perspective, other than DHC investments in the energy sector are considered less risky and have a higher return on investment.

Price of DHC – minor opportunity

The price of DH is levelized with the cost of natural gas making DH a competitive option. If the price could not be made competitive, utilities would not build LTDHC networks.

Specific cost of heat supply – minor opportunity

The specific cost of heat supply (in MEUR per PJ of heat) in Germany averaged over the period 2020-2050 is estimated to be lower if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 11 for country details and Annex 17 for modelling details).

4.4.3 Social

For all the responses in the social section the scores have been allocated based on the results of a survey performed by 8 customers connected to the demo site in Hamburg. The experts in the workshops would like to highlight that this is probably not representative for the German population.

Customers' opinion about DHC – major opportunity

The customers connected to the existing DH network are positive towards the technology and hence, this is deemed as an opportunity. Increased public concern about climate change will likely drive the positive opinion further. In general, the opinion towards DHC is positive, at least among those who are aware of it.

Customers' awareness about DHC – minor barrier

It is a barrier that people are not so aware about the technology since there is no "educational push" from the market side.

Customers' cost expectancy – minor opportunity

Most of the respondents think the price of energy will be lower with integrated LTDHC solutions. In reality, the price will likely be the same (depending on the development of the carbon tax and the local utility) and this is important to communicate to customers to avoid disappointment.

4.4.4 Technical

Technical maturity/establishment – minor barrier

DH companies know the conventional DH technology but less familiar with new technologies, e.g., HPs. There is a difference between the countryside, where DH technologies are less mature, and the metropolitan areas, where they are more established.

Replication/standardization – minor barrier

The lack of experience in LTDHC is a barrier for the replication and due to different local conditions, it will be difficult to standardize.

Building stock suitability – major barrier

Connecting the infrastructure to the existing buildings is a barrier and with a low refurbishment rate not many buildings will be suitable for LTDHC.

4.4.5 Legal

Permissions – minor barrier

The permission procedure is complex and unpredictable. Bureaucracy is considered a barrier. The process can be simplified in the future through digital solutions.

DHC market legislation – minor barrier

Legislations governing the DHC market are scarce and I generally are not in favor of DHC (except CHP production).

Buildings/construction – minor opportunity

LTDHC has a low PEF, which makes it favorable for energy performance requirements. The integration of renewable heat production and waste heat is promoted.

4.4.6 Environment

Specific primary energy use – minor opportunity

The specific primary energy use of heat supply (in PJ of fuel per PJ of heat) in Germany in year 2050 is estimated to significantly decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 11 for country details and Annex 17 for modelling details).

Accumulated air pollutant emissions – minor opportunity

The accumulated air pollutant emissions (in kton) attributed to heat supply in Germany over the period 2020-2050 are estimated to noticeably decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 11 for country details and Annex 17 for modelling details).

4.4.7 Other comments

Utility perspective – Comments from Wärme Hamburg on the PESTLE analysis

- economically, with existing financial support, gas-only boilers are mostly the cheapest heating technology.
- generally, it is not possible to have one picture of the German HC market. There are plenty of regional differences. Currently, there are a lot of social and political changes, which could change the market in Hamburg and Germany within the next years.

4.5 France

In France, it is difficult for DHC to compete if the focus is on the price of energy only. From the customers' perspective, price of heating and cooling is expected to decrease with "greener" supply. From the energy suppliers' perspective, the decrease in energy prices is not evident with higher shares of renewable resources. The awareness of the technology needs to increase, as well as building refurbishment rates.

Figure 5 shows the overview of the identified barriers and opportunities for the replication of the *REWARDHeat* solutions in France.

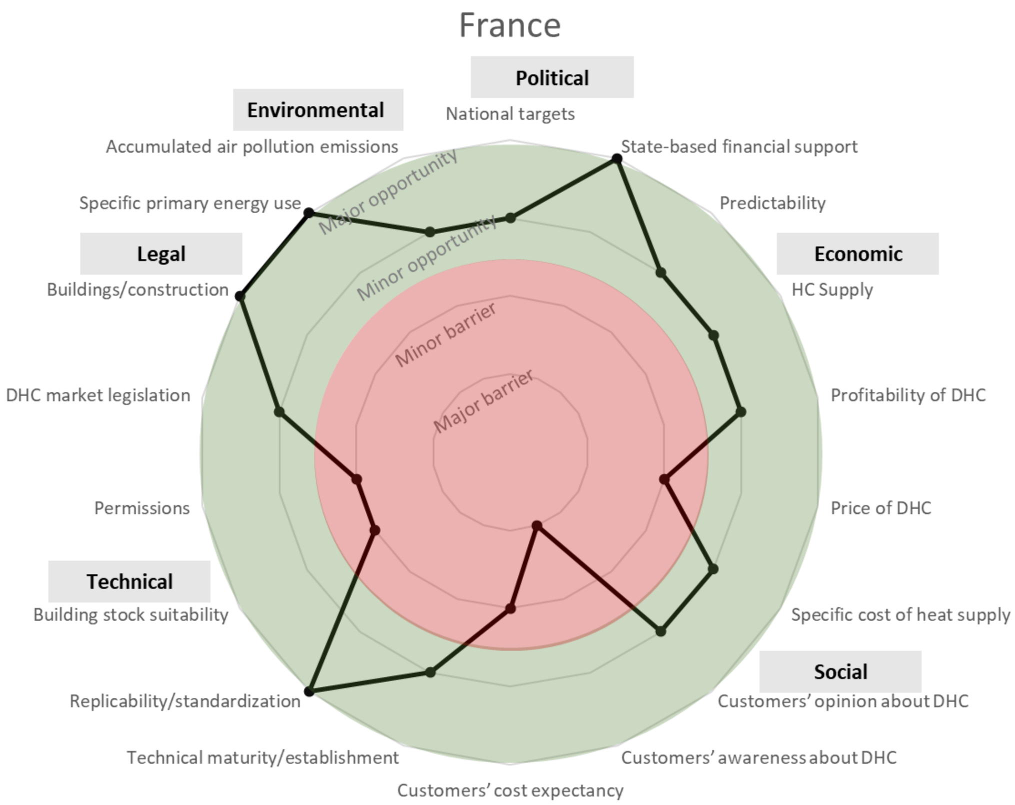


Figure 5 – Overview of the barriers and opportunities for the REWARDHeat solutions in France.

4.5.1 Political

National targets – minor opportunity

The overall national strategy is positive for the development of REWARDHeat solutions and heat networks are mentioned explicitly. It is however just political objective and not a regulation.

State-based financial support – major opportunity

Financial support is available for both DH and DC and therefore, is a major opportunity for the development of LTDHC networks.

Predictability – minor opportunity

When a contract is signed the terms of financial support are secured for the stated duration and hence predictable. In the long term, there is always a degree of uncertainty as to how political support will change.

4.5.2 Economic

HC Supply – minor opportunity

Since the political objective is to phase out fossil fuels, an opportunity arises in the longer-term perspective as market shares become available. However, there is an ongoing competition from electricity-based technologies supplying heating and cooling. In the short term, the economy is still dominated by gas solutions.

Profitability of DHC – minor opportunity

Delegation of services (DSP) is the ownership structure dominating the market. DHC networks are required to be profitable (privately owned more than the publicly owned) and competitive in an open market. An investment in DHC is competitive against other investments in the long term.

Price of DHC – minor barrier

DH needs to compete against alternative heat supply options in an open market and the customer can always choose a cheaper option. Looking only at the price of heat, DH is not competitive now.

Specific cost of heat supply – minor opportunity

The specific cost of heat supply (in MEUR per PJ of heat) in France averaged over the period 2020-2050 is estimated to be lower if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 12 for country details and Annex 17 for modelling details).

4.5.3 Social

For all the responses in the social section the scores have been allocated based on the results of a survey performed with 5 customers in connection to the demo site in La Seyne-sur-Mer. The experts in the workshops would like to highlight that the responses are not representative for the French population, especially considering the customers' opinion.

Customers' opinion about DHC – minor opportunity

From the results of the survey, the customers who know about DH are positive towards the solutions and this is seen as a minor opportunity. In general, people in France are likely to be less positive towards DHC then the survey shows, and many people probably don't have an opinion as the technology is unfamiliar in France.

Customers' awareness about DHC – major barrier

People in general, also those who responded to the survey, are unfamiliar with the technology and this is a major barrier.

Customers' cost expectancy – minor barrier

People expect the price of energy to be the same, or even less, when switching to a new system based on RE sources. This is a barrier. In reality the price will likely increase due to higher generation costs.

4.5.4 Technical

Technical maturity/establishment – minor opportunity

DH is not very common in France, but it has been around since the 1980's. The technology is available and mature, and this spills over to the LTDH technology which is not assessed to be more difficult than conventional DH. DC networks also exist in France and should serve as a basis for the development of LTDHC solutions.

Replication/standardization – major opportunity

France is a large country with much variation between the north and south. The knowledge of working with different types of energy sources for LTDHC is available and therefore, standardization and replication of the REWARDHeat solutions should not be a problem.

Building stock suitability – minor barrier

LTDHC is mostly implemented in new buildings. The fact that most of the existing buildings are supplied with heat using natural gas is considered a barrier (hydronic systems in buildings are available but dimensioned to fit the system based on gas, not DH). For buildings that have electric heaters, the investment cost to change to DH is even higher since a hydronic system needs to be installed.

4.5.5 Legal

Permissions – minor barrier

The procedure to obtain permissions is a highly standardized procedure in France but it is still a long and time-consuming process. It would probably be difficult to make the process easier than it is.

DHC market legislation – minor opportunity

There are no tariffs applied to DHC and the prices of heating and cooling must compete on an open market. There is a classification system, which identifies areas around DH systems where a building must connect if undergoing major energy renovations. The price of DH must still be competitive for the customer, i.e., if a cheaper option is available the customer can opt out of the classification obligation to connect.

Buildings/construction – major opportunity

Building regulations are in favor of DH produced by renewable and recovered energy. If a building connects to a DHC network the thermal coefficient is automatically very good for the building.

4.5.6 Environment

Specific primary energy use – major opportunity

The specific primary energy use of heat supply (in PJ of fuel per PJ of heat) in France in year 2050 is estimated to significantly decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 12 for country details and Annex 17 for modelling details).

Accumulated air pollutant emissions – minor opportunity

The accumulated air pollutant emissions (in kton) attributed to heat supply in France over the period 2020-2050 are estimated to decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 12 for country details and Annex 17 for modelling details).

4.6 Italy

In Italy, the financial support focuses on individual heating and cooling solutions at the building level. Profitability is higher for other than DHC investments, diverting investments away from DHC. Awareness of the technology needs to increase as DHC is unfamiliar and the building stock needs to improve.

Figure 6 shows the overview of the identified barriers and opportunities for the replication of the *REWARDHeat* solutions in Italy.

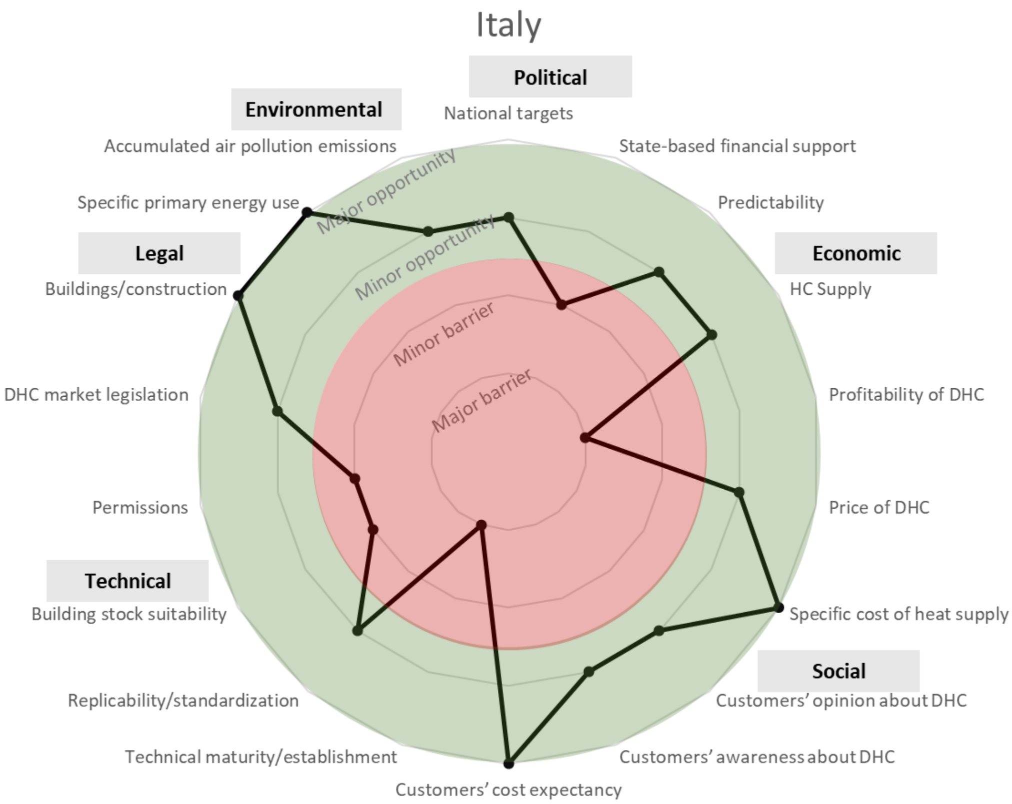


Figure 6 – Overview of the barriers and opportunities for the REWARDHeat solutions in Italy.

4.6.1 Political

National targets – minor opportunity

DHC is barely mentioned in the national strategy but this is not considered a barrier for the technology. The possible connection between DHC and the electricity system through HPs and CHP plants together with the ambitious national goals to make the energy system more sustainable (specifically the HC sector) makes *National targets* a minor opportunity.

State-based financial support – minor barrier

Tax incentives are available for DHC systems with waste incineration, solar thermal and geothermal energy but the support is not deemed as enough to realize DHC networks. RE and EE actions at the building level are more incentivized and therefore the state-based support is more of a barrier for DHC.

Predictability - minor opportunity

Historically, support and regulations have sometimes been unpredictable, but a change has taken place in recent years and there is now a clear strategy to transform the energy system towards renewables and the concept of energy communities is being developed.

4.6.2 Economic

HC Supply - minor opportunity

The share of HPs in the HC sector increases rapidly and is likely to overtake the shares of fossil fuels in the future. This is aligned with the national strategy for the promotion of RE sources, which is focused on electricity. Since LTDHC networks include centralized HPs, *HC supply* is considered an opportunity for the replication of the REWARDHeat solutions.

Profitability of DHC – major barrier

Cities without DH networks today are unfamiliar with the concept and it will be difficult to realize DHC networks in them. Energy companies deem other than DHC businesses, e.g. electricity generation and distribution, natural gas supply, more profitable and this possess a barrier for the development of LTDHC networks.

Price of DHC - minor opportunity

The price of DH is generally aligned with the price of natural gas and is therefore competitive. Further, an energy company can take over the maintenance of DHC substations. Hence, a customer can get a competitive price for energy while having less responsibilities to maintain the service of the HC equipment.

Specific cost of heat supply – major opportunity

The specific cost of heat supply (in MEUR per PJ of heat) in Italy averaged over the period 2020-2050 is estimated to be significantly lower if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 13 for country details and Annex 17 for modelling details).

4.6.3 Social

For all the responses in the social section the scores have been allocated based on the results of a survey performed with 12 potential customers in Milan. The experts in the workshop would like to highlight that this is not representative for the Italian population.

Customers' opinion about DHC - minor opportunity

Respondents' general opinion is positive towards DHC and this is believed to be an opportunity. However, it is worth mentioning again that the respondents live in the city with existing DH system and their responses are likely to be overoptimistic towards LTDHC.

Customers' awareness about DHC - minor opportunity

The respondents were aware of the technology. However, LTDHC networks and even DH is not common in Italy and it is likely that the opinion of the Italian population would be different.

Customers' cost expectancy - major opportunity

It is assumed as an opportunity that the respondents believe that the price of energy will become lower or stay the same with the integration of LTDHC networks, as compared to conventional grids.

4.6.4 Technical

Technical maturity/establishment – major barrier

Considering the whole country, DH is currently not common, and DC is very rare in Italy. This makes technical maturity and establishment of the technologies a major barrier. If only looking at northern Italy and only DH, the answer would have been minor opportunity.

Replication/standardization - minor opportunity

There is potential for replicability of LTDHC solutions in Italy. Standardization should be possible by proposing standard solutions for 3/4 macro-areas/contexts in the country having similar climate and available resources.

Building stock suitability - minor barrier

In general, the building stock is not suitable for LTDHC. However, there could be more opportunities in the future. New buildings have requirements on energy performance and targets on retrofitting old buildings with better insulation exist. Since many buildings have centralized hydronic systems only minor adaptations would be required in buildings to become compatible with LTDHC.

4.6.5 Legal

Permissions - minor barrier

The regulatory framework around DH is complex and receiving the necessary permissions requires much administration. However, when a DHC network is to be implemented, the company has the support of the municipality, which may somehow ease the process of obtaining a permit.

DHC market legislation - minor opportunity

Historically, DHC was not a regulated market in Italy; legislation around DHC has room for interpretation and does not pose boundaries. Starting year 2021, the ARERA (Italian Regulatory Authority for Energy, Networks and Environment) started to implement a series of norms in order to regulate the DHC market.

Buildings/construction - major opportunity

In the energy performance requirements for buildings, there is no push towards a single technology. Heating generated by a HP or by DH (produced by waste incineration or RE) is valued equally.

4.6.6 Environment

Specific primary energy use – major opportunity

The specific primary energy use of heat supply (in PJ of fuel per PJ of heat) in Italy in year 2050 is estimated to significantly decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 13 for country details and Annex 17 for modelling details).

Accumulated air pollutant emissions – minor opportunity

The accumulated air pollutant emissions (in kton) attributed to heat supply in Italy over the period 2020-2050 are estimated to noticeably decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 13 for country details and Annex 17 for modelling details).

4.6.7 Other comments

Utility perspective – Comments from A2A on the PESTLE analysis

- politically and economically, DHC is not seen as a strategic tool to meet the environmental and energy goals, yet, this could be translated as a minor opportunity. Therefore, not many investments are dedicated to the development of this technology.
- socially, non-experts are not aware of how the DHC technology works, even in the areas where DH is present. Therefore, when developing new systems, it is important to engage deeply the involved communities and authorities in order to explain DHC systems and gain their supports.

4.7 Sweden

Sweden has a large share of opportunities (78%) and the identified barriers are mainly in the political section. With a strong tradition of conventional DH, targeted financial support and increased knowledge are necessary for LTDHC to develop. In the short-term, prices are likely to increase with LTDHC and customers need to be prepared for and accept this.

Figure 7 shows the overview of the identified barriers and opportunities for the replication of the *REWARDHeat* solutions in Sweden.

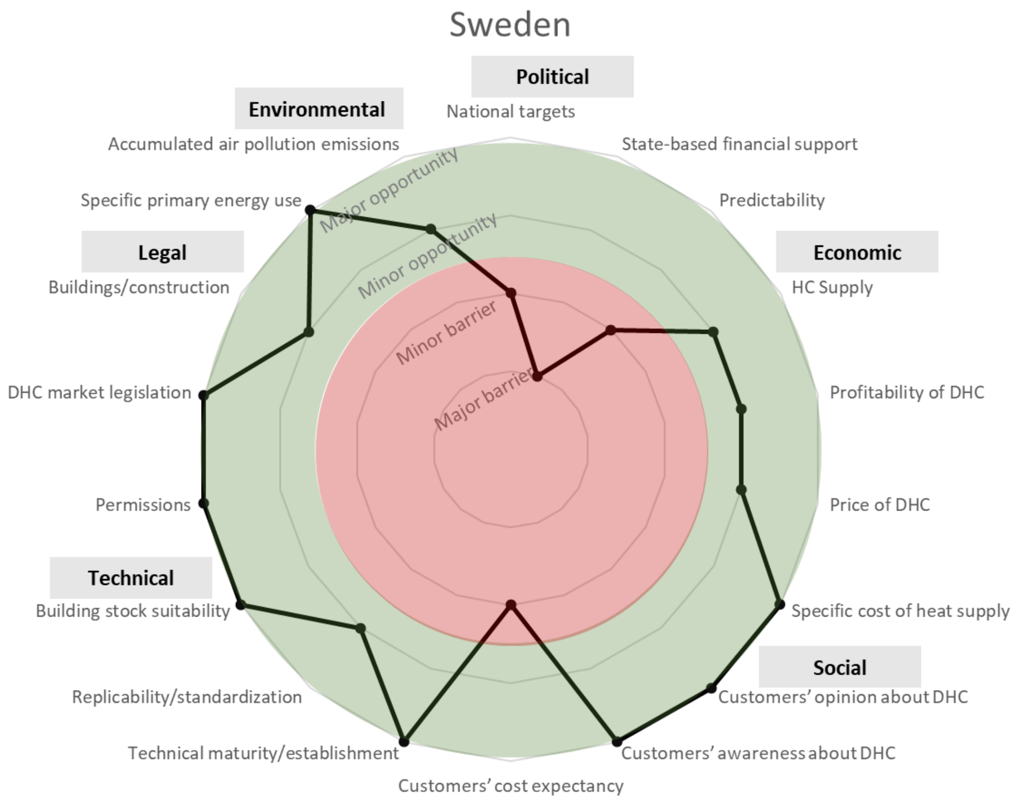


Figure 7 – Overview of the barriers and opportunities for the REWARDHeat solutions in Sweden.

4.7.1 Political

National targets – minor barrier

Politicians are still steering towards conventional DH. Combustion of waste and biofuels in CHP plants is still in focus. The knowledge among politicians about LTDHC needs to be improved.

State-based financial support – major barrier

There is no targeted support available today. Economic incentives are necessary for LTDHC to take off as the tradition in Sweden is to build large, centralized generation plants.

Predictability – minor barrier

The political agenda with ambitious environmental policies are predictable and long-term. The Swedish building code (BBR) is important for DHC and needs to be more predictable.

4.7.2 Economic

HC Supply – minor opportunity

DH and HPs (both large-scale in the DHC networks and individual) are well-established technologies in Sweden, which is an opportunity for LTDHC solutions. In a future where biomass availability if limited, LTDHC is an appealing option. The tradition of investing in large-scale waste incineration plants reduces the incentive for the exploitation of LTH sources and is therefore a barrier.

Profitability of DHC – minor opportunity

Development of LTDHC networks is deemed profitable, especially if such networks can be close/connected to the existing DH networks and to sources of waste heat, e.g., data centers.

Price of DHC – minor opportunity

Conventional DH is not always the cheapest heating option, but the price is competitive and stable, the supply is easy and there is a strong tradition of centralized heating solutions.

Specific cost of heat supply – major opportunity

The specific cost of heat supply (in MEUR per PJ of heat) in Sweden averaged over the period 2020-2050 is estimated to be significantly lower if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 14 for country details and Annex 17 for modelling details).

4.7.3 Social

For all the responses in the social section the scores have been allocated based on the results of a survey performed with 7 customers in Sweden, 3 connected to the demo sites and 4 representing an approximation of end-users at the Swedish demo sites. The results of the surveys are not necessarily representative for the Swedish population.

Customers' opinion about DHC – major opportunity

The customers already connected to DH are generally positive about the technology. Considering that DH covers more than half of the total heating demand in Sweden, positive opinion about the technology can be assumed to be true for most of the population.

Customers' awareness about DHC – major opportunity

Customers have good knowledge about conventional DH, and this is deemed as an opportunity for the development of LTDHC networks. However, to further improve the awareness of the customers is beneficial.

Customers' cost expectancy – minor barrier

Most of the customers believe that the price of energy would decrease with the integration of LTDHC networks and LTH and RE sources. The experts indicated that in the short-term the prices are likely to increase (because significant investments are necessary) or remain the same. In the long-term, customers are likely to experience lower prices if LTDHC networks are developed, as compared to the prices in the future with conventional DHC.

4.7.4 Technical

Technical maturity/establishment – major opportunity

DH and HPs are well-established technologies in Sweden, which is an opportunity for the replication of the REWARDHeat solutions.

Replication/standardization– minor opportunity

DH networks have been successfully replicated in most of the Swedish cities. Standardized substations keep maintenance costs down. The experience of standardization in Sweden is extensive and developing different concepts for LTDHC based on the available technologies should be comparatively easy.

Building stock suitability – major opportunity

Newly constructed buildings are the largest opportunity for LTDHC however a great share of the existing building stock is also suitable (slightly lower efficiency). Smart control systems become more important for LTDHC solutions.

4.7.5 Legal

Permissions – major opportunity

Obtaining permissions in Sweden is a fairly straightforward process.

DHC market legislation – major opportunity

There are no obligations to connect to a DHC network. The prices of heating and cooling are not regulated but there is a tradition of transparency in the pricing structure. Transparency and freedom of choice are considered as great opportunities for LTDHC networks.

Buildings/construction – minor opportunity

The Swedish building code (BBR) has improved recently and is now fairer between DH and individual heating solutions. A difficulty is, however, that the BBR is changing often.

4.7.6 Environment

Specific primary energy use – major opportunity

The specific primary energy use of heat supply (in PJ of fuel per PJ of heat) in Sweden in year 2050 is estimated to significantly decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 14 for country details and Annex 17 for modelling details).

Accumulated air pollutant emissions – minor opportunity

The accumulated air pollutant emissions (in kton) attributed to heat supply in Sweden over the period 2020-2050 are estimated to noticeably decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 14 for country details and Annex 17 for modelling details).

4.7.7 Other comments

The most important barrier identified by experts in the Swedish workshop was not covered by the selected key factors and is therefore highlighted here. The strong tradition and culture in Sweden of having large central production plants is a major barrier for LTDH. Upscaling LTDH requires a shift from production-oriented to distribution-oriented.

4.8 The Netherlands

In the Netherlands, barriers are identified in all the sections. Financial support and increased awareness are necessary, as well as incentives for building owners to improve the building stock. Price regulations and that the heating demand within an area cannot be guaranteed are barriers. DH is often competing for investments with the electricity system, in which profitability is higher.

Figure 8 shows the overview of the identified barriers and opportunities for the replication of the *REWARDHeat* solutions in the Netherlands.

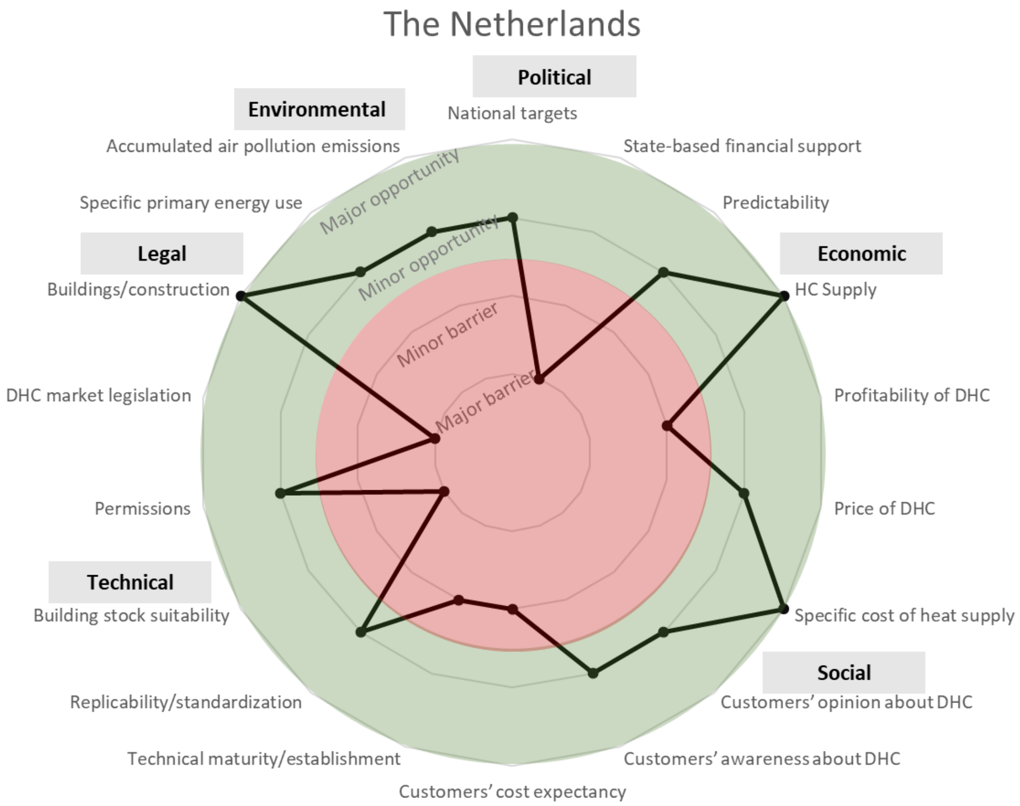


Figure 8 – Overview of the barriers and opportunities for the REWARDHeat solutions in Netherlands.

4.8.1 Political

National targets – minor opportunity

DHC is acknowledged as being necessary for achieving national targets and phase out natural gas from the energy system. Conventional DH suits the targets well, some adjustments might be required to encourage development of LTDHC.

State-based financial support – major barrier

DHC networks are managed as a commercial enterprise and do not receive financial support from the state. "Zero interest" loans are available from the government, but a 7% return is required.

Predictability – minor opportunity

The political direction is predictable. For example, the SDE++ support is guaranteed for 15 years when granted. Recently the support for biomass in DHC networks was removed. Knowledge about LTDHC needs to be improved amongst politicians.

4.8.2 Economic

HC Supply - major opportunity

HC sector is currently dominated by natural gas and it is a major opportunity that DHC is the most feasible substitution option. Combustion of biomass is not promoted due to its impact on local air quality. The Netherlands aim at not being dependent on fuel imports.

Profitability of DHC – minor barrier

Most of the DH market is controlled by large energy companies, which also own local power grids. Electricity branch is more profitable than heating and hence, companies are likely to prioritize investments in the electricity sector.

Price of DHC - minor opportunity

The price of heating is not allowed to exceed the price of natural gas according to the Heat Act. Customers receive a better solution with DH than with a gas boiler but at the same price.

Specific cost of heat supply – major opportunity

The specific cost of heat supply (in MEUR per PJ of heat) in the Netherlands averaged over the period 2020-2050 is estimated to be significantly lower if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 15 for country details and Annex 17 for modelling details).

4.8.3 Social

In the social section, the scores have been allocated based on the results of a survey performed with 12 customers connected to the Mijnwater demo site. The experts in the workshop would like to highlight that the results of the surveys might not be representative of the Dutch population.

Customers' opinion about DHC - minor opportunity

It is an opportunity that customers are more positive about DHC than negative. In case of Mijnwater, the possibility to provide district cooling is thought to increase the general opinion.

Customers' awareness about DHC - minor opportunity

Customers' knowledge about DHC is high enough to make this an opportunity. People can talk about the technology to others and further increase awareness.

Customers' cost expectancy - minor barrier

The respondents think transitioning to the new solution will result in higher energy bills. Normally, it is not the end-user who makes the decision on the heat supply option, so the opinion of the professional customers is more important.

4.8.4 Technical

Technical maturity/establishment – minor barrier

Technologies used in LTDHC networks are mature and well-known but combining them in a functioning system has not yet been performed. Improved knowledge and more experience are required.

Replication/standardization - minor opportunity

Standardization of the REWARDHeat solutions is possible but since all customers are different the solutions need to be flexible, i.e., adapted to individual customers. Due to a great number of densely populated areas in the Netherlands, replication is achievable. In rural areas, the cost is the limiting factor and replication is not possible.

Building stock suitability – major barrier

Building owners are typically not willing to invest in their buildings New buildings are suitable for LTDHC.

4.8.5 Legal

Permissions - minor opportunity

The process of obtaining permissions in the Netherlands is straight-forward and is easier than in many other countries, even though it is necessary to engage multiple instances. With the new Environmental Act (2021) it is likely to be even easier.

DHC market legislation - major barrier

DHC networks are managed as commercial enterprises. Unless enough customers connect, the investment cost of the infrastructure is too high for the companies. It would be more beneficial if public service utility companies oversaw DHC networks.

Buildings/construction – major opportunity

Being connected to a DHC network, which relies on the utilization of waste heat or HPs running on "green" electricity, is beneficial for buildings from the perspective of fulfilling energy performance requirements. This makes it easier to start a discussion with building owners about connecting to DHC.

4.8.6 Environment

Specific primary energy use – minor opportunity

The specific primary energy use of heat supply (in PJ of fuel per PJ of heat) in the Netherlands in year 2050 is estimated to decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 15 for country details and Annex 17 for modelling details).

Accumulated air pollutant emissions – minor opportunity

The accumulated air pollutant emissions (in kton) attributed to heat supply in the Netherlands over the period 2020-2050 are estimated to noticeably decrease if LTDH networks are developed and LTH sources are utilized, as compared to the future with only conventional DH being developed and used (see Annex 15 for country details and Annex 17 for modelling details).

5 Modelling results

This section presents selected results from the developed and applied optimization modelling and is focused on the differences between the impacts of conventional and LTDH systems with LTH sources on the heating sectors of the investigated countries under different climate targets. The results presented in Sections 5.1-5.6 are for Germany, which was chosen as a reference country, while the results for the other investigated countries can be accessed through the interactive webpage accessible from the project official website: www.rewardheat.eu.

The presented analysis is based on the modelled technology development and climate scenarios briefly described below (for the detailed explanations of the modelled scenarios please see Annex 17 – TIMES model, Table 20 and Table 21):

- WEO-NP (climate scenario) – both fossil and total CO_2 emissions in the heating and power sectors decrease linearly by 60% by 2050, compared to 2015.
- WEO-SD (climate scenario) – both fossil and total CO_2 emissions decrease linearly by 95% by 2050, compared to 2015
- Ambitious (climate scenario) – both fossil and total CO_2 emissions decrease to zero already by 2030.
- ConventionalDH (technology scenario) – only conventional DH, no LTH sources are available.
- TransitionDH (technology scenario) – only conventional DH, utilization of LTH source is allowed.
- FutureDH (technology scenario) – investments in low temperature DH and utilization of LTH source are allowed.

It is worth mentioning here that the cooling demand was not included in the developed optimization model. The shares of cooling in the heating and cooling markets of the demo-site countries are small, infrastructure for district cooling is lacking and investment costs in cooling networks are high. However, cooling demand might increase in the future because of global warming and urban heat islands effect. District cooling interacts with district heating though absorption HPs, in which district heating is used to produce cooling. Thus, investments in district cooling infrastructure could open opportunities for higher market shares of DH. Since urban LTH sources are more available during summer, when the heating demand is low, investments in district cooling infrastructure could increase LTH use to meet buildings' heating and cooling demand.

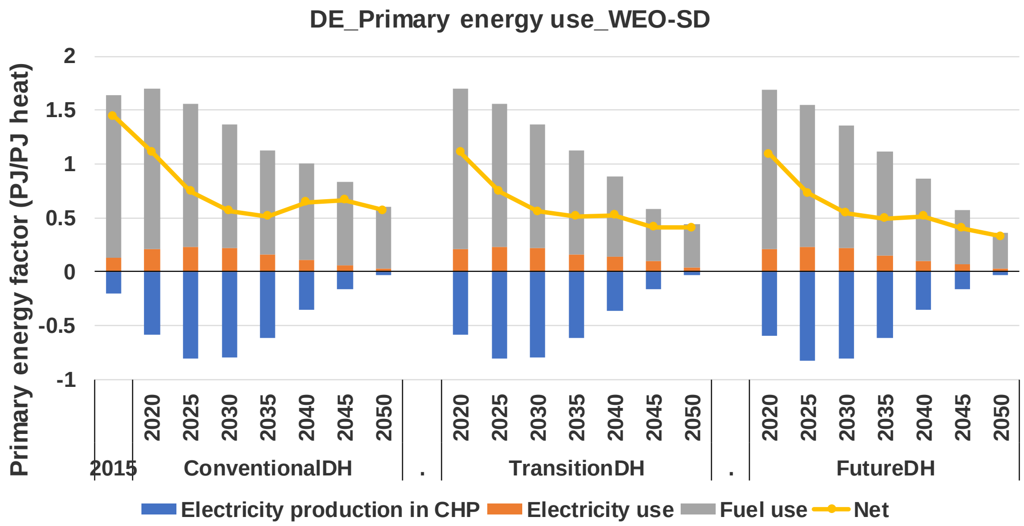
Neutral-temperature DHC is a comparatively new concept with very little information about it from the demonstration projects. Neutral-temperature DHC is often associated with higher costs compared to implementation of projects including mature technologies. In addition, these systems are suitable in areas with low-energy buildings, which have very low heat demand even during coldest time of the year. For the development of neutral-temperature DHC networks, essential changes in buildings' substations (integrated electric boiler or heat pump and a storage tank in substations) and DH networks are needed. Thus, neutral-temperature DHC is associated with higher costs and electricity use in substations (replacing DH use) while it is only applicable to specific buildings and areas. This study is at the national level and covers the entire heating sector and all types of buildings, out of which low-energy buildings comprise only a small share.

Therefore, the assumed DH temperature level in the FutureDH technology development scenario is limited to 55/25 °C (supply/return). By modelling low-temperature DH, the uncertainties of performance and the higher cost of neutral-temperature DHC are avoided. Instead, we believe that the overall outcomes of the performed PESTLE analysis on the barriers and opportunities for low-temperature DHC networks can be applicable for the neutral-temperature solutions; i.e., the need for a high cap on CO_2 emissions and the existence of renewable electricity in order to LTH sources to be used in DH systems.

Impact of LTH sources and LTDH on the primary energy use

Figure 9 illustrates the variations in the specific primary energy use factors (primary energy use per unit of generated heat), divided into fuel use, electricity use and electricity production (orange, grey and blue bars, respectively) and the net of these (yellow line), for Germany in different climate and technology scenarios.

The results show that the utilization of LTH sources in the TransitionDH and FutureDH technology development scenarios reduces the specific primary energy use of heat generation in both the WEO-SD and WEO-NP climate scenarios. The main reason for the primary energy use reduction is that RE sources (LTH sources) replace fuel use for heat production in individual boilers, centralized heat-only boilers and CHP plants, as compared to the fuel use in the ConventionalDH (TransitionDH and FutureDH) technology development scenario. In the WEO-NP climate scenario, however, the net specific primary energy use is reduced to a lesser extent than in the WEO-SD climate scenario. This is because of the increased use of electricity by the HPs in the latter scenario.



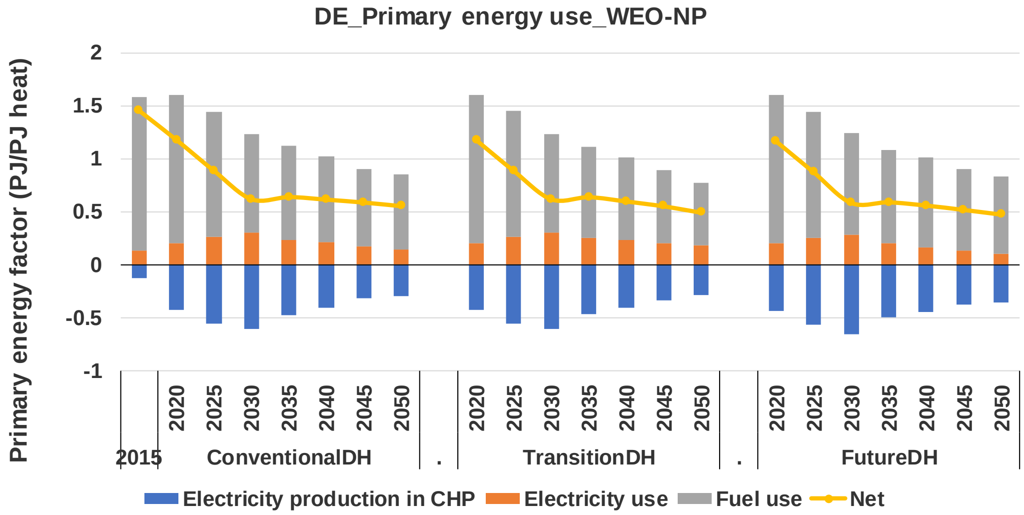


Figure 9 – Variations in the specific primary energy use factors for each of the technology development scenarios (ConventionalDH, TransitionDH, FutureDH) in WEO-SD (top) and WEO-NP (bottom) climate scenarios in Germany. The specific primary energy use factors for electricity production are negative because electricity is assumed to be exported from the heating sector system boundary.

5.1 Impact of LTH sources and LTDH on the air pollutant emissions

The modelling results show that the effects of the utilization of LTH sources and development of LTDH networks on the air pollutant emissions associated with heat generation in the investigated countries depend significantly on the applied climate scenario. Figure 10 shows the differences in the estimated air pollutant emissions: NOx, SO_2, and PM2.5 (in kTon), in the TransitionDH and FutureDH technology development scenarios each compared to the Conventional DH scenario (both differences are shown for the WEO-SD and WEO-NP climate scenarios). The differences in emissions are presented for Germany. For the description of how the air pollutant emissions were calculated based on the modelling results please see Section 17.11 “Air pollutant calculations”.

In the case of Germany and the WEO-SD climate scenario, all considered air pollutant emissions are estimated to decrease in both the TransitionDH and FutureDH scenarios (scenarios with allowed utilization of the LTH sources), as each compared to the ConventionalDH scenario. This is because of the successful utilization of the LTH sources, which replace other types of energy used for heat generation, but also because other technologies available in the DH sector have comparatively low emission factors. In the WEO-NP climate scenario, the air pollutant emissions decrease in the FutureDH scenario but increase in the TransitionDH scenario, as each compared to the ConventionalDH scenario. The increase in the air pollutant emissions in the TransitionDH scenario is because of the higher share of heat and electricity being generated in the coal-fired CHP plants available in the DH sector.

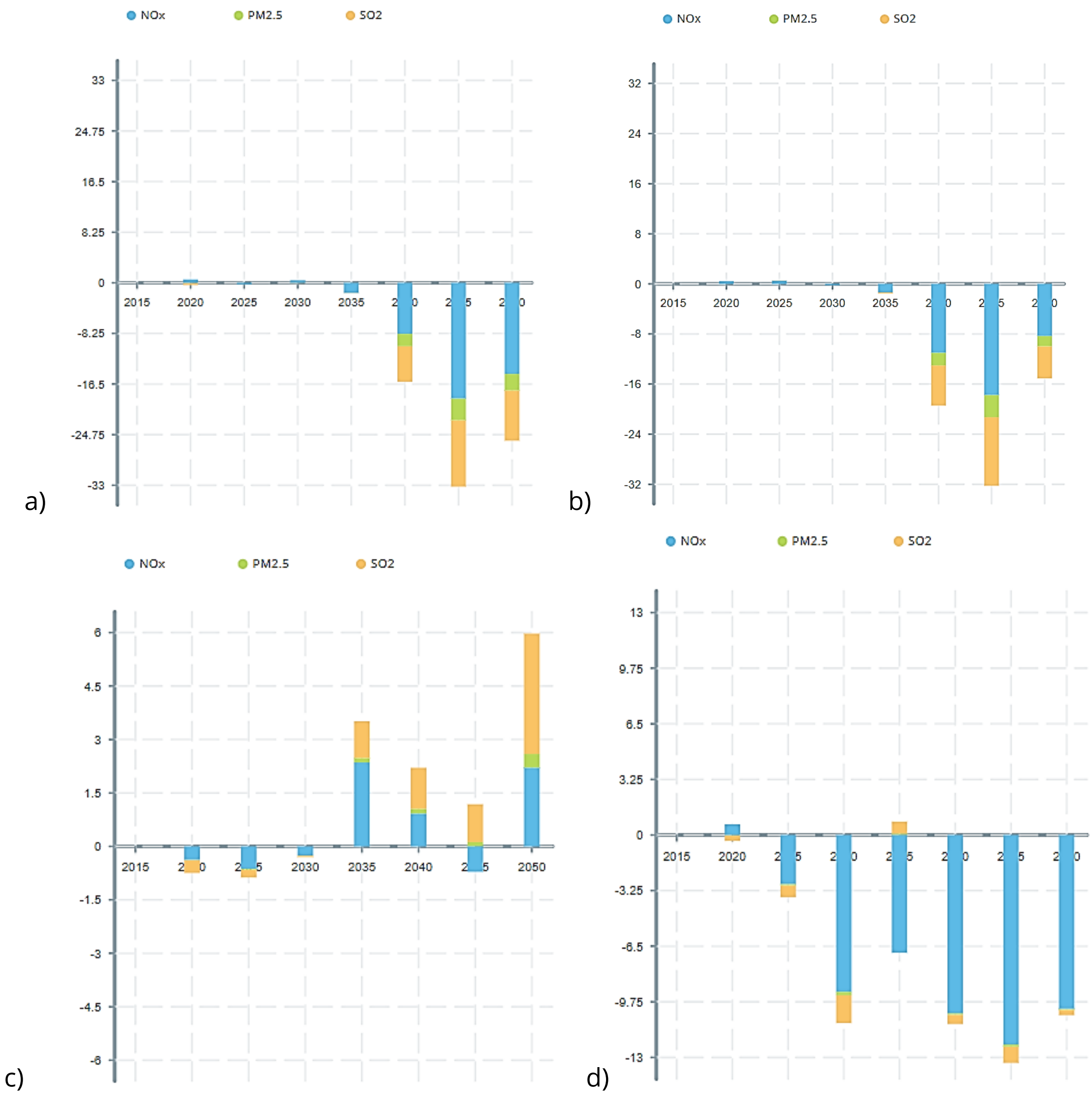


Figure 10 – The differences in the air pollutant emissions: NOx, SO_2, and PM2.5 (in kTon), in Germany in the a) TransitionDH compared to ConventionalDH technology development scenario (WEO-SD climate scenario), b) FutureDH compared to ConventionalDH technology development scenario (WEO-SD climate scenario), c) TransitionDH compared to ConventionalDH technology development scenario (WEO-NP climate scenario), and d) FutureDH compared to ConventionalDH technology development scenario (WEO-NP climate scenario).

5.2 Use of LTH sources in DH systems

The modelling results indicate that the utilization of the LTH sources in DH networks can be feasible and cost-efficient regardless of the modelled climate scenario. It is also observed that the available potentials of the LTH sources are greater than what is cost-efficient to use. Figure 11 (a, b) for the results for Germany.

Figure 11 shows that in the case of Germany, in the WEO-SD climate and TransitionDH technology development scenario (Future DH), only 0 - 42 % (44 - 75%) of the estimated LTH sources potential were used in the heating sector at the end of the modelled time horizon – year 2050 (for the estimated total potentials of the LTH sources see Table 23). In the WEO-NP climate and TransitionDH technology development scenario (Future DH), 29 - 53% (42 - 75 %) of the available LTH sources were used in year 2050. The cost-efficient utilization levels are limited by seasonal availability of the LTH sources, i.e., the availability of the LTH sources is high during summer time and low during winter time, being opposite to the seasonal heat demand distribution. The utilization of HPs, which use ambient-temperature heat sources and/or industrial excess heat, together with the operation of CHP plants create additional competition and limit the use of the LTH sources.

In the TransitionDH technology development scenario, the share of the LTH sources used in the WEO-NP climate scenario is greater than the respective share in the WEO-SD climate scenario. This is because of the system boundary assumed in the analysis. In this analysis, carbon emissions associated with the electricity use in HPs and with the electricity generation in CHP plants (further described in Section 17.10.2) are considered. Since the heating sector needs to comply with the total CO_2 emissions constraint, the degree of utilization of LTH sources via HPs is dependent on the CO_2 emissions factor applied to consumed electricity. In the WEO-NP climate scenario, the total CO_2 emissions are less constrained than in the WEO-SD climate scenario, resulting in higher share of HPs that use the LTH sources.

The modelling results show that the utilization of excess heat from ”Data centers” is more cost-efficient than the utilization of the other LTH sources: “Metro stations”, “Sewage systems” and “Cooling systems of buildings”. Overall, the LTH sources that are available during winter time and at as high as possible temperatures, are the most desirable for the heating systems. The model results show that ambitious climate policies and possibility of developing LTDH networks provide more opportunities for the utilization of LTH sources.

It can also be noticed from Figure 11 that the LTH sources are being utilized only starting year 2035 (in the presented scenarios). The reason or this is that a stringent CO2 emissions cap is required for the utilization of the LTH sources to become cost-efficient from the systems perspective. This is shown in more details in the sensitivity analyses in Section 17.14.

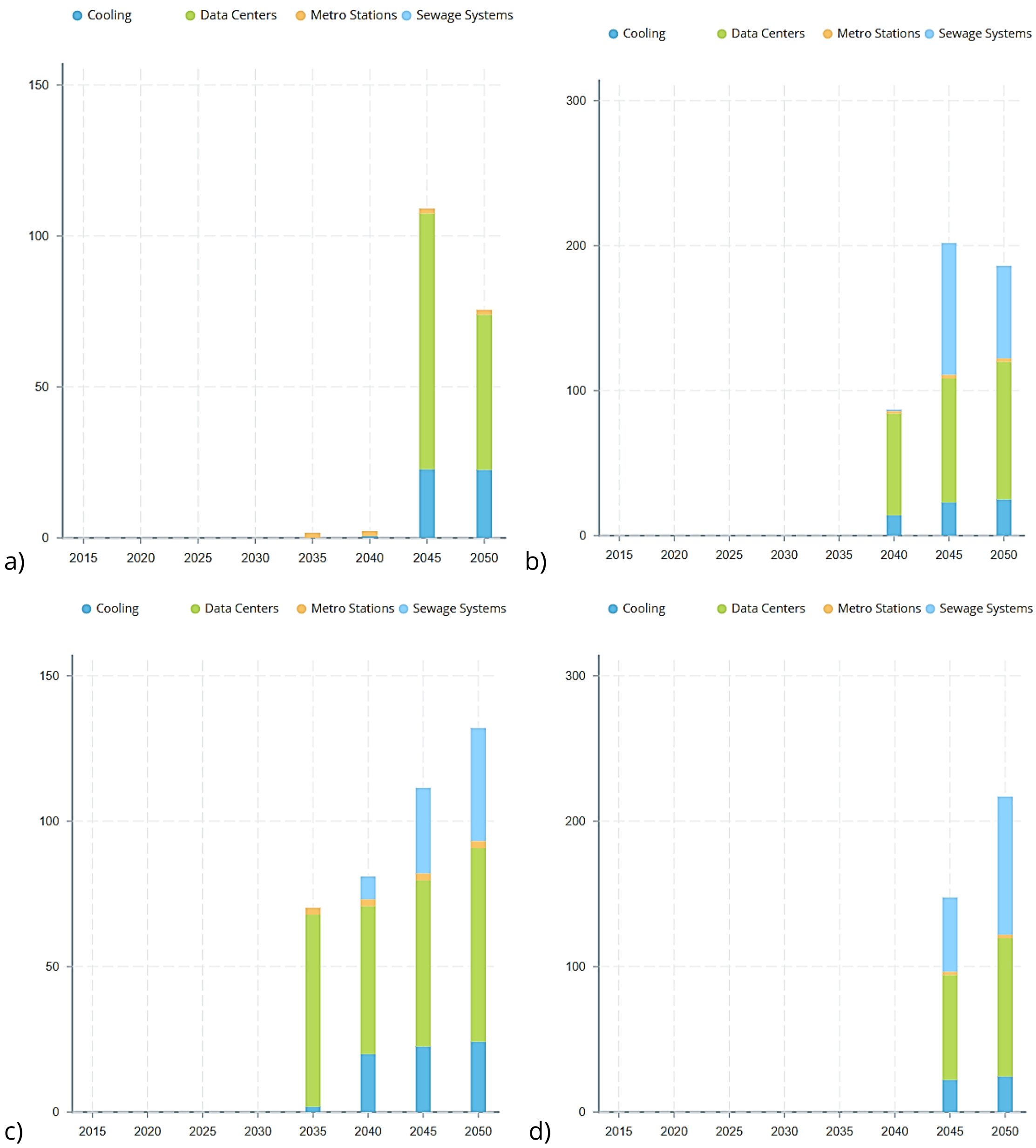


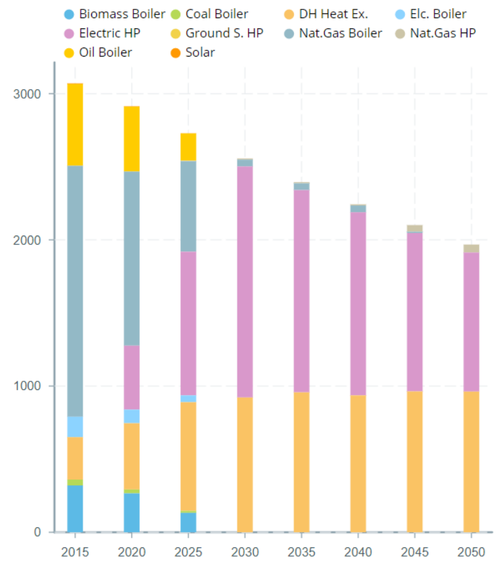
Figure 11 – The cost-efficient levels of utilization of the LTH sources (in Pj) in Germany in the a) TransitionDH technology development scenario (WEO-SD climate scenario), b) FutureDH technology development scenario (WEO-SD climate scenario), c) TransitionDH technology development scenario (WEO-NP climate scenario), and d) FutureDH technology development scenario (WEO-NP climate scenario).

5.3 Impact of LTH sources and LTDH on the share of DH in the heating sector

The modelling results show that the use of DH increases over the modelled time horizon both in absolute terms and as a market share of the heating sectors in all the investigated scenarios. In all the case countries, except for DK and SE, the heating sectors went through large changes over time, compared to their current states, in that a shift from almost entirely induvial heating-dominated market to a market with the balanced mix of individual and DH technologies has occurred. For an example, see Figure 12 that shows the end use heat demand from the German building stock, covered by both individual heating solutions and DH, as obtained from the modelling of the ConventionalDH and FutureDH technology development scenarios in the WEO-SD and WEO-NP climate scenarios.

In the WEO-SD climate scenario, individual heating based on natural gas, which competes with DH in the first model years, is replaced by individual ground source- and ambient air-based HPs by the end of the modelled time period in all the modelled countries. Whereas in the WEO-NP climate scenario, individual heating based on ambient air-based HPs gradually became the only competitor to DH for building heating. The reasons for this are 1) different CO2 emissions constraint levels in the WEO-SD and WEO-NP scenarios (note that electricity used by HPs for heat generation is not CO2-neutral), 2) techno-economic parameters applied to the HPs. In the WEO-NP climate scenario, the cap on CO2 emissions is not as tight as in the WEO-SD scenario and therefore, ambient air-based HPs, being the most cost-optimal option, take over the market share of the individual heating technologies. In the WEO-SD climate scenario – scenario with tighter CO2 cap compared to the WEO-NP scenario, the use of only air-based HPs is not enough to meet the demand for heating while keeping the CO2 emissions constraint. Hence, investments in ground source-based HPs – HPs with better COP values than for air-based HPs, were made in addition to ambient air-based HPs.

The results show that the utilization of the LTH sources using large-scale, centralized HPs increases competitiveness of DH in the heating market. In all the climate policy scenarios, higher use of DH can be noted when large-scale HPs based on LTH sources are allowed (compare the results for the ConventionalDH and FutureDH technology development scenarios in Figure 12).



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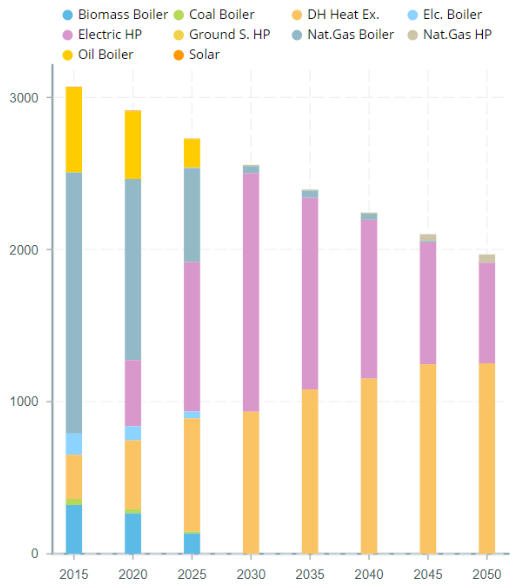


d)

Figure 12 – End use heat demand in buildings (in PJ), covered by both individual heating solutions and DH, in Germany in the a) ConventionalDH technology development scenario (WEO-SD climate scenario), b) FutureDH technology development scenario (WEO-SD climate scenario), c) ConventionalDH technology development scenario (WEO-NP climate scenario), and d) FutureDH technology development scenario (WEO-NP climate scenario).

5.4 Impact of LTH sources and LTDH on heat generation in DH systems

The modelling results show that the fuels and technologies used for heat generation in DH systems are case and scenario dependent and vary over time. Figure 13 illustrates the cost-efficient heat generation in the DH sector of Germany for the different scenarios and different years.

The model results show that in the WEO-SD and Ambitious climate scenarios (ConventionalDH technology scenario), fossil fuel–based technologies are gradually replaced by biofuel HOBs, geothermal heat, solar and industrial excess heat if investments in large HPs did not occur. The possibility to invest in HPs based on LTH sources change the course of DH development. Compared to the ConventionalDH scenarios, the TransitionDH and the FutureDH scenarios show a higher level of heat generated in DH systems and lower levels of heat generated in the biofuel HOBs. In these scenarios, the large-scale HPs replaces large shares of biofuel HOB production in the ConventionalDH scenario.

In the WEO-NP scenarios, the current fossil fuel–based technologies for DH production were also gradually replaced by renewables, but at a slower rate compared to the WEO-SD scenarios. While in the WEO-SD scenarios, biofuel HOBs constituted a large share of DH production, in the WEO-NP scenarios they were not cost-efficient. Instead, coal and natural gas CHP dominated the DH supply, limiting industrial EH and solar use. However, in the WEO-NP scenarios, if investment in HPs based on LTH sources was allowed, i.e. in the TransitionDH and FutureDH scenarios, DH development varied. In Germany, ambient temperature HPs significantly limited the use of LTH sources. The reason is that with modest CO_2 restrictions as in the WEO-NP scenario, HPs are more cost-efficient than natural gas and coal CHPs.

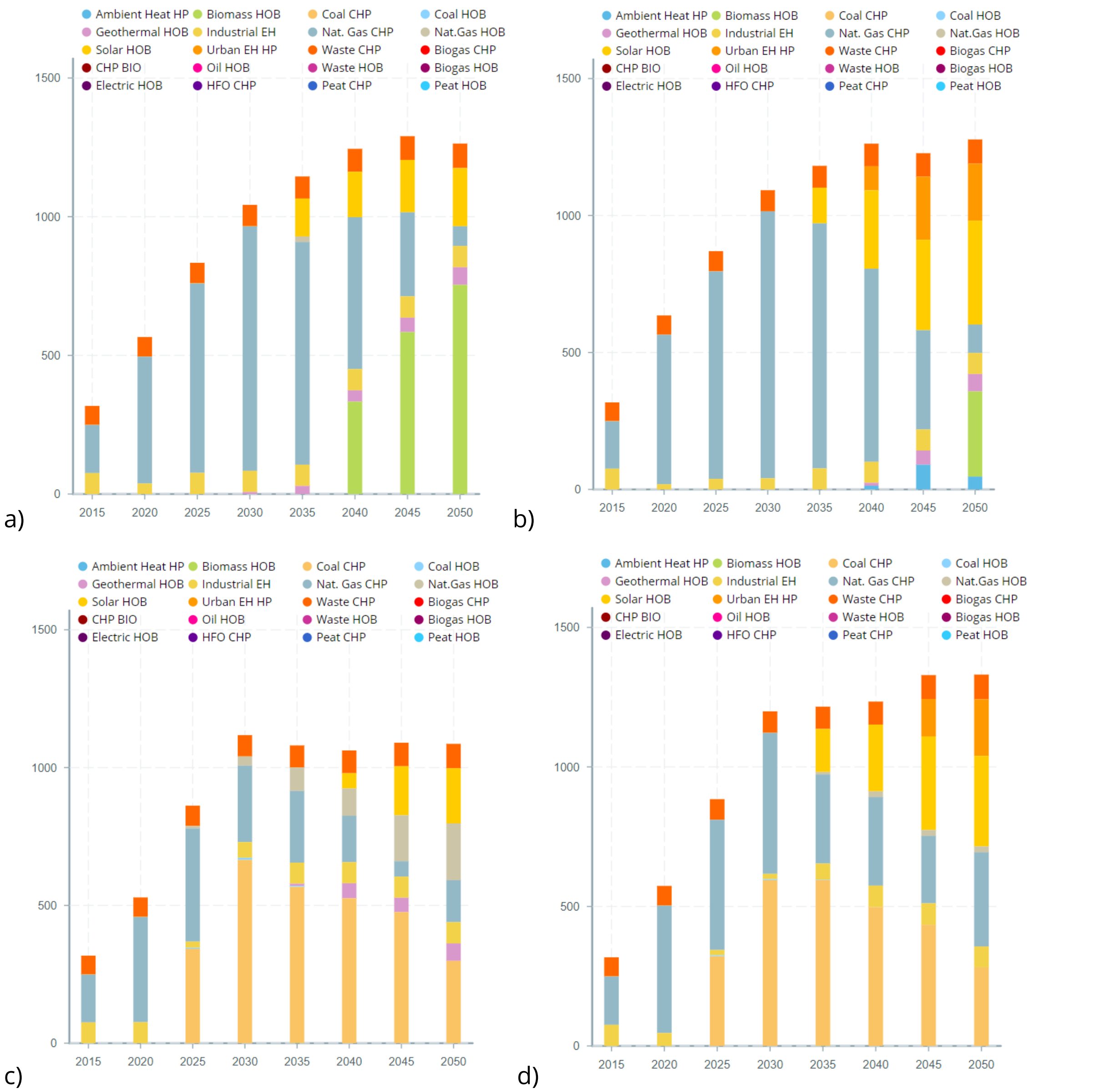
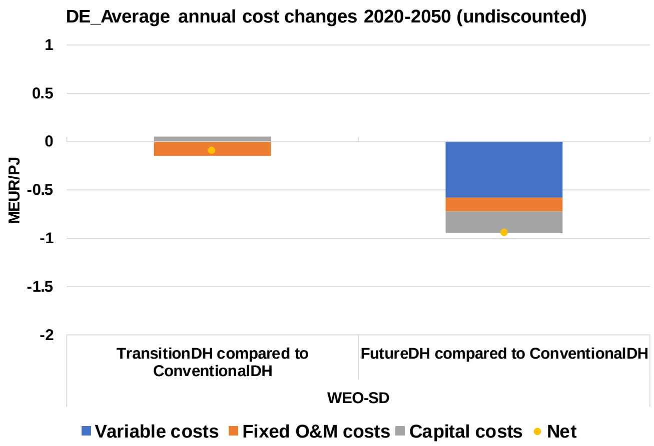


Figure 13 – The generation mix of the heat generation (in PJ) in the German DH sector in the a) ConventionalDH technology development scenario (WEO-SD climate scenario), b) FutureDH technology development scenario (WEO-SD climate scenario), c) ConventionalDH technology development scenario (WEO-NP climate scenario), and d) FutureDH technology development scenario (WEO-NP climate scenario).

5.5 Impact of LTH sources and LTDH on the system cost

Figure 14 shows the differences between the specific, undiscounted variable, fixed O&M, and capital costs of heat supply in the heating sector of Germany in the modelled TransitionDH and Conventional DH technology scenarios, as well as in the FutureDH and Conventional DH technology scenarios. The differences in costs are presented in both WEO-SD and WEO-NP climate scenarios.

It is shown that the specific total system cost decreases as a result of the utilization of the LTH sources (TransitionDH compared to ConventionalDH) and as a result of the development of LTDH networks (FutureDH compared to Conventional DH). In the WEO-SD climate scenario, the LTH sources utilized in large-scale HPs in the TransitionDH and the FutureDH technology scenarios mainly replace biomass HOBs used in the ConventionalDH. In the WEO-NP climate scenario, the LTH sources exploited in the TransitionDH technology development scenario mainly replace natural gas use in CHP plants and in HOBs in the ConventionalDH scenario, resulting in cost reduction in terms of fuel cost (included in the variable cost in Figure 14). The LTH sources utilized in the FutureDH technology development scenario (WEO-NP climate scenario) mainly replace natural gas use in HOBs and geothermal heat in the ConventionalDH, resulting in the variable cost reduction. In addition, utilization of the LTH sources increases the competitiveness of DH investments and DH production compared to investments in and running of individual HPs in the ConventionalDH scenario. Consequently, capital costs increase due to investments costs associated with larger DH infrastructure development.



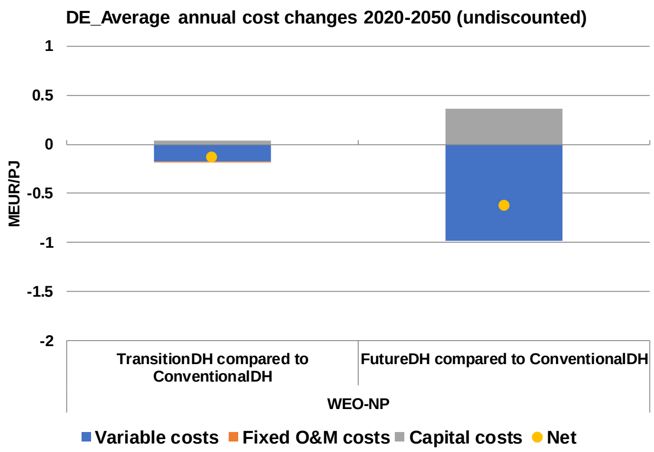


Figure 14 – Differences in the specific annual costs, divided into Variable, Fixed O&M and capital, averaged over the period 2020-2050, as a result of LTH sources use (in TransitionDH and FutureDH) and LTDH (In FutureDH) in the WEO-SD (top) and WEO-NP (bottom) scenarios in Germany.

6 Conclusions

The results of the performed PESTLE analysis indicate that overall, there are more opportunities than barriers for the development of low-temperature district heating and cooling (LTDHC) networks and REWARDHeat solutions in the demonstration countries.

Political section of the analysis indicates that overall, the national targets, set to transform the heating and cooling sectors of the demonstration countries to become more sustainable, acknowledge the concept of LTDHC and provide opportunities for its further development. Only in Sweden, the country with well-established centralized heating, the current national targets seem to continue favoring conventional DHC technology rather than LTDH installations. The ambitious national targets, though, are not yet backed-up with solid state-based financial support schemes necessary to promote the development of innovative technologies, such as REWARDHeat solutions. The predictability of the national development goals was found to be strong in most of the countries and therefore an opportunity for the expansion of LTDHC networks. **To conclude, ambitious national targets should be supported by hands-on state-based support for LTDHC networks to take off.**

Economic factors are opportunities for the development of LTDHC networks in most of the analyzed countries. The results of the performed modelling exercise indicate that the development of LTDH networks, which will effectively utilize low-temperature waste heat and renewable energy sources, will result in lower specific cost of heating in the heating sectors of all the analyzed countries, as compared to the future with only conventional DH networks being developed. The modelling results also indicate that with tighter cap on CO2 emissions the cost-effectiveness of the exploitation of the LTH sources also increases. Hence, in the future with no fossil fuels to resort to and with the cost of carbon being high enough, the utilization of LTH sources is an economically viable solution. However, with great amounts of available industrial excess heat and large potentials of solar and ground energy, the share of cost-effectively utilized LTH sources may become smaller. In addition to the modelling results, the conclusions form the held workshops are that the prices of DHC for the end-users in most of the demonstration countries are competitive to other energy supply options. **To conclude, with the exception of a few key factors being rated as barriers for some of the countries, the whole economic section of the PESTLE analysis indicates that the integration of LTDHC networks into the heating and cooling sectors of the demonstration countries will be economically beneficial to energy consumers as well as to suppliers, while also contribute to the decarbonization of the national energy systems.**

Social aspects show that the opinions and the awareness of the end-users about the LTDHC concept correlates with the country they live in as well as with the type of energy supply they currently have. The opinions of the customers already connected to DH networks are positive about LTDHC in all the countries. However, a number of experts working with DHC indicated during the held workshops that the responses of these customers should not be assumed as applicable to the overall national populations, especially if the share of DH in the heating and cooling sector is currently insignificant as, e.g., in Italy or Croatia. The same is true for the customers' awareness about and cost expectancy from LTDHC. **This indicates that active work directed at educating existing and potential customers about the technology is required for the successful replication of LTDHC networks.** This is something also identified in the ReUseHeat project, which is focused on the demonstration of four low temperature excess heat recovery solutions. From it, we learned that technology is not the bottleneck for LTDH investments. Rather, it is the knowledge about low temperature investments and the ability of stakeholders to arrange themselves into new business constellations that is challenging and that needs further improvement via e.g., research and demonstration projects.

Technical section of the analysis shoes that the suitability of the building stocks in most of the demonstration countries is rated as a barrier for the replication of REWARDHeat solutions. This is because LTDHC networks can be successfully connected to either newly built or substantially refurbished buildings, which together constitute only a small share of the national building stocks. For four out of 7 analyzed countries, technical maturity of the technologies required for centralized heating and cooling was ranked as a barrier. This is the case for the countries with currently underdeveloped DHC networks, such as Germany, Croatia, Italy and the Netherlands. The challenge is to combine the heat pumps technology with the heat sources into new systems: the challenge facing both ReUseHeat and REWARDHeat demo-sites. Nevertheless, for almost all the countries the replicability and standardization of the LTDHC concept was assessed to be viable and hence, an opportunity for further development. **It can be concluded that the technologies necessary to recover and utilize LTH and renewable energy sources are developed and available on the market, although maybe not fully matured in some of the countries, while the demand side is in need of major changes to cope with the supply side.** It is important that both the building side and the energy provider are interested in new, LTDHC solutions.

Legal section provides both opportunities and barriers for LTDHC. National legislations related to buildings and construction are assessed as opportunities in most of the countries. This is mainly because of ambitious EU targets for the energy efficiency of buildings translated into national legal frameworks that require new and refurbished buildings to be low- or zero-energy buildings. These types of buildings are suited for LTDHC. The processes of obtaining permissions, required to develop centralized heating and cooling networks, are categorized as long and unclear in more than half of the countries. The EU Strategy on Heating and Cooling proposed in 2016 provides a framework for integrating efficient heating and cooling into EU energy policies but is written on an overall level, allowing countries to design their own legal heating and cooling frameworks. In some of the analyzed countries, heating and cooling legislative frameworks for DHC are either scarce or nonexistent. In other countries, legislations governing DHC exist but are still weak for LTDHC. As a result, economic incentives are directed to other kinds of investments like, for example, solar energy-based solutions taking the competitive edge out of LTDH investments. To conclude, legislations clearly governing together with clearer and faster permission obtaining process are required in the analyzed counties to support faster and more efficient development of LTDHC networks.

Environmental section shows several opportunities for the development of LTDH networks in the demonstration countries. **The utilization of LTH and renewable energy sources in LTDH networks can result in lowered air pollutant emissions and reduced primary energy use of heat generation, when compared to the operation of conventional DH**. Further, we show that the utilization of LTH sources in large-scale centralized heat pumps can contribute to increased competitiveness of DH compared to individual heating solutions such as boilers, ambient-temperature source and ground-based heat pumps in buildings. This is observed to be especially true for Italy and France, which currently have low DH coverage.

7 References

2015. ES. NACE Rev. 2: Statistical classification of economic activities in the European Community *Downloaded category: NACE_REV2_20150518_163840.csv, (Accessed 2019-12-06).* Luxembourg: Eurostat

2018. ES. RAMON - Reference And Management Of Nomenclatures: Eurostat's Concepts and Definitions Database. Final energy consumption - services (Code B_102035). Available at (http://ec.europa.eu/eurostat/ramon/nomenclatures/). Accessed (2019-12-06). Luxembourg: Eurostat.

AAU 2020. EnergyPlan model. Department of Development and Planning, Aalborg University (https://www.energyplan.eu/useful_resources/existingcountrymodels/).

ADEME 2015. Schéma directeur d'un réseau existant de chaleur et de froid. Guide de realisation.

ADEME 2017a. Excess Heat.

ADEME. 2017b. *Les réseaux de chaleur* [Online]. ADEME. Available: https://www.ademe.fr/expertises/energies-renouvelables-enr-production-reseaux-stockage/passer-a-laction/transport-lenergie/reseaux-chaleur [Accessed 2020].

ADEME. 2020. *Le Fonds Chaleur en bref* [Online]. ADEME. Available: https://www.ademe.fr/expertises/energies-renouvelables-enr-production-reseaux-stockage/passer-a-laction/produire-chaleur/fonds-chaleur-bref [Accessed 2020].

AGFW 2016. Hauptbericht 2015 (In German). Frankfurt (https://www.agfw.de/zahlen-und-statistiken/agfw-hauptbericht/): The German DHC association.

AIRU 2018. The Urban Resale (In Italian: Il Riscaldamento Urbano in Italia nel 2017). Italy: AIRU.

AMANN, M., ANDERL, M., BORKEN-KLEEFELD, J., COFALA, J., HEYES, C., HÖGLUND-ISAKSSON, L., KIESEWETTER, G., KLIMONT, Z., MOOSMANN, L., RAFAJ, P., SANDER, R., SCHÖPP, W., TISTA, M., WAGNER, F. & WINIWARTER, W. 2018. PROGRESS TOWARDS THE ACHIEVEMENT OF THE EU'S AIR QUALITY AND EMISSIONS OBJECTIVES. International Institute for Applied Systems Analysis (IIASA).

ANCIAUX, S. 2019. *Netherlands: Overall Summary* [Online]. RES Legal Europe. [Accessed 22/11 2019].

AUTHORITY FOR CONSUMERS AND MARKETS. 2020. *Levering van warmte* [Online]. Authority for consumers and markets. Available: https://www.acm.nl/nl/onderwerpen/energie/energieleveranciers/levering-van-warmte/ik-wil-warmte-leveren-wat-moet-ik-doen#regels [Accessed 2020].

AXELSSON, E., BERNTSSON, T., HARVEY, S. & HOLM, J. 2018. Utilisation of industrial excess heat from Stenungsund's industries for use in the Gothenburg distrcit heating- Economic and environmental impacts under different scenarios (Nyttjande av industriell restvärme från Stenungsundsindustrierna som fjärrvärme i Göteborg– Ekonomisk och klimatmässig nytta under olika förutsättningar) (In Swedish). Gothenburg (https://chalmersindustriteknik.se/app/uploads/2018/11/Rapport-fjv-fr%C3%A5n-Stenungsund-slutgiltig.pdf).

BHUSHAN, N. & BANU, Z. 2019. *Strategic business choices using pestel and ahp* [Online]. Available: https://triz-journal.com/innovation-best-practices/innovation-general/strategic-business-choices-using-pestel-ahp/ [Accessed 2020].

BOVERKET. 2020. *Översiktsplanen* [Online]. Boverket. Available: https://www.boverket.se/sv/PBL-kunskapsbanken/planering/oversiktsplan/oversiktsplanen/ [Accessed 2020].

BRAND, M. & SVENDSEN, S. 2013. Renewable-based low-temperature district heating for existing buildings in various stages of refurbishment. *Energy,* 62**,** 311-319.
BRÖER, G. 2017. *New subsidy program for 4th generation district heating in Germany* [Online]. Solar District Heating (SDH). Available: https://www.solar-district-heating.eu/new-subsidy-program-for-4th-generation-district-heating-in-germany/#:~:text=The%20German%20Ministry%20for%20Economic,energy%20sources%20or%20waste%20heat. [Accessed 21/11 2019].
BUNDEMINISTERIUM DET JUSTIZ UNDER FÜR VERBRAUCHERSCHUTZ. 2014. *Gesetz für den Ausbau erneuerbarer Energien (Erneuerbare-Energien-Gesetz - EEG 2017)* [Online]. Bundesamt für Justiz. Available: https://www.gesetze-im-internet.de/datenschutz.html [Accessed 2020].
BUNDESMINISTERIUM DER JUSTIZ UND FÜR VERBRAUCHERSCHUTZ 2020. Verordnung über Allgemeine Bedingungen für die Versorgung mit Fernwärme.
BUNDESMINISTERIUM FÜR WIRTSHAFT UND ENERGIE. *Energieeinsparverordnung* [Online]. Bundesministerium für Wirtshaft und Energie. Available: https://www.bmwi.de/Redaktion/DE/Gesetze/Energie/EnEV.html [Accessed 2020].
BÜHLER, F., HOLM, F. M., HUANH, B., ANDREASEN, J. G. & ELMEGAARD, B. Mapping of low temperature heat sources in Denmark. Proceedings of ECOS 2015: 28th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, 2015.
BÜHLER, F., PETROVIC, S., KARLSSON, K. & ELMEGAARD, B. 2017. Industrial excess heat for district heating in Denmark. *Applied Energy,* 205**,** 991-1001.
ĆETKOVIĆ, S. 2019. *Croatia: Overall Summary* [Online]. RES LEGAL Europe. [Accessed 20/11 2019].
COMMISSION DE RÉGULATION DE L'ÉNERGIE. 2020. *CE QU'IL FAUT SAVOIR POUR COMPRENDRE L'AUTOCONSOMMATION* [Online]. Commission de Régulation de L'énergie. Available: http://autoconsommation.cre.fr/ce-qu-il-faut-savoir.html [Accessed].
CONCERTED ACTION EPBD. 2017. *What is the CA EPBD* [Online]. Available: http://www.epbd-ca.eu/ [Accessed 8/2 2017].
CONNOLLY, D., LUND, H., MATHIESEN, B. V., WERNER, S., MÖLLER, B., PERSSON, U., BOERMANS, T., TRIER, D., ØSTERGAARD, P. A. & NIELSEN, S. 2014. Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. *Energy Policy,* 65**,** 475-489.
CORRADO, V., BALLARINI, I., PADUOS, S. & TULIPANO, L. 2017. A new procedure of energy audit and cost analysis for the transformation of a school into a nearly zero-energy building. *Energy Procedia,* 140**,** 325-338.
DALENBÄCK, J.-O., LENNERMO, G., ANDERSSON-JESSEN, P.-E. & KOVACS, P. 2013. Solvärme i fjärrvärmesystem- Utvärdering av primärkopplade system.
DANISH ENERGY AGENCY 2015. Regulation and planning of district heating in Denmark.
DANISH ENERGY AGENCY 2017. ENERGY STATISTICS 2016- Data, tables, statistics and maps.
DANISH ENERGY AGENCY 2018. Energy Agreement 2018- Greener heating.
DANISH ENERGY AGENCY 2019. Denmark's Energy and Climate Outlook.
DANSK FJERNVARME 2016. Heat generation in Denmark.
DEA 2018. Socio-economic calculation assumptions for energy prices and emissions (Samfundsøkonomiske beregningsforudsætninger for energipriser og emissioner: in Danish). Copenhagen, Denmark: Danish Energy Agency.

DEA 2019. Technology Data for Energy Plants for Electricity and District heating generation. Denmark (https://ens.dk/en/our-services/projections-and-models/technology-data): Danish Energy Agency.

DEUTSCHES ZENTRUM FÜR LUFT- UND RAUMFAHRT, ÖKO-INSTITUT; INSTITUT FÜR ZUKUNFTS ENERGIE SYSTEME, FRAUNHOFER INSTITUT & BREMER ENERGIE INSTITUT 2009. Ergänzende Untersuchungen und vertiefende Analysen zu möglichen Ausgestaltungsvarianten eines.

DUMAS, P. & BARTOSIK, A. 2014. D2.2 Geothermal DH Potential in Europe.

EC 2016. EU Reference Scenario 2016, EU ENERGY, TRANSPORT AND GHG EMISSIONS - TRENDS TO 2050. Luxembourg: European Commission.

ENERGIBUREAUET 2020. Rapport: Kommuner og regioners arbejde med klimamål og energieffektivisering.

ENERGIFORSK 2016. Fjärrsyn: Ny kunskap till nytta i det praktiska arbetet. Energiforsk.

ENERGIFÖRETAGEN 2019. Tillförd energi till kraftvärme och fjärrvärmeproduktion och fjärrvärmeleveransen 2018.

ENERGIFÖRETAGEN. 2020a. *Fjärrvärme* [Online]. Energiföretagen. Available: https://www.energiforetagen.se/energifakta/fjarrvarme/ [Accessed 2020].

ENERGIFÖRETAGEN. 2020b. *Fjärrvärmeproduktion* [Online]. Energiföretagen. Available: https://www.energiforetagen.se/energifakta/fjarrvarme/fjarrvarmeproduktion/ [Accessed 2020].

ENERGIMARKNADSINSPEKTIONEN. 2016. *Fjärrvärme* [Online]. Energimarknadsinspektionen. Available: https://www.ei.se/sv/for-energikonsument/fjarrvarme/ [Accessed 2020].

ENERGIMARKNADSINSPEKTIONEN. 2020. *Lagar och regler* [Online]. Energimarknadsinspektionen. Available: https://www.ei.se/sv/ei-s-verksamhet/lagar-regler/ [Accessed 2020].

ENERGIMYNDIGHETEN. 2017. *Nära-nollenergibyggnader* [Online]. Energimyndigheten. Available: http://www.energimyndigheten.se/energieffektivisering/program-och-uppdrag/nara-nollenergibyggnader/ [Accessed 8/2 2017].

ENERGIMYNDIGHETEN 2019. Energiläget i siffror 2019.

EPM. 2018. *IFE & EFE Matrices* [Online]. Available: https://expertprogrammanagement.com/2017/01/competitive-profile-matrix-cpm/ [Accessed 2020].

ERBS POULSEN, S., BJORN, H., MATHIESEN, A., NIELSE, L. H., VOSGERAU, H., VANGKILDE-PEDERSEN, T., DITLEFSEN, C. & ROGEN, B. 2019. Geothermal Energy Use, Country Update for Denmark. *European Geothermal Congress 2019.* Den Haag.

ERHORN, H. & ERHRON-KLUTTIG, H. 2015. Overview of national applications of the Nearly Zero-Energy Building (NZEB) definition - Detailed report.

ETSAP. *Energy technology systems analysis Program* [Online]. http://www.etsap.org/index.asp. [Accessed].

EU SCIENCE HUB. 2019. *Renewable energy- Recast to 2030 (RED II)* [Online]. EU Science Hub. Available: https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii [Accessed 14/8 2020].

EUR-LEX. 2009. *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources* [Online]. [Accessed].

EUR-LEX. 2010. *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings* [Online]. [Accessed].

EUROBSERV'ER CONSORTIUM 2018. The state of renewable energies in Europe Edition 2018.
EUROHEAT & POWER. 2017. *Country Profiles* [Online]. EuroHeat & Power. Available: https://www.euroheat.org/knowledge-hub/country-profiles/ [Accessed 2020].
EUROPEAN COMMISSION. 2012. *Energy topics* [Online]. European Commission. Available: https://ec.europa.eu/energy/topics_en [Accessed].
EUROPEAN COMMISSION. 2014. *Renewable energy directive* [Online]. European Commission. [Accessed 8/2 2017].
EUROPEAN COMMISSION 2016. An EU Strategy on Heating and Cooling- Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions.
EUROPEAN COMMISSION. 2019a. *Climate strategies & targets* [Online]. European Commission. Available: https://ec.europa.eu/clima/policies/strategies_en [Accessed 15/11 2019].
EUROPEAN COMMISSION 2019b. Communication from the commission to the European parliament, the European council, the council, the European economic and social committee and the committee of the regions- The Europan green deal.
EUROPEAN COMMISSION. 2019c. *Energy efficiency directive- The 2012 energy efficiency directive* [Online]. Available: https://ec.europa.eu/energy/topics/energy-efficiency/targets-directive-and-rules/energy-efficiency-directive_en [Accessed 14/8 2020].
EUROPEAN COMMISSION. 2019d. *Energy performance of buildings directive* [Online]. European Commission. Available: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en [Accessed 14/8 2020].
EUROPEAN COMMISSION. 2020a. *EU taxonomy for sustainable activities* [Online]. Available: https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en [Accessed 2020].
EUROPEAN COMMISSION. 2020b. *International action on climate change- Paris Agreement* [Online]. European Commission. Available: https://ec.europa.eu/clima/policies/international/negotiations/paris_en [Accessed 15/11 2019].
EUROPEAN COMMISSION. 2020c. *National energy and climate plans (NECPs)* [Online]. European commission. Available: https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en [Accessed 23/6 2020].
EUROSTAT. 2019a. *Cooling and heating degree days by country - annual data (database)* [Online]. Eurostat. Available: https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do [Accessed 26/11 2019].
EUROSTAT. 2019b. *Final energy consumption by product* [Online]. Eurostat. Available: https://ec.europa.eu/eurostat/databrowser/view/ten00123/default/table?lang=en [Accessed 23/4 2019].
EUROSTAT 2019c. Population on 1 January 2019-06-06 ed.: Eurostat.
EUROSTAT. 2019d. *Share of energy from renewable sources* [Online]. EuroStat. Available: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_ind_ren&lang=en [Accessed 2020].
EUROSTAT 2020a. Energy, transport and environment statistics. Luxembourg: Publications Office of the European Union.
EUROSTAT 2020b. Natural gas price statistics (nrg_pc_202). Eurostat.
FEDENE 2018. National survey on heating and cooling networks (In French, Enquête nationale sur les réseaux de chaleur et de froid). Paris (https://www.fedene.fr/wp-

content/uploads/sites/2/2019/08/Restitution-enquete-2016-donnees-2015-final.pdf): The French environmental ministry (Fedene).
FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY. 2017. *Innovation in the heating market: funding for fuel cells will be expanded and 4th generation heating networks will be particularly promoted* [Online]. Federal Ministry for Economic Affairs and Energy. Available: https://www.bmwi.de/Redaktion/EN/Pressemitteilungen/2017/20170630-bmwi-setzt-auf-brennstoffzellenfoerderung.html [Accessed 30/6 2017].
FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY 2018. 7th Energy Research Programme of the Federal Government- Innovations for the Energy Transition.
FEDERAL MINISTRY FOR THE ENVIRONMENT 2016. Climate Action Plan 2050.
FINANCIAL STABILITY, F. S. A. C. M. U. 2020a. *The European Green Deal Investment Plan and Just Transition Mechanism* [Online]. European Commission. Available: https://ec.europa.eu/info/publications/200114-european-green-deal-investment-plan_en [Accessed 28/2 2020].
FINANCIAL STABILITY, F. S. A. C. M. U. 2020b. *Renewed sustainable finance strategy and implementation of the action plan on financing sustainable growth* [Online]. European Commission. Available: https://ec.europa.eu/info/publications/sustainable-finance-renewed-strategy_en [Accessed 2020].
FLEITER, T., ELSLAND, R., REHFELDT, M., STEINBACH, J., REITER, U., CATENAZZI, G., JAKOB, M., HARMSEN, R., RUTTEN, C., DITTMANN, F., RIVIÉRE, P. & STABAT, P. 2017. Profiles and Baselines for heating and cooling energy demands in 2015 for EU28 countries.
FORSYNINGSTILSYNET 2020. PRISSTATISTIK FOR FJERNVARMESELSKABER PR. JANUAR 2020.
GADD, H. 2014. To analyse measurements is to know!
GALINDO FERNÁNDEZ, M., ROGER-LACAN, C., GÄHRS, U. & AUMAITRE, V. 2019. Efficient district heating and cooling systes in the EU.
GEHLIN, S. & ANDERSSON, O. 2019. Geothermal Energy Use, Country Update for Sweden.
GOVERNMENT OF THE NETHERLANDS 2019. Climate Agreement.
HOFMAN, E. 2015. Social Acceptance of Renewable Energy.
HRVATSKA ENERGETSKA REGULATORNA AGENCIJA 2014. OPĆE UVJETE ZA ISPORUKU TOPLINSKE ENERGIJE.
HÖGSKOLAN HALMSTAD. 2020. *Lågtempererad fjärrvärme hållbar lösning på framtidens värmebehov* [Online]. Högskolan Halmstad. Available: https://samspel.hh.se/artiklar/2020-03-09-lagtempererad-fjarrvarme-hallbar-losning-pa-framtidens-varmebehov.html [Accessed 2020].
IEA 2017. World Energy Outlook 2017, Scenario analysis of future energy trends. https://www.iea.org/weo2017/: International Energy Agency.
IIASA. 2018. *The GAINS Model* [Online]. Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA). Available: https://iiasa.ac.at/web/home/research/researchPrograms/air/GAINS.html [Accessed January 2021].
INFORMATIONSDIENST, B. 2010. *Neue Kraftwerke mit fossilen brennstoffen* [Online]. BINE Informationsdienst. Available: http://www.bine.info/fileadmin/content/Publikationen/Themen-Infos/II_2010/themen_II10_internetx.pdf [Accessed].

INTERNATIONAL ENERGY AGENCY. 2019a. *Addressing Climage Change Database* [Online]. Available: https://www.iea.org/policiesandmeasures/climatechange/ [Accessed 20/11 2019].

INTERNATIONAL ENERGY AGENCY 2019b. Statistics data browser. International Energy Agency.

INTERNATIONAL ENERGY AGENCY 2020. Global Renewable Energy Policies and Measures Database. IEA/IRENA

ITALIAN MINISTRY OF ECONOMIC DEVELOPMENT. 2015. *Decreto Ministeriale 26 Giugno 2015* [Online]. Tratto da Gazzetta Ufficiale della Repubblica. Available: https://www.gazzettaufficiale.it/eli/id/2015/07/15/15A05198/sg [Accessed].

ITALIAN PARLIAMENT. 2005. *Legislative Decree August 19, 2005, No. 192* [Online]. Tratto da Gazzetta Ufficiale della Repubblica Italiana. Available: https://www.gazzettaufficiale.it/eli/id/2005/09/23/005G0219/sg [Accessed].

ITALIAN PARLIAMENT. 2011. *DECRETO LEGISLATIVO 3 marzo 2011, n. 28* [Online]. Tratto da Gazzetta Ufficiale della Repubblica Italiana. Available: https://www.gazzettaufficiale.it/eli/id/2011/03/28/011G0067/sg [Accessed].

ITALIAN PARLIAMENT. 2016. *232/2016 - Italian Budget Law for Year 2017* [Online]. Tratto da Gazzetta Ufficiale della Repubblica Italiana. Available: https://www.gazzettaufficiale.it/eli/id/2016/12/21/16G00242/sg [Accessed 21/12 2016].

ITALIAN PARLIAMENT. 2020. *DECRETO-LEGGE 19 maggio 2020, n. 34* [Online]. Tratto da Gazzetta Ufficiale della Repubblica Italiana. Available: https://www.gazzettaufficiale.it/eli/id/2020/05/19/20G00052/sg [Accessed].

IVL SWEDISH ENVIRONMENTAL RESEARCH INSTITUTE 2019. D2.3 – Macro-market analysis, value chain and conceptual business models.

IVL SWEDISH ENVIRONMENTAL RESEARCH INSTITUTE 2020. Underlag till energistrategi.

JENNY GODE, FREDRIK MARTINSSON, LINUS HAGBERG, ANDREAS ÖMAN, JONAS HÖGLUND & PALM, D. 2011. Miljöfaktaboken 2011 Estimated emission factors for fuels, electricity, heat and transport in Sweden (in Swedish). Stockholm (https://energiforskmedia.blob.core.windows.net/media/17907/miljoefaktaboken-2011-vaermeforskrapport-1183.pdf): Värmeforsk.

JESSEN, K. 2015. DISTRICT HEATING in The Danish Energy System.

JUREVICIUS, O. 2014. *IFE & EFE Matrices* [Online]. Available: https://strategicmanagementinsight.com/tools/ife-efe-matrix.html [Accessed 2020].

KAARUP OLSEN, P., HOLM CHRISTIANSEN, C., HOFMEISTER, M., SVENDSEN, S. & THORSEN, J.-E. 2014. Guidelines for Low-Temperature District Heating.

KL. 2020. *Et ensartet måleværktøj for alle kommuner* [Online]. KL. Available: https://www.kl.dk/tema/klima/hvad-goer-kommunerne/case-et-ensartet-maalevaerktoej-for-alle-kommuner/ [Accessed 2020].

KLIMA INITIATIVE 2019. Abschlussbericht Rahmenbedingungen für Nahwärmenetze.

KLUGMAN, S., NILSSON, J., NILSSON, A., UNLUTURK, B., LYGNERUD, K. & STRAND, A. 2020. D3.1 Report on current barriers to industrial WH/C recovery and exploitation.

KRKLEC, R. 2015. Toplinska energija i OIE, Planovi i barijere.

LINDAHL, M., BENSON, J., WALFRIDSON, T., MARKUSSON, C., RÄFTEGÅRD, O. & GUSTAFSSON, O. 2018. Värmepumpar i fjärrvärmesystem.

LUND, H., MÖLLER, B., MATHIESEN, B. V. & DYRELUND, A. 2010. The role of district heating in future renewable energy systems. *Energy,* 35, 1381-1390.

LUND, R. & HANSEN, K. 2019. ReUseHeat_Deliverable 1.5 (Urban excess heat utilization in future energy systems). Denmark: Aalborg University.
LUTSCH, R. & WERNER, S. 2017. District Heating in Europe and Germany.
M. GARGIULO 2009. Getting Started with TIMES-veda, Version 2.7, . Energy Technology Systems Analysis Program (ETSAP).
MANZELLA, A., SERRA, D., CESARI, G., BARGIACCHI, E., CEI, M., CERUTTI, P., CONTI, P., GIUDETTI, G., LUPI, M. & VACCARO, M. 2019. Geothermal Energy Use, Country Update for Italy.
MARAS, H. & ŠIMEK, T. 2018. D1.2 Energy Policy Baseline Country Report: CROATIA.
MATHIESEN, B. V., BERTELSEN, N., SCHNEIDER, N. C. A., GARCÍA, L. S., PAARDEKOOPER, S., THELLUFSEN, J. Z. & DJØRUP, S. R. 2019. Towards a decarbonised heating and cooling sector in Europe: Unlocking the potential of energy efficiency and district energy. Aalborg University.
MINISTARSTVO GRADITELJSTVA I PROSTORNOGA UREĐENJA 2018. EHNIČKI PROPIS O IZMJENAMA I DOPUNAMA TEHNIČKOG PROPISA O RACIONALNOJ UPORABI ENERGIJE I TOPLINSKOJ ZAŠTITI U ZGRADAMA.
MINISTARSTVO GRADITELJSTVA I PROSTORNOGA UREDNJA 2017. Faktori primarne energije i emisija CO2.
MINISTARSTVO GRADITELJSTVA I PROSTORNOGA UREDNJA 2018. Program poticanja gradnje novih i obnavljanja postojećih zgrada do standarda gotovo nulte energije.
MINISTARSTVO ZAŠTITE OKOLIŠA I ENERGETIKE 2019. Integrirani nacionalni energetski i klimatski plan za Republiku Hrvatsku.
MINISTÉRE DE LA TRANSITION ÉCOLOGIQUE ET SOLIDAIRE 2019. The Multiannual Energy Plan.
MINISTERIUM FÜR UMWELT KLIMA UND ENERGIEWIRTSCHAFT BADEN-WÜRTTEMBERG. 2008. *Erneuerbare-Wärme-Gesetz* [Online]. Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg. Available: https://um.baden-wuerttemberg.de/de/energie/neubau-und-gebaeudesanierung/erneuerbare-waerme-gesetz-2008/ [Accessed 2020].
MINISTERIUM FÜR UMWELT KLIMA UND ENERGIEWIRTSCHAFT BADEN-WÜRTTEMBERG. 2015. *Erfüllungsoptionen für Wohngebäude* [Online]. Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg. Available: https://um.baden-wuerttemberg.de/de/energie/neubau-und-gebaeudesanierung/erneuerbare-waerme-gesetz-2015/erfuellungsoptionen-wohngebaeude/#:~:text=Das%20Erneuerbare%2DW%C3%A4rme%2DGesetz%20(,sobald%20sie%20ihre%20Heizungsanlage%20austauschen.&text=Wohngeb% [Accessed 2020].
MINISTRY OF ECONOMIC AFFAIRS 2017. Energy Agenda - Towards a low-carbon energy supply.
MOE 2015. Programme of Exploiting Heating and Cooling Efficiency Potential for 2016-2030. Ministry of the Economy (https://ec.europa.eu/energy/sites/ener/files/documents/croatia_report_eed_art_141update_en.pdf).
MUSEC, M. & KANCELJAK, M. 2019. *2019 Amendments of the Croatian Renewables Act* [Online]. CEE Legal Matters. Available: https://ceelegalmatters.com/croatia/10830-2019-amendments-of-the-croatian-renewables-act [Accessed 6/12 2019].
MÜNSTER, M., MORTHORST, P. E., LARSEN, H. V., BREGNBÆK, L., WERLING, J., LINDBOE, H. H. & RAVN, H. 2012. The role of district heating in the future Danish energy system. *Energy,* 48**,** 47-55.

NATIONAL INSTITUTE FOR PUBLIC HEALTH AND THE ENVIRONMENT. 2017. *Regelgeving stoffen in het binnenmilieu : In Nederland en andere EU-landen. Een verkennende studie* [Online]. National Institute for Public Health and the Environment. Available: https://www.rivm.nl/publicaties/regelgeving-stoffen-in-binnenmilieu-in-nederland-en-andere-eu-landen-verkennende-studie [Accessed 2020].
NETHERLANDS ENTERPRISE AGENCY. 2020. *Energy Investment Allowance - EIA* [Online]. Netherlands Enterprise Agency. Available: https://english.rvo.nl/subsidies-programmes/energy-investment-allowance-eia [Accessed 22/11 2019].
NIELSEN, S., HANSEN, K., LUND, R. & MORENO, D. 2020. Unconventional Excess Heat Sources for District Heating in a National Energy System Context. *Energies,* 13**,** 1-18.
NIESSINK, R. & RÖSLER, H. 2015. Development of Heat Distribution Networks in the Netherlands.
OBSERV'ER 2018. THE STATE OF RENEWABLE ENERGIES IN EUROPE. Paris: Observ'ER (https://energy.nl/wp-content/uploads/2019/06/EurObservER-The-State-of-RES-in-Europe-2018-v3.pdf).
ODGAARD, O. 2016. District heating and integration of wind power in Denmark.
ODYSSEE-MURE. 2019. *Country profiles (Database)* [Online]. Odyssee -Mure. Available: https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/ [Accessed 5/12 2019].
OPSD 2019. Data Platform_ When2Heat Heating Profiles. https://data.open-power-system-data.org/when2heat/2019-08-06.
PAARDEKOOPER, S., LUND, R. S., MATHIESEN, B. V. & CHANG, M. 2018a. Heat Roadmap Germany-Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps.
PAARDEKOOPER, S., LUND, R. S., MATHIESEN, B. V. & CHANG, M. 2018b. Heat Roadmap Italy-Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps.
PAARDEKOOPER, S., LUND, R. S., MATHIESEN, B. V. & CHANG, M. 2018c. Heat Roadmap Netherlands- Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps.
PAARDEKOOPER, S., LUND, R. S., MATHIESEN, B. V., CHANG, M., PEDERSEN, U. R., GRUNDAHL, L., DAVID, A., DAHLBAEK, J., KAPETANAKIS, I. A., LUND, H., BERTELSEN, N., HANSEN, K., DRYSDALE, D. W. & PERSSON, U. 2018d. Heat Roadmap Sweden: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps.
PAARDEKOOPER, S., LUND, R. S., MATHIESEN, B. V., CHANG, M., PETERSEN, U. R., GRUNDAHL, L., DAVID, A., DAHLBÆK, J., KAPETANAKIS, I. A., LUND, H., BERTELSEN, N., HANSEN, K., DRYSDALE, D. W. & PERSSON, U. 2018e. *Main Report and Heat Roadmaps by Country* [Online]. https://heatroadmap.eu/roadmaps/: Main Report and Heat Roadmaps by Country. [Accessed 2020].
PAARDEKOOPER, S., LUND, R. S., MATHIESEN, B. V., CHANG, M., PETERSEN, U. R., GRUNDAHL, L., DAVID, A., DAHLBAEK, J., KAPETANAKIS, I. A., LUND, H., BERTELSEN, N., HANSEN, K., DRYSDALE, D. W. & PERSSON, U. 2018f. Heat Roadmap France- Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps.
PAASKE, B. 2015. Lavtemperatur fjernvarme i forhold til varmepumper (Low temperature district heating in relation to heatpumps).
PAPAPETROU, M., KOSMADAKIS, G., CIPOLLINA, A., LA COMMARE, U. & MICALE, G. 2018a. Industrial waste heat: Estimation of the technically available resource in the. *Applied Thermal Engineering,* 138.
PAPAPETROU, M., KOSMADAKIS, G., CIPOLLINA, A., LA COMMARE, U. & MICALE, G. 2018b. Industrial waste heat: Estimation of the technically available resource in the EU per

industrial sector, temperature level and country. *Applied Thermal Engineering,* 138**,** 207-216.
PARRA-LOPEZ, C., SAYADI-GMADA, S. & DURAN-ZUAZO, V. H. Production and use of biomass from short-rotation plantations in Andalusia, southern Spain: limitations and opportunities. *New Medit,* 14.
PERSSON, U. 2013. European potential of waste heat recovery via district heating.
PERSSON, U. 2015. Quantifying the Excess Heat Available for District Heating in Europe.
PERSSON, U. 2018. D1.4: Accessible urban waste heat. Halmstad: Halmstad University of Technology.
PERSSON, U. & AVERFALK, H. 2018. D1.4 Accessible urban waste heat.
PERSSON, U., WIECHERS, E., MÖLLER, B. & WERNER, S. 2019. Heat Roadmap Europe: Heat distribution costs. *Energy,* 176**,** 604-622.
PETA4.3. 2018. *Pan-European Thermal Atlas Peta Version 4.3, Europa-Universität Flensburg, ArcGIS Online. Heat Roadmap Europe - A low-carbon heating and cooling strategy for Europe.* [Online]. https://heatroadmap.eu/peta4/. [Accessed].
PLANENERGI. 2019. *Solar district heating* [Online]. PlanEnergi. Available: http://planenergi.eu/activities/district-heating/solar-district-heating/1-gw-sdh-in-dk/ [Accessed 11/11 2019].
POŽAR, H. 2015. Program korištenja potencijala za učinkovitost u grijanju i hlađenju za razdoblje 2016. – 2030.
PRISDIALOGEN. 2020. *Så fungerar det* [Online]. Prisdialogen. Available: http://www.prisdialogen.se/sa-fungerar-det/ [Accessed 2020].
PROVOOST, M., ALBEDA, L., GODSCHALK, B., VAN DER WERFF, B. & SCHOOF, F. 2019. Geothermal Energy Use, Country Update for The Netherlands.
PUKSEC, T. & DUIC, N. 2016. D2.5 Framework conditions DHC in Croatia and Ozal.
R2M 2020. D8.1 Market & PESTLE analysis.
REGERINGEN 2020. Markante drivhusgasreduktioner og investeringer i den grønne omstilling.
REHVA. 2020. *Renewable Energy Directive (RED, RED II)* [Online]. REHVA. Available: https://www.rehva.eu/eu-policy/renewable-energy-directive-red-red-ii [Accessed 14/8 2020].
REPUBLIC OF CROATIA MINISTRY OF ENVIRONMENT AND ENERGY 2018. Energy in Croatia - Annual Energy Report.
RESEAUX DE CHALEUR ET TERRITOIRES. 2018. *District heating and cooling in France* [Online]. Reseaux de Chaleur et Territoires. Available: http://reseaux-chaleur.cerema.fr/district-heating-and-cooling-in-france [Accessed 25/11 2019].
RÉSEAUX DE CHALEUR ET TERRITOIRES. 2013. *Classer un réseau de chaleur ou de froid : guide pratique et FAQ* [Online]. Réseaux de chaleur et territoires. Available: http://reseaux-chaleur.cerema.fr/classer-un-reseau-de-chaleur-ou-de-froid-guide-pratique-et-faq [Accessed].
RÉSEAUX DE CHALEUR ET TERRITOIRES. 2014. *Aide à l'élaboration d'un dossier Titre V Réseaux de chaleur/froid* [Online]. Réseaux de chaleur et territoires. Available: http://reseaux-chaleur.cerema.fr/aide-titre-v-reseaux-de-chaleur [Accessed 2020].
REZAIE, B. & ROSEN, M. A. 2012. District heating and cooling: Review of technology and potential enhancements. *Applied Energy,* 93**,** 2-10.
RIISGAARD PEDERSEN, B. 2017. District Heating in Denmark- The development from fossil fuels to green fuels and green electricity.

RUIZ, P., SGOBBI, A., NIJS, W., THIEL, C., LONGA, F. D., KOBER, T., ELBERSEN, B. & HENGEVELD, G. 2015. The JRC-EU-TIMES model. Bioenergy potentials for EU and neighbouring countries. Luxembourg: European Union.

RUTZ, D., WINTERSHEID, C., PAUSCHINGER, T., GRIMM, S., ROTH, T., DORAČIĆ, B., DYER, G., A. ØSTERGAARD, T. & HUMMELSHOJ, R. 2019. Upgrading the performance of district heating networks- A handbook.

RÄMÄ, M., LINDROOS, T. J., SVENDSEN, S., ØSTERGAARD, D. S., TUNZI, M., SANDVALL, A. & HOLMGREN, K. 2020. Stepwise transition strategy and impact assessment for future district heating systems. https://www.iea-dhc.org/home: IEA DHC/CHP.

SALVUCCI, R., GARGIULO, M. & KARLSSON, K. 2019. The role of modal shift in decarbonising the Scandinavian transport sector: Applying substitution elasticities in TIMES-Nordic. *Applied Energy,* 253, 113593.

SANDVALL, A., HAGBERG, M. & LYGNERUD, K. 2021. Modelling of urban excess heat use in district heating systems. *Energy Strategy Reviews,* 33, 100594.

SCABELL, C., ECHTERNACHT, L., RECKHAUS, H., MANIRJO, N. & BERG , H. 2015. Regime analysis of stability and tensions in incumbent socio-technical regimes - Regime analysis of the German heat system.

SCHMELA, M. 2018. Global Market Outlook- For Solar Power 2018-2022.

SCHMIDT, D., KALLERT, A., BLESL, M., SVENDSEN, S., LI, H., NORD, N. & SIPILÄ, K. 2017. Low Temperature District Heating for Future Energy Systems. *Energy Procedia,* 116, 26-38.

SCHWARZ, J. 2019. *Italy: Overall summary* [Online]. RES LEGAL Europe. Available: http://www.res-legal.eu/search-by-country/italy/ [Accessed 21/11 2019].

SHELL. 2017. *EINSATZ VON ERDGAS IN KOHLEKRAFTWERKEN – EINE REALISTISCHE OPTION FÜR DEN KLIMASCHUTZ?* [Online]. Available: https://www.shell.de/medien/shell-presseinformationen/2017/use-of-natural-gas-in-coal-power-plants-a-realistic-option-for-climate-protection.html [Accessed 9/5 2017].

SKÖLDBERG, H. & RYDÉN, B. 2014. The heating market in Sweden- an overall view.

SNODIN, H. & GARSIDE, C. 2019. INTERNATIONAL HEAT NETWORKS Market frameworks research – Regulatory document review.

SOLAR DISTRICT HEATING. 2019. *Solar District Heating- Förnybar utsläppsfri värme* [Online]. Solar district heating. Available: http://solar-district-heating.se/ [Accessed 12/11 2019].

SOLARGIS 2020. Solar resource maps. SOLARGIS.

STATE OF GREEN 2018. District energy- Energy efficiency for urban areas.

STATE OF GREEN. 2020. *Solar thermal energy* [Online]. State of Green. Available: https://stateofgreen.com/en/sectors/clean-energy-sources-sector/solar-energy/solar-thermal-energy/ [Accessed 11/11 2019].

STERNKOPF, T. 2019. *Germany: Overall Summary* [Online]. RES LEGAL Europe. [Accessed 11/1 2019].

STORM SIMONSEN, J. 2020. *Mangler redskaber til at styrke grøn omstilling: Kommuner efterspørger bedre rammevilkår* [Online]. CSR. Available: https://csr.dk/mangler-redskaber-til-styrke-gr%C3%B8n-omstilling-kommuner-eftersp%C3%B8rger-bedre-rammevilk%C3%A5r [Accessed].

SVEUČILIŠTE U ZAGREBU FAKULTET STROJARSTVA I BRODOGRADNJE 2017. Algoritam za proračun potrebne energije za grijanje i hlađenje prostora zgrade prema HRN EN ISO 13790.

THE GOVERNMENT OF SWEDEN. 2019. *Sweden's carbon tax* [Online]. The Government of Sweden. Available: https://www.government.se/government-policy/taxes-and-tariffs/swedens-carbon-tax/ [Accessed 3/12 2019].
UMWELT BUNDESAMT. 2019. *Erneuerbare-Energien-Gesetz* [Online]. Umwelt Bundesamt. Available: https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-gesetz#erfolg [Accessed 2020].
UNICEF 2015. SWOT and PESTEL.
UNION, T. E. 2021. *2030 climate & energy framework* [Online]. Available: https://ec.europa.eu/clima/policies/strategies/2030_en [Accessed 2.february 2021].
VAN ECK, H. 2016. EPBD Implementation in The Netherlands - Status in December 2016.
WEBER, J., BORN, H. & MOECK, I. 2019. Geothermal Energy Use, Country Update for Germany 2016 - 2018.
WERNER, S. 2017. District heating and cooling in Sweden. *Energy,* 126.
WERNER, S. & DALENBÄCK, J.-O. 2012. Market for solar district heating.
VON ULRICH, F. Umbau: VW-Kraftwerke verfeuern künftig Gas2018. *Wolfsburger Allgemeine Zeitung*, 2018-03-08.
VÅGERÖ, O. 2019. *Sweden: Summary* [Online]. RES LEGAL Europe. Available: http://www.res-legal.eu/search-by-country/sweden/summary/c/sweden/s/res-e/sum/200/lpid/199/ [Accessed 21/11 2019].
ŽIVKOVIĆ, S., KOLBAH, S., ŠKRLEC, M. & TUMARA, D. 2019. Geothermal Energy Use, Country Update for Croatia.
ÅBERG, M., FÄLTING, L., CARLSSON, J., JOHANSSON, L., FORSELL, A., WIDÉN, J., NILSSON, A., MUNKHAMMAR, J. & LINGFORS, D. 2017. Nya lösningar för fjärrvärme i miljonprogramsområden.

8 Annex: Heating and cooling in the EU

This section provides an overview of the policies and targets relating to heating and cooling that can impact the scalability and replicability of low temperature DH networks with waste heat and renewable energy integration that are implemented at EU level and thus effect all the membership countries. The section also provides an overview of the heating and cooling supply and demand within the EU with a focus towards DH and cooling, renewable energy sources and waste heat.

Table 4 – Share of renewable energy in total energy, HC, electricity and transport in 2017 (EuroStat, 2019d)

	RES in energy	RES in HC	RES in electricity	RES in transport
EU28	17.5%	19.5%	30.7%	7.4%

8.1 Climate and energy

In December 2015, at the Paris climate conference (COP21), 195 countries agreed on a global climate deal with the long-term goal to limit the increase in global average temperature well below 2°C, compared to pre-industrial levels. The goal under the Paris Agreement is for the global average temperature to increase by maximum 1.5°C. For this to happen global emissions of GHG must peak as soon as possible. As a part of the Paris Agreement, EU decided to reduce GHG emissions by at least 40% by 2030, compared to 1990 (European Commission, 2020b). All REWARDHeat demo sites countries have signed the Nationally Determined Contribution.

8.1.1 The European Green Deal

The European Green Deal sets the framework, with policies and measures, for Europe to become the first climate-neutral continent by 2050. An ambition first presented at the end of 2018 in "A Clean Planet for all – A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy". The Green deal is defined as "*a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decupled from resource use*". All sectors need to transition, and new policies need to be derived to meet the target; Decarbonising the energy sector, renovate buildings, innovate the industry, transition mobility to renewables and the transition must be socially sustainable. The EU-ETS system will be revised and possibly include more sectors. For the sectors outside EU-ETS, targets will be decided on state level to ensure effective carbon-pricing. The annual building renovation rate among member states vary from 0.4-1.2% and a need for doubling is foreseen to meet the targets. Except for reducing the energy demand, energy efficient building can also reduce energy poverty, improve indoor climate and increase local jobs (European Commission, 2019b).

The European Green Deal Investment Plan presented by the European Commission at the beginning of 2020 plans to facilitate at least €1 trillion of investment to the public and private sector to transition to a climate-neutral and inclusive economy. The Just Transition Mechanism will ensure that all regions develop and the most affected regions, today heavily dependent on fossil fuels, will receive special attention in order for the transition to be inclusive and socio-economically fair (Financial Stability, 2020a).

Figure 15 – The European Green Deal.

An important measure to transition to a climate-neutral economy as part of the Green Deal is the EU Action Plan on Financing Sustainable Growth that impacts financial market players such as banking, asset management, insurance and pension funds by channeling investments. The EU Action plan has three main goals (Financial Stability, 2020b);

1. Reorienting capital flows towards a more sustainable economy
2. Mainstreaming sustainability into risk management
3. Fostering transparency and long-termism

Within the EU Action Plan the EU taxonomy for sustainable activities is currently being implemented. The EU taxonomy is a classification system listing environmentally sustainable economic activities. A project qualifies for green investments by being aligned with the conditions set up in the taxonomy and the benefits are easier access to a wider range of investors and potentially access to capital at a lower cost (European Commission, 2020a).

8.1.2 2030 climate and energy framework

The *2030 climate and energy framework* was adopted in 2014 and revised in 2018 for more ambitious targets on renewables and energy efficiency. The framework is the follow-up after the 2020 package and sets the tone for the climate and energy efforts in the EU between 2021-2030. The key targets for 2030 are listed below (European Commission, 2019a):

- At least 40% reduction in GHG emissions (compared to 1990)

The GHG emissions covered by the EU-ETS are to reduce by 43% compared to 2005 and for the non-ETS sector the equivalent number is 30%. For the non-ETS sectors the targets will again be divided into individual national targets.

- At least 32% share of renewable energy in final energy consumption

  The original target of 27% was revised in 2018 to a more ambitious level and a review of the target will be performed in 2023 that could lead to an upward revision.

- At least 32,5% improvement in energy efficiency (compared to projections)

  The original target of 27% was revised in 2018 to a more ambitious level and a review of the target will be performed in 2023 that could lead to an upward revision.

Under the 2030 climate and energy framework member states must supply the European Commissions with a National Climate and Energy Plan (NECP) for the period 2021-2030. Drafts were submitted by the end of 2018 and final versions by the end of 2019 or beginning of 2020. The members states NECPs are to cover the five dimensions of the EU's energy union strategy (European Commission, 2019a):

- Security, solidarity and trust
- A fully integrated internal energy market
- Energy efficiency
- Climate action- decarbonising the economy
- Research, innovation and competitiveness

8.1.3 EU strategy for heating and cooling

In 2016, EU presented the first HC strategy with the main goal to decarbonize the HC sector. The goals are meant to be achieved by increased energy efficiency, renewable energy and synergies between the HC sector and the electricity system. DH systems based on waste heat, cogeneration and renewables are considered an enabler for decarbonization. The EU HC strategy has four main points (European Commission, 2016):

- Make renovating buildings easier
- Increase the share of renewables
- Reuse of energy waste from industry
- Getting consumers and industries involved

The building stock in Europe is old. As a result, the buildings heating systems are generally old too. Half of the building have boilers with an efficiency rate below 60% and many of the fossil fuelled boilers and direct electric heaters are past the technical lifetime. Changing obsolete heating systems to RE or DH is necessary to drive decarbonization in the sector (European Commission, 2016).

EU wants to see a further expansion of the synergies between the HC market and the electricity market. As more renewables are integrated in the electrical system the supply and demand must be more flexible and integration with the HC sector can provide that flexibility. DH has a large potential for integrating renewables both as electricity (via heat pumps or electric boilers) and heat (solar thermal, geothermal) and utilizing waste heat that would otherwise be wasted. Heat produced in cogeneration plants for heat and power is encouraged as an energy efficient solution (European Commission, 2016).

The HC strategy is deployed by several legislative reviews of the *Energy Efficiency Directive*, the *Energy Performance of Buildings Directive* and the *Smart Financing for Smart Building Initiative* as well as the *New Electricity Market Design* and the *Renewable Energy Framework* (European Commission, 2016).

8.1.4 EU Directives impacting retrofitting of buildings, DHN and energy supply systems (production and distribution) generally

EU Directives are legislative acts obligatory to implement by all member states through national legislation. Each member state forms its own laws on how to reach the goals defined by the directive. The individual member state implementation means that the impact of the EU Directives at national level cannot be highly generalized. Relevant legal factors concerning DHC systems nationally are thus sensible to consider country per country (see sub-chapters 9.5, 10.5, …, 15.5).

Three of the most relevant directives for increased building retrofitting and modernized thermal energy supply systems (in direct connection to the 2030 Framework) are the Energy Efficiency Directive, the Energy Performance of Buildings Directive and the Renewable Energy Directive. An overview of these directives is presented under separate headlines below.

8.1.5 Energy Efficiency Directive (EED) (2012/27/EU) and the Amending Directive on Energy Efficiency (2018/2002)

The EED was adopted in 2012 with the aim to establish binding measures for EU to reach the energy efficiency target for 2020 that was set in 2008, the so called 20-20-20 targets: target for energy efficiency improvement set at 20 %, and to aid further improvements beyond 2020. The EED has stated requirements for the member states to use energy more efficient, from production to final use.

The following list comprises the national measures that are included in the EED for ensuring energy savings (European Commission, 2012):

- Energy distributors or retail energy sale companies have to achieve 1.5% energy savings per year by implementing energy efficiency measures.
- Member states can decide to achieve these same levels of savings by other means. E.g. by improving the efficiency of heating systems, increasing windows insulation or insulating roofs.
- The public sector within the EU member states should procure energy efficient buildings, products and services.
- On a yearly basis, the member state governments will carry out energy efficiency renovations covering at least 3% (by floor area) of the buildings they own and inhabit.
- Empowerment of energy consumers for better managing of consumption. This includes free and easy access to data on consumption by individual metering systems.
- Incentives on a national basis for SMEs to carry through energy audits.

- Large companies will perform audits concerning their energy consumption to help them identify ways to reduce energy.
- Monitoring of efficiency levels reached in newly established energy generation facilities.

In 2018, within the 'Clean energy for all Europeans package', it was agreed to update the policy framework to 2030 and beyond through the new amending Directive on Energy Efficiency (2018/2002). The key element of the amended directive is the aforementioned energy efficiency improvement target for 2030 of 32.5%. In accordance to the amending directive, EU member states have to achieve new energy savings of 0.8% final energy consumption per year within 2021-2030 (European Commission, 2019c).

The amended directive also includes (European Commission, 2019c):

- More robust rules concerning metering and billing of thermal energy, by giving consumers clearer entitlement to get more frequent and useful energy consumption information, also enabling a better understanding and control of their heating bills
- Requirements on member states to implement transparent and publicly available rules on the allocation of heating, cooling and hot water consumption costs in multi-household and multi-purpose buildings with collective energy systems
- Monitoring of efficiency levels in new energy generation capacities
- An update of primary energy factor (PEF) for electricity generation to 2.1 (down-adjustment from the current 2.5)
- A comprehensive review of the EED (which is required by 2024)

8.1.6 Energy Performance of Buildings Directive (EPBD) (2010/31/EU) and the Amending Energy Performance of Buildings Directive (2018/844/EU)

The main aim of the EPBD implemented in 2010 is described as to realize the energy saving potential in buildings, as buildings account for nearly 40 % of the energy consumption in the EU (Concerted Action EPBD, 2017).

Requirements for the member states according to this directive regard (EUR-Lex, 2010):

- The common general framework for a method to calculate the integrated energy performance for buildings and building units.
- Minimum requirements to apply for the energy performance of new buildings and building units.
- Minimum requirements to apply for the energy performance of:
    - existing building units, buildings and elements that are subject for major renovations;
    - building elements that form parts of building envelopes and have a significant impact on energy performance of the building envelopes when retrofitted or replaced; and

- technical systems of buildings whenever they are replaced, installed or upgraded.

- National plans to increase the amount of nearly zero-energy buildings (NZEB).
- Energy certification for building units or buildings.
- Regular inspections of heat and air-conditioning systems for buildings.

The decision that every new building within the EU member states should be a NZEB latest from the 31st of December 2020 is also incorporated, as well as that support measures should be made for refurbishing buildings to NZEB. General requirement of NZEB are defined, but with each member state being responsible to transpose and implement it into its national legislation and regulations, clarifying the term NZEB within its national context (Energimyndigheten, 2017, Erhorn and Erhron-Kluttig, 2015).

As well as the EED, the EPBD was amended within the 'Clean energy for all Europeans package' in 2018-2019. This amended EPBD directive (2018/844/EU) particularly introduces new elements and sends a political signal on the commitment of EU to modernize the buildings sector in light of increased building renovation and technological improvement (European Commission, 2019d).

8.1.7 Renewable Energy Directive [RED] [2009/28/EC] and the revised Renewable Energy Directive [RED II] [2018/2001/EU]

The RED taken into force 2009 encompasses a common framework for promotion and production of renewable energy within the EU and is based on the main targets of a 20% share of renewables of EU energy consumption and a 10% share of renewable transport fuel by 2020.

The directive incorporates specific national renewable energy targets for each member state by 2020, based on the starting point and overall potential for renewable energy for each state. The national targets range between 10% and 49%. The RED has left to the member states to form their own plans and courses of renewable energy policy to reach the targets, within their *national renewable energy action plans*.

The directive's aim is described also as to promote cooperation amongst member states, through statistical transfers, joint renewable energy projects and support schemes. By the RED, rules has been established on these statistical transfers between the member states and joint projects, as well as administrative procedures, origin guarantees, information/training and access to electricity grids for renewable energy (European Commission, 2014, EUR-Lex, 2009).

In December 2018, a revised version of the RED (RED II) (2018/2001/EU) was taken into force. In RED II, the raised overall EU target for RES consumption by 2030 of 32% is incorporated. An obligation for the member states to require fuel suppliers to supply a minimum of 14% renewable energy to the energy consumed in road and rail transport is also included. As well as in the original RED, sustainability criteria for the bioliquids is included in RED II, to comply with to be able to include them within the 14% target (EU Science Hub, 2019).

Sustainability criteria is also included for solid and gaseous biomass fuels for heating and cooling as well as power production, which is a notable feature in the RED II connected to heat and cooling systems. Most of the further new elements in the revised directive will need to be transposed into national law by each member state by 30 June 2021 (REHVA, 2020). After this transposition, a comprehensive view could be given on how RED II impacts the prerequisites nationally for renewable energy in heat and cooling supply in general and DHC systems in particular.

8.2 EU heating and cooling supply and demand

8.2.1 Heating and cooling supply and demand

In 2015, 50% of the total final energy demand in the EU28 was used for HC (approximately 6400 TWh). Space heating accounted for just over 50% of the total HC demand, process heating just over 30% and domestic hot water 8% (Fleiter et al., 2017) (Figure 16). Gas was dominating the HC supply for EU28 at 42% of total final HC. The share of renewables reached 19.5% of the supply in 2017 (Figure 17). The residential sector has the largest energy use of HC and the main demand as space heating. The industrial sector has the second highest demand and the dominant driver is process heating. The tertiary sector mainly requires space heating (Figure 18) (Fleiter et al., 2017).

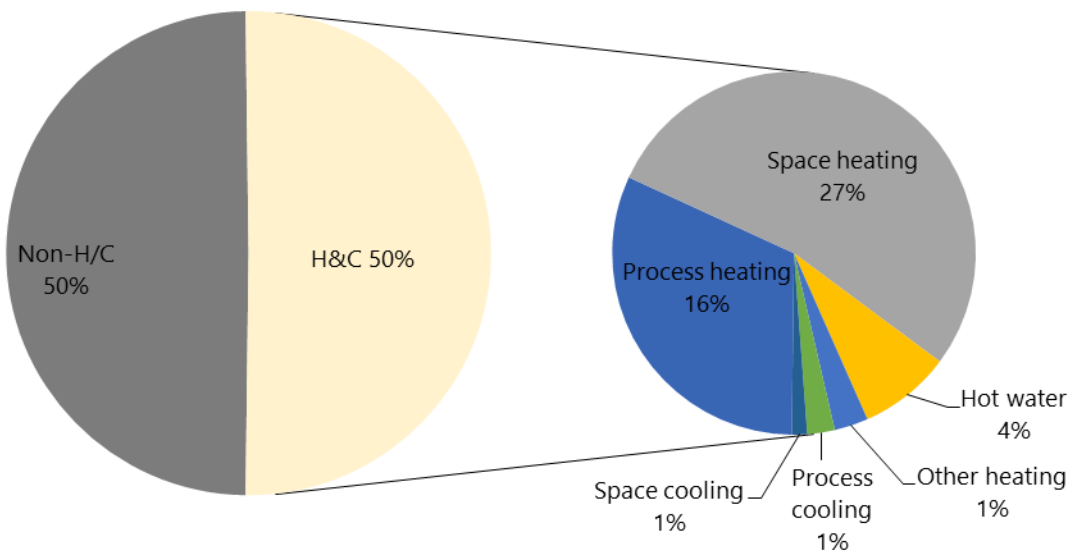


Figure 16 – Different types of HC demand in the EU (Fleiter et al., 2017).

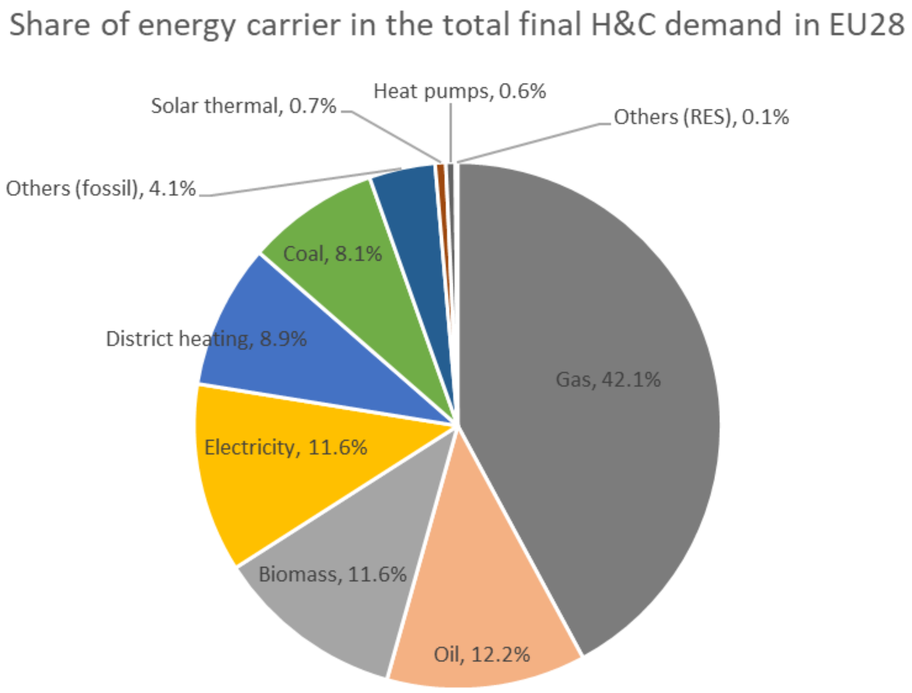


Figure 17 – Shares of energy carrier in the total final HC demand in EU28 (Fleiter et al., 2017).

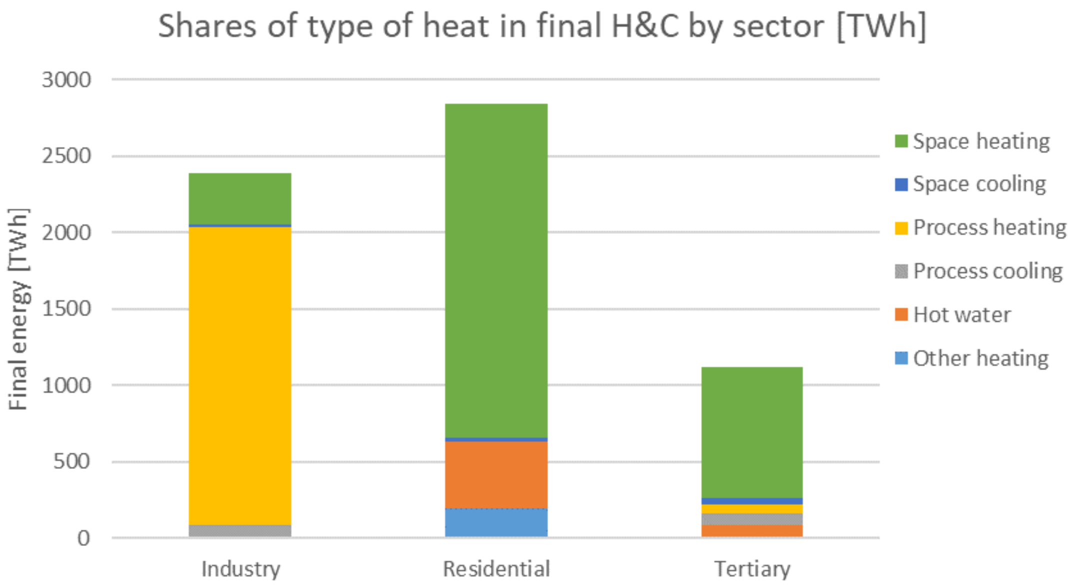


Figure 18 – Shares of type of heat in final HC by sector [TWh] (Fleiter et al., 2017).

8.2.2 District heating and cooling

8.9% of the HC demand in the EU28 in 2015 was supplied by DH (Fleiter et al., 2017). In 2012 the EU27 had 3584 DHN located in 25 of the member state countries. 13 countries had cooling systems and there existed in total 105 cooling systems in EU27 (Persson, 2013).

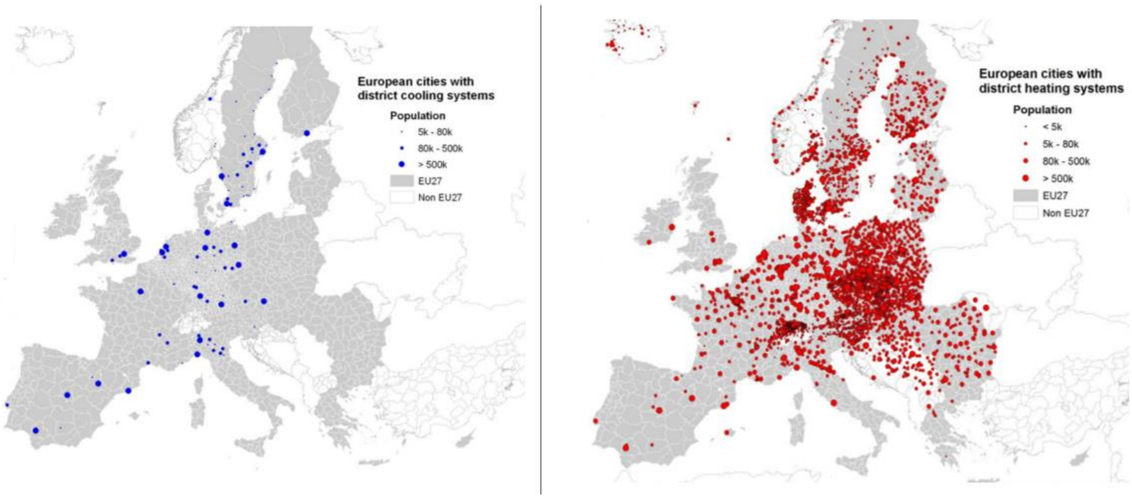


Figure 19 – District heating and cooling networks in Europe (Persson, 2013).

8.2.3 Geothermal and solar energy in Europe

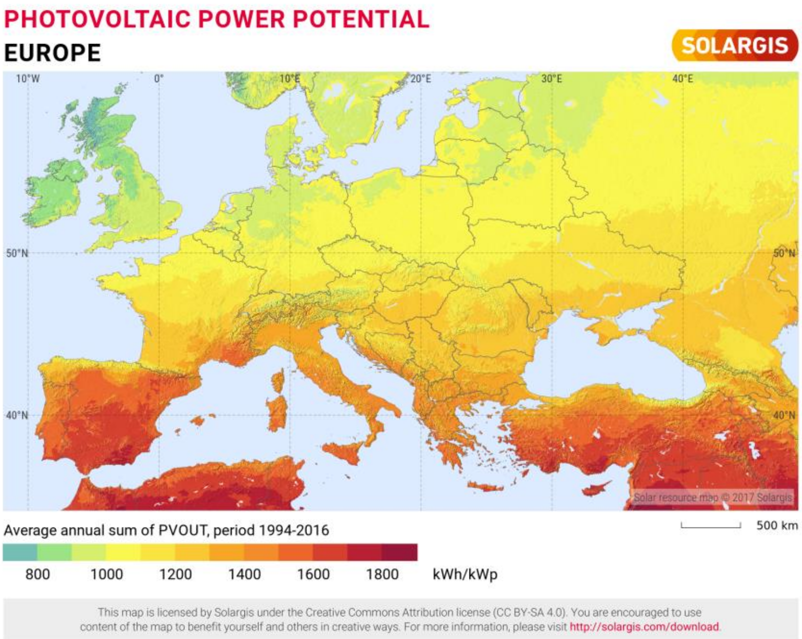


Figure 20 – Photovoltaic power potential in Europe (SOLARGIS, 2020).

The installed capacity of solar PV in EU28 in 2017 was 107,7 GW and electricity production was 113.7 TWh (EurObserv'ER consortium, 2018). The solar PV potential in Europe measured as kWh/kWp is visualised in Figure 20. The power potential generally increases the further south in

Europe the installation is located (Schmela, 2018). Figure 21 shows the installed solar PV capacity in Europe (Schmela, 2018).

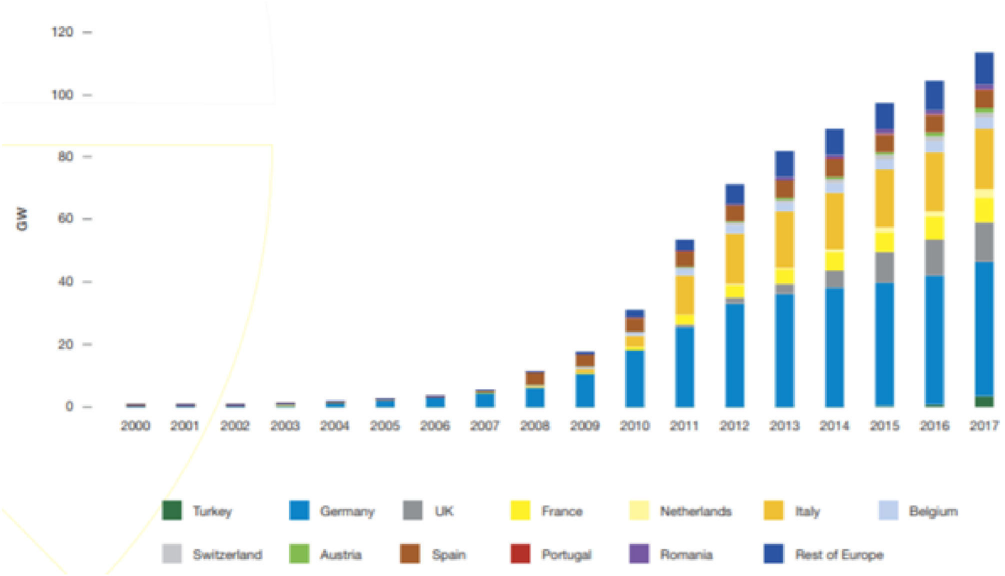


Figure 21 – Installed solar PV capacity in Europe (Schmela, 2018).

The installed solar thermal capacity in EU28 in 2017 was 36.5 GW_{th} (EurObserv'ER consortium, 2018). Direct supply of solar thermal to the HC demand in the EU28 reached 41.4 TWh in 2015. 20 TWh was supplied to each of the residential and tertiary sector as space heating and hot water (Fleiter et al., 2017). At the end of 2015 there were 252 solar thermal installations in Europe with an installed capacity of at least 350 kW_{th}, some of the installations are used for producing cooling. The driving market for solar thermal energy in Europe is Denmark but the development is also noticeable in Sweden, Germany and Austria (Solar district heating, 2019). Large systems, as described above, are only a very small fraction of the total solar thermal market. The main market comprises of small installations for single houses with an installed capacity between 3-10kW_{th} providing DHW, and possibly also space HC. A study from 2012 identified that solar thermal heat can contribute to between 200-580 TWh per annum and that that 20-58 TWh per annum could be as solar DH, which would cover approximately 4-10% of the total use of DH in 2030 (Werner and Dalenbäck, 2012).

The installed geothermal electricity capacity in 2017 was 1 GW_e (with a vast majority in Italy) and produced 6.7 TWh. The installed capacity of geothermal DH systems was 1763 MW_{th} in 2017 (EurObserv'ER consortium, 2018). In 2014 around 250 geothermal DH systems were in operation in Europe. More than 25% of the EU population are in regions suitable for geothermal HC (Dumas and Bartosik, 2014).

8.2.4 Waste heat recovery potential in the EU

The technical potential for industrial waste heat recovery in the EU has been estimated at 300 TWh/year. 30% of the total potential is waste heat at a temperature less than 200°C, 25% is between 200-500°C and the rest is above 500°C. The iron and steel industrial sector accounts for more than half of this potential at approximately 170 TWh/year (Papapetrou et al., 2018a).

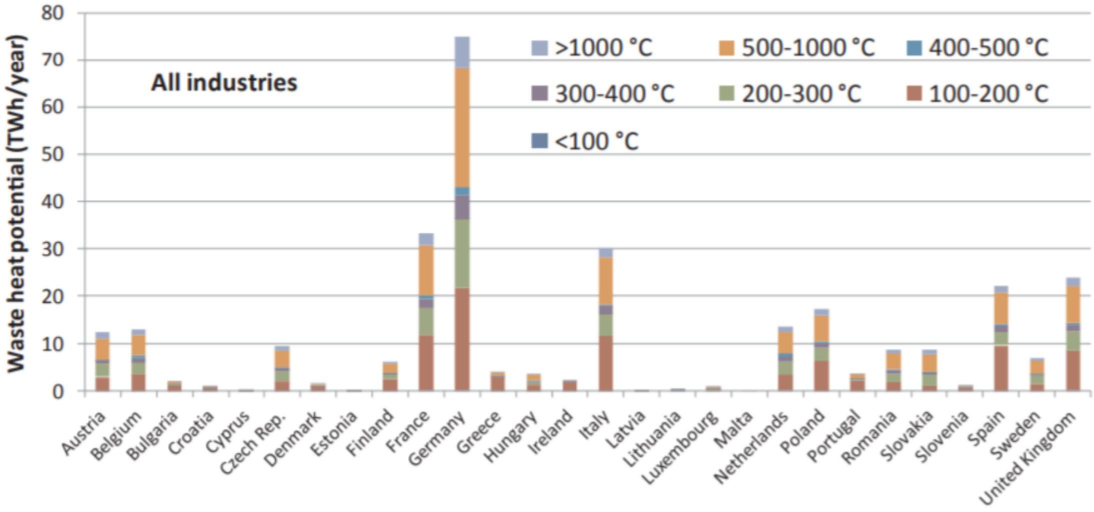


Figure 22 – Industrial waste heat potential in each EU country per temperature level in all industries (Papapetrou et al., 2018a).

The available waste heat from low temperature urban heat sources in EU28 has been assessed by looking at four heat source categories; Data centres, metro stations, service sector buildings and wastewater plants. The total potential was estimated at 1562 PJ/year. When applying a limit of 2km on the distance to current DH systems the available potential is reduced to 824 PJ. The practical utilization potential for annual available waste heat volumes is assessed at 1235 PJ (Persson and Averfalk, 2018).

9 Annex: PESTLE Denmark

Denmark is part of Scandinavia and located in northern Europe, between the North Sea and the Baltic Sea. The population as of 1 January 2019 was approximately 5.8 million (Eurostat, 2019c). The number of heating degree days in Denmark in 2018 was 3051, and cooling degree days 14 (Eurostat, 2019a). The energy consumption for heating in buildings (normal climate) in 2015 was 137 kWh/m^2 (Odyssee-Mure, 2019). The total primary energy supply in Denmark in 2018 consisted of 37.5% oil, 28.7% biofuels and waste, 8.2% wind, solar etc, 16.1% natural gas and 9.5% coal (International Energy Agency, 2019b). The final energy consumption in 2017 was 161 TWh (Eurostat, 2019b).

Table 5 – Share of renewable energy in total energy, HC and electricity in 2017 (EuroStat, 2019d)

	RES in energy	RES in HC	RES in electricity	RES in transport
Denmark	36%	47%	60%	7%

9.1 Political factors

9.1.1 National energy and climate plan (NECP)

The national energy and climate plan for Denmark sets the target to reduce GHG emissions by 70% by 2030 compared to 1990 levels and to reach net zero emissions by 2050 at the latest. Emissions in the non-ETS is to be reduced by 39% by 2030 compared to the emissions in 2005.

The target for renewable energy in gross final energy consumption is 55% by 2030. The share of renewable energy in electricity consumption should be above 100% by 2030. The target for DH consumption is that at least 90% is provided by other sources than coal, oil or natural gas by 2030. 80% of the DH consumption and 60% of the total HC demand will be based on renewables by 2030, mainly achieved by biomass and HPs. The main share of non-renewables left in the DH supply 2030 will be from waste incineration.

Energy efficiency will be promoted through a subsidy scheme 2021-2024 targeting private enterprise and buildings as well as renovations in both the public and private building sector. The share of heat pumps both in the individual heating solutions and DH sector is expected to increase and contribute to a more flexible energy system. A variety of heat pump technologies is expected using low temperature sources such as air, ground, sea water, geothermal energy and surplus heat.

From 2021 the tax on electrical heating will be reduced and is expected to increase the use of HPs and excess heat. The share of excess heat utilization in DHN is expected to increase and new measures will be evaluated to realise a higher potential in 2022. Geothermal energy is also expected to increase as supportive measure will be implemented (European commission, 2020c).

Until the 1st of January 2019 electricity generated in CHP based on natural gas and waste incineration was subsidized. As a consequence of removing the subsidy, the heat tariff is expected to increase and this could potentially lead to customers moving towards individual heating solutions. A specific subsidy scheme will be implemented to replace oil burners with HPs in buildings outside the DH and gas grids. For decentralized natural gas-based DH plants a support scheme is being established in 2020 supporting investments in electric heat pumps, biomass boilers and solar thermal plants. In relation to district cooling strategies, the policies and legislative barriers will be assessed from 2020 and developed to realise a higher potential.

Denmark has evaluated the potential for developing high-efficiency cogeneration and efficient DH and cooling (in accordance with Article 14 (1) of Directive 2012/27/EU). The potential for CHP in Denmark is expected to decrease as more renewable energy is integrated in the electricity grid. The marginal costs for CHP are higher than for RE alternatives in electricity production. Investments in DHN is expected to move more towards heat only producing units (European commission, 2020c).

9.1.2 Political interest in REWARDHeat solutions

The Danish 2050 Energy Strategy states that DH supplied by renewable energy will be the main driver to enable a fossil free heating sector (International Energy Agency, 2020) and the Danish Energy Agency states that DH is a cornerstone in the Danish energy system (Riisgaard Pedersen, 2017).

In the 2019 *Danish Climate and Energy Outlook* expected outcomes of current policies are identified. The renewable energy share of the DH system is expected to reach 80% by 2028, large scale coal-fired and small-scale gas fired CHP are expected to be phased out by 2030 and replaced by biomass and heat pumps. Industrial waste heat will increase by 2030 and other waste heat sources can be recovered by heat pumps. 11% of the DH supply is expected to come from large heat pumps and electric boilers which will enable a better integration with the electricity system as 109% of the electricity consumption in 2030 will be produced by renewables energy. The growth in electricity production is expected mainly by wind power and solar PV (Danish Energy Agency, 2019).

Between 2006-2020 supply companies of energy have had an obligation to reduce end-user's energy usage. Moving from oil boiler to DH has been of economic value for the companies. This has also promoted solar thermal collectors being integrated into the DHN as it counts as energy savings.

The Danish energy agency considers LTDHN to be an optimal and efficient way to include heat pumps, waste heat, solar thermal and geothermal energy in the heating system (Danish Energy Agency, 2015). The recommendation for newly built areas with low energy houses is that low temperature heating systems should always be considered (Kaarup Olsen et al., 2014).

9.1.3 Financial support for REWARDHeat solutions

One measure in the Danish energy agreement was targeted at green heating measures. Amending the Heat Supply Act to promote large-scale power plant to convert from coal and natural gas to biomass, and to make funding available for the promotion of mainly geothermal energy and demonstration of large heat pumps. Funding will be made available for private residents in 2021-2025 to encourage energy efficiency measure and especially the replacement of oil-fired boilers to heat pumps (Danish Energy Agency, 2018). The Danish Energy Agency states that large scale solar heating is usually a good investment for the heating companies, often in combination with seasonal storage (Riisgaard Pedersen, 2017). DH companies can acquire investment through the KommuneKredit institution.

Since 2012 self-producers of small electricity installations from renewable energy are exempt from paying tariffs, duties and VAT based on net-metering calculated on hourly basis (International Energy Agency, 2020). Feed-in premium tariffs are available for renewable power. The feed-in tariffs provide a variable add-on, per kWh delivered to the grid, to the market price for the electricity produced by renewable sources (International Energy Agency, 2020). From 2018 the support is reduced and only provide a small financial support, approximately 0.13-0.26 eurocents per kWh.

9.2 Economic factors

9.2.1 Heating and cooling demand

The total final HC demand in Denmark in 2015 was 77 TWh (Fleiter et al., 2017), approximately 48% of the total energy consumption. Figure 23 shows that the largest sectoral demand for HC occurs in the residential sector where space heating and hot water is in demand. The tertiary sector is dominated by space heating and the industrial sector is mainly using process heat (Fleiter et al., 2017).

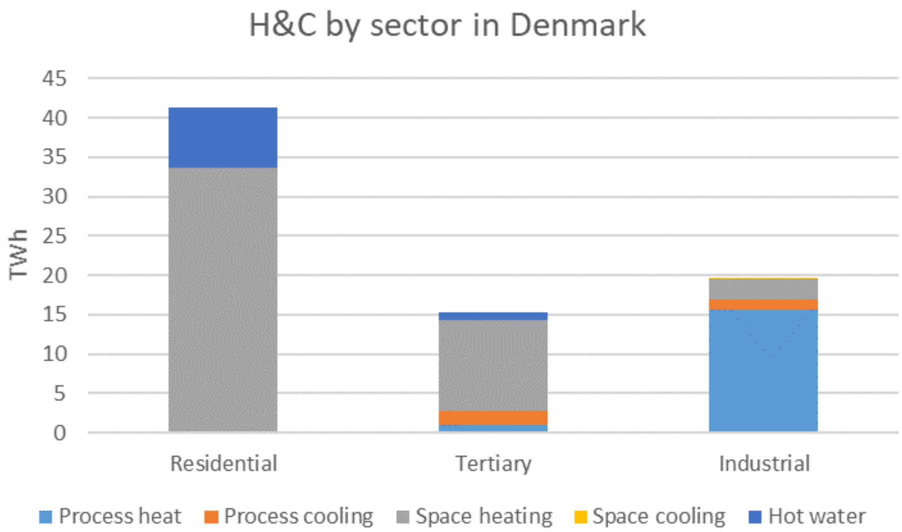


Figure 23 – Heating and cooling by sector in Denmark (Fleiter et al., 2017).

9.2.2 Heating and cooling supply

The HC demand in Denmark is mainly supplied by DH followed by gas, displayed in Figure 24. Figure 25 shows that DH is mainly used for space heating and hot water in the residential and tertiary sector. Gas is mainly used for space heating to the residential sector and process heating to the industrial sector (Fleiter et al., 2017)

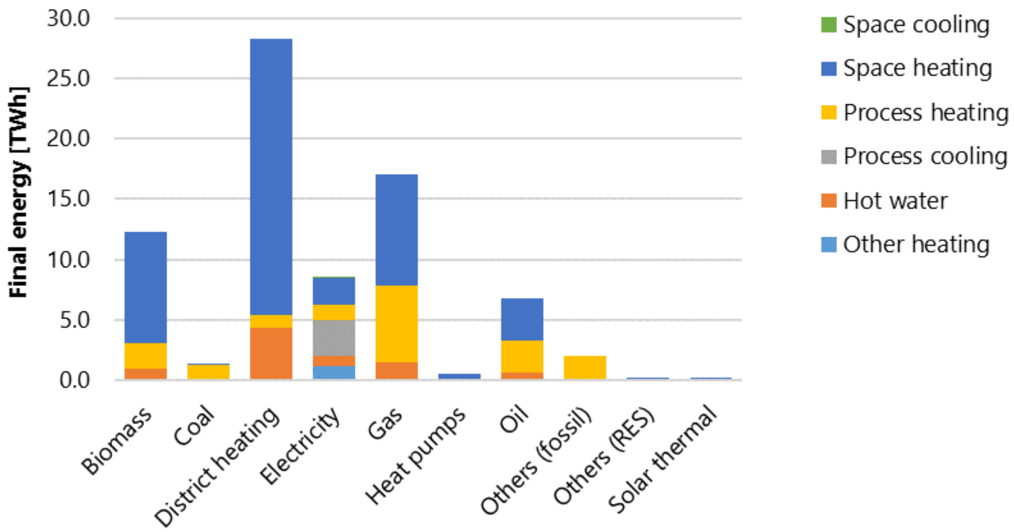


Figure 24 – Energy carrier for the final HC demand for all sectors in Denmark [TWh] (Fleiter et al., 2017)

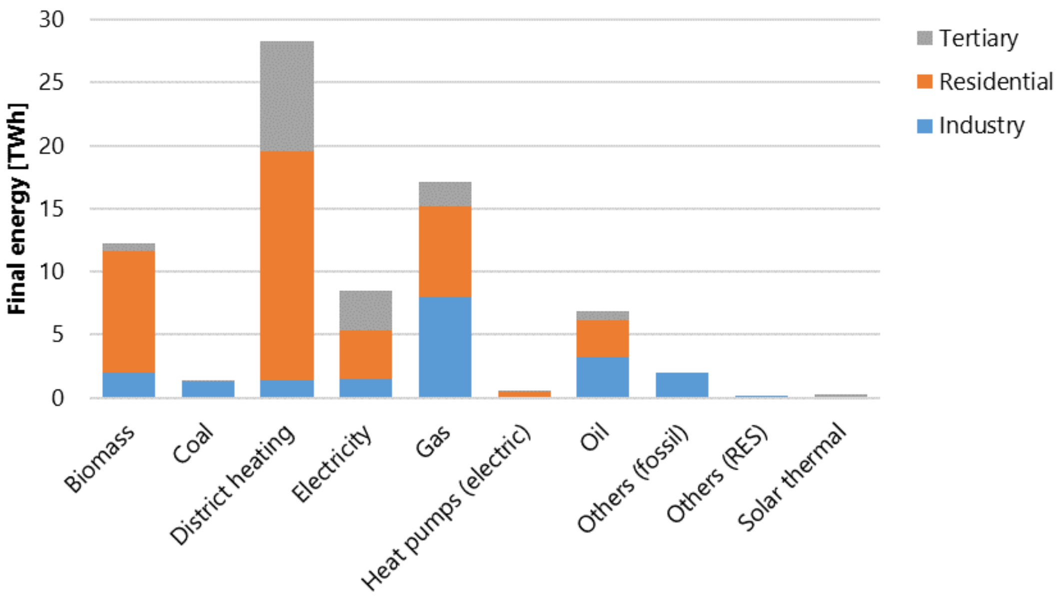


Figure 25 – Energy carrier split by sectoral demand in Denmark (Fleiter et al., 2017)

9.2.3 District heating

DHN has been part of Denmark's energy supply since the beginning of the 20's century. The expansion continued and covered 30% of residents by the 70's. As a result of the oil crises in the 70's, CHP were promoted to a larger degree and in 1979 the first law governing DH supply came (Danish Energy Agency, 2015).

DH in Denmark is divided into six large DH areas, the Greater Copenhagen area is by far the largest network in Denmark. 68% of the DH is produced in CHP plants (Danish Energy Agency, 2015). The main fuel sources in the DH networks are biomass, natural gas, coal and waste. 52% of the DH supply is renewable. Industrial waste heat recovery in Denmark reached 3.6% of total heat production in 2016 (Danish Energy Agency, 2017). There are also some examples of urban waste heat recovery in Denmark, however small scale(State of Green, 2018). Excess heat is currently utilized at 5 PJ with an estimated potential of 12-18 PJ (European commission, 2020c).

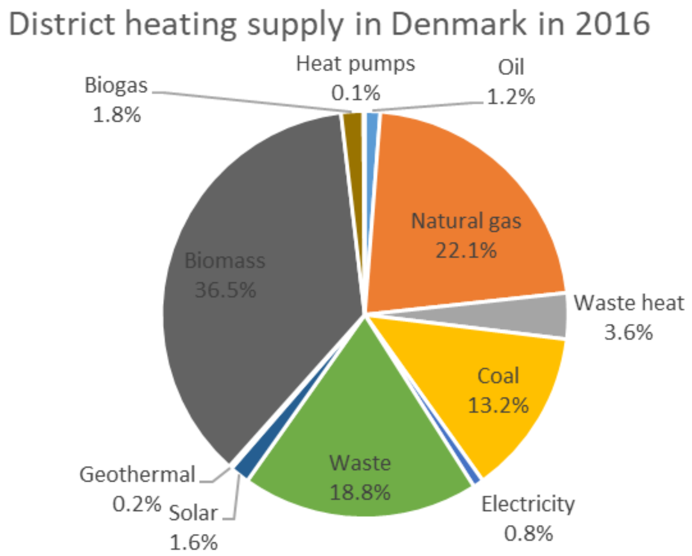


Figure 26 – District heating supply by energy carrier in 2016 (Danish Energy Agency, 2017).

In Denmark there are LTDHN with supply temperatures down to 50°C and return temperature down to 25°C. LTDHN mainly develop in newly built housing areas and in housing areas that are thoroughly refurbished. Opportunities for LTDHN arise due to national building regulations act that make all new buildings in Denmark suitable for LTDHN. The tendency towards urbanisation is also seen as an opportunity. District cooling networks has been growing since 2012 and the installed capacity is 21.8 MW and mainly supplies the tertiary sector (EuroHeat & Power, 2017).The largest district cooling system is in the city of Copenhagen. Opportunities for district cooling are in that the demand for cooling is high and concentrated. District cooling is not expected to increase much by 2030 (European commission, 2020c).

DH companies are organized in two organisations, the Danish DH Association and the Association of Danish CHP plants (Danish Energy Agency, 2015). Under the Danish Heating association is a think tank called Green Energy. Another think tank that has a broader perspective on climate change, including DH, is Concito. The Danish Utility Regulator regulates the Danish market for electricity, natural gas and DH.

The ownership structure of DHN in Denmark in mainly cooperative societies, 340, owned by the users, 50 are municipally owned and a few are privately owned (Dansk Fjernvarme, 2016). 12.5% owned by municipalities and 85% consumer-owned (Riisgaard Pedersen, 2017).

DH networks are non-profit in Denmark. In Copenhagen the district cooling is delivered as a profit generating business but the recommendation from the Danish DH association is that DC should also be a non-profit business.

Solar heating is supplying 1.6% of the DH supply. In 2016 there were 100 units of solar thermal connected to the DHN (Danish Energy Agency, 2017). The solar thermal capacity in Denmark has seen a large growth since 2009 and the installed capacity reached 1 GW in 2019 (PlanEnergi, 2019). Geothermal energy in DH supply is 0.2% of the total heat production (Danish Energy Agency, 2017). In 2019 there were three geothermal plants in operation in Denmark supplying heat to DHN and several licences have been granted to explore further potential.

9.2.4 Potential for waste heat and renewable energy sources

The practical utilization potential for annual available urban waste heat from four studied categories was identified at 20 PJ (5.6 TWh) in Denmark (Persson and Averfalk, 2018). The four categories individual potential was data centres (3.7 PJ), metro stations (0.2 PJ), service sector buildings (1.9 PJ) and wastewater plants (14.5PJ). Another Danish study identified the accessible waste heat potential in the specified sectors, industry buildings, utility services, construction, transport including maritime, in the country to be 74TWh, 58% of which was below 100 degrees. Waste heat from the building sector, approximately 8 TWh, only had temperatures below 100 degrees. The identified potential of waste heat from the industry sectors in Denmark is 28TWh (Bühler et al., 2015)., but not all this potential can be feasible recovered to a DHN. The feasible industrial waste heat recovery potential to the DH systems in the country has been estimated in three different studies to be at 1.36 (Bühler et al., 2017) (of which 50% is low temperature and would require a heat pump) -2 (Papapetrou et al., 2018a)- 3.3 TWh/year (Persson, 2015).

The installed capacity of geothermal energy in 2017 was 33 MW_{th} (EurObserv'ER consortium, 2018). Geothermal energy aquifers have been identified around many Danish cities with DHN with the potential to supply 20-50% of the DH demand in Denmark from geothermal sources for hundreds of years. An example is in the Greater Copenhagen area where 3.3 TWh per annum could be supplied for 5000 years. Only very little of this potential is utilized today, primarily by ground source heat pumps with horizontal collectors (Erbs Poulsen et al., 2019). A study from 2014 assessed, as a percentage of the population that can be reached by geothermal DH, and found that it is possible for 75% of the Danish population, with temperature between 60-100°C at 2000 meters (Dumas and Bartosik, 2014).

Solar PV installed capacity 906 MW and produced 0,751 TWh in 2017. Installed capacity of solar thermal in 2017 was 1080 MW_{th} (EurObserv'ER consortium, 2018). The solar PV potential in Denmark is mapped in Figure 27 (SOLARGIS, 2020). The theoretical solar thermal potential has been calculated at 139 TWh (Bühler et al., 2015). The solar heating contribution to the DH network has an estimated potential to contribute with 10% of the DH supply by 2030 (State of Green, 2020).

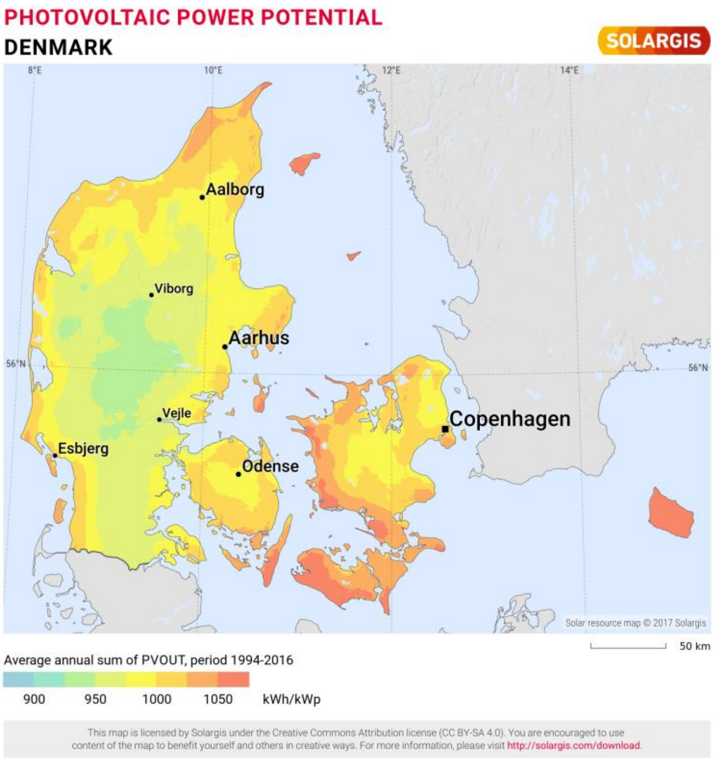


Figure 27 – Photovoltaic power potential in Denmark (SOLARGIS, 2020).

The installed capacity of wind power in 2017 was 5522 MW and its net production reached 14.8 TWh. In Denmark wind power production has grown a lot in this century and is taking over the role of national power supply from CHP electricity production (Odgaard, 2016). The electricity production from CHP has decreased between 2000-2014 and has been replace by wind power. Wind power increased from 12-39% of electricity production during the same time period (Riisgaard Pedersen, 2017). The potential for wind power is more than enough to cover the Danish consumption and the option for wind power-to-heat (via heat pumps and electric boilers) is expected to be an enabler for continued uptake. The DH system can both work as a balance and a storage (Jessen, 2015).

9.3 Social factors

In Denmark, responses were collected by distributing the survey via email to customers connected to the REWARDHeat demonstration site in Albertslund. 8 responses were collected, 5 end-users and 3 professional customers. The respondents were all connected to a DH network.

9.3.1 General opinion of DHN

The respondents are generally very positive towards DHC system, only one professional customer did not respond with a 4 (very positive) but instead answered 3. The lowest average score was for the statement: “DHC is a cost-efficient option”, however the average was still more than 3 (Figure 28).

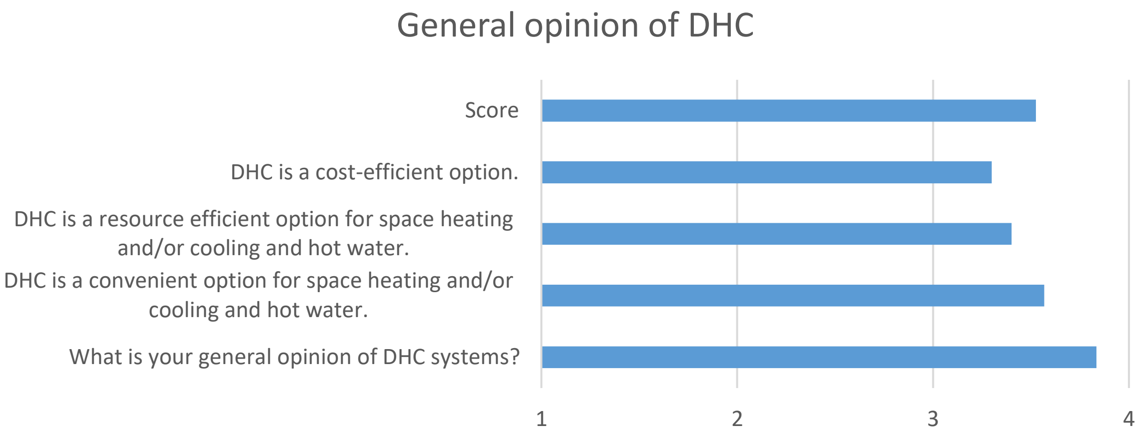


Figure 28 – Mean values of the respondents on their general opinion about DHC (Danish demo site), as well as the resulting score. The respondents answered on a 4-degree Likert-scale were 1= I don't agree, or very negative, and 4= I agree completely, or very positive.

9.3.2 Awareness of technology

Respondents have a good understanding of how a DHC system works and most perceives that most cities in Denmark have a heat network. All but one respondent had heard about LTDHN but only three respondents had heard about DHN that integrate renewable energy, excess heat or both (Figure 29).

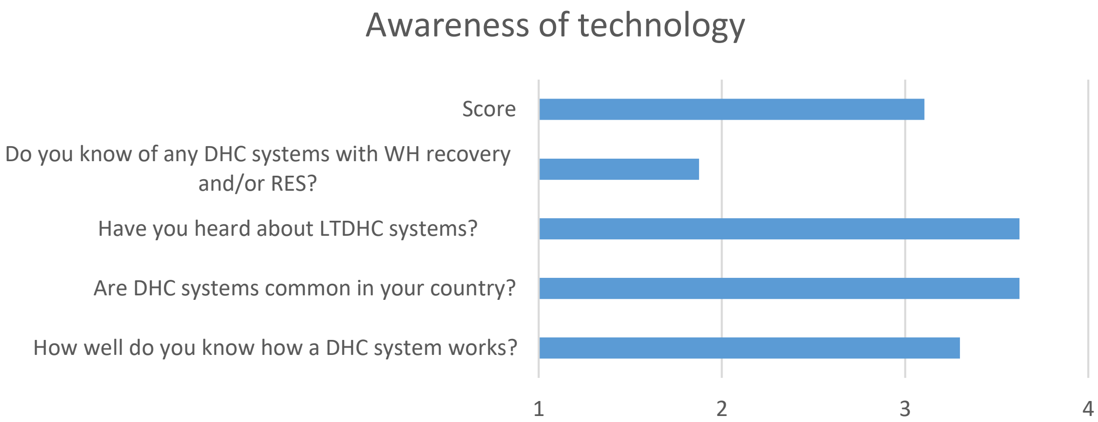


Figure 29 – Mean values on the awareness of the technology as well as the resulting score (Danish demo site).

9.3.3 Risks and benefits

The main benefit perceived by respondents with having a LTDHN is energy efficiency, sometimes specifically stated as being due to reduced heat losses in the system. The main perceived risk with LTDHN is that it will not be sufficient to heat some houses (older buildings or buildings in the outer bound of the system). The benefits of having RES and waste heat integrated into the system are perceived to be energy savings and beneficial for the environment. The perceived risks relate to unstable heat supply and error (Table 6).

Table 6 – Perceived risks and benefits of the REWARDHeat technologies by respondents as well as the resulting score (Danish demo site). Respondents answered in open text fields and could write as many benefits or risks as they wanted. The number displayed in the parenthesis is how many respondents stated the risk/benefit.

	Benefits LTDHN	Risks LTDHN	Benefits RES & WH	Risks RES & WH
Professional c ustomers	Energy efficiency (3), less corrosion (1), higher efficiency of CHP plant (1)	Not sufficient heat for older buildings (1), None (1)	Saves fuel (1), energy savings (2), less CO2 emissions (1)	Unstable heat supply (1), Error affects more consumers (1), None (1)
End-users	Energy efficiency (4), Environmental benefits (1), Possible to use LT heat sources (1)	Not sufficient heat for some buildings (3), Larger consumption for same heat (1). Difficult to ensure proper cooling of return water (1)	less expensive (2), environmental (2), better use of energy (1), energy efficiency (1), don't know (1)	Tax issues (1), unstable heat supply (1), None (2), don't know (1)

9.3.4 Environmental consideration

The respondents are concerned about climate change, all respondents make the connection between using energy for HC and effects on climate change and all respondents believe that including WH and RES is beneficial for the environment. Five out of the eight respondents think that the effect of climate change is uncertain which could result in reduced willingness to act (Figure 30).

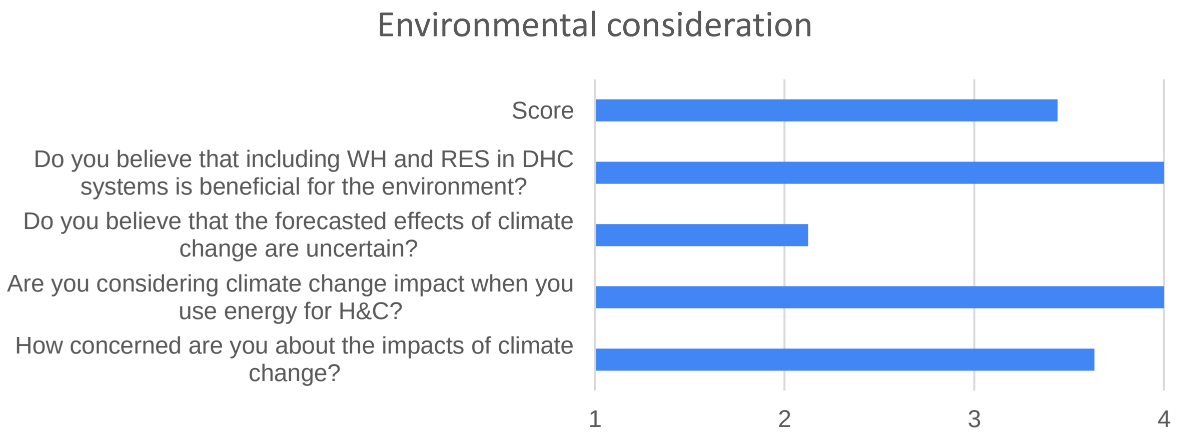


Figure 30 – Mean values on the environmental consideration, as well as the resulting score (Danish demo site)

9.3.5 Cost expectancy

None of the respondents think that having a LTDHN, or integrating RES or WH, will be more expensive. Most end-users think that the cost will remain the same and many professional customers think it will be less expensive than conventional DHN (Figure 31).

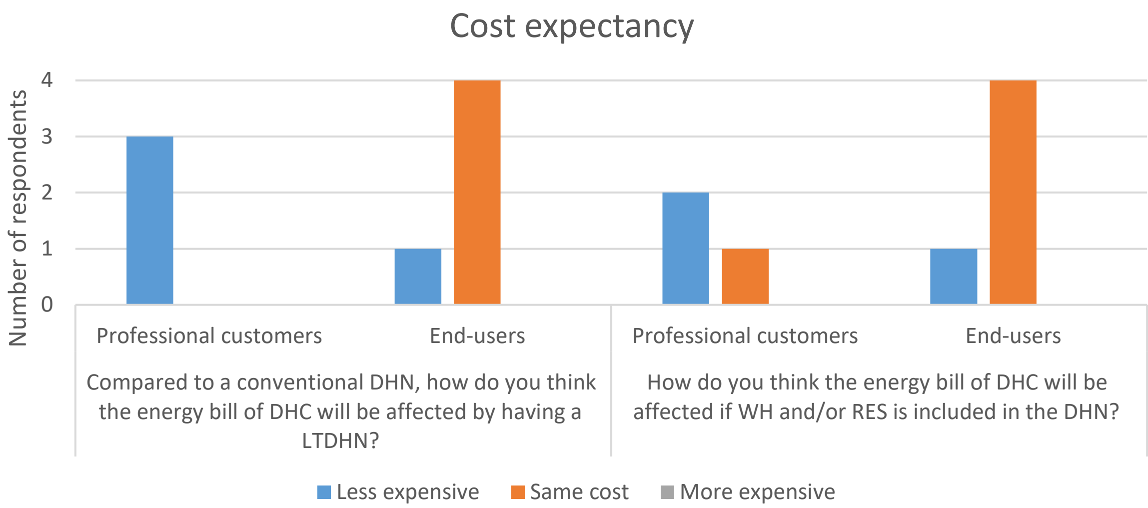


Figure 31 – Cost expectancy of end-users and professional customers (Danish demo site)

9.4 Technical factors

The technology of conventional DH is mature in Denmark. Low temperature heating systems are though relatively new and often used in connection with new housing areas with low energy buildings. Denmark has potential of geothermal sources, which could be one way to further develop low temperature DH. The market of manufacturers of technical components is dominated by a few companies. Generally, low temperature DH solutions supply enough heat to secure the indoor comfort in new buildings and in buildings that have made continuous energy efficiency measures.

9.4.1 Level of maturity of the DHC network technology

DH is a mature technology in Denmark, competing with other heat systems (e.g. heat pumps). 1.7 million Danish households are heated by DH, which is around 64% of all households. The potential for district cooling is good but it is more common with individual cooling systems. In larger cities, especially in Copenhagen, DC is becoming more common.

LTDH systems is a relatively new technique but has been tested in some demo- and pilot projects. Today it is mainly applied to new housing areas. When dimensioning a heating system in Denmark it needs to deliver enough heat at an outdoor temperature of -12°C. However, the temperature only drops to -12°C for a few hours during a few days per year. During these hours the temperature can be raised by a backup system (e.g. heat pump or connection to a conventional district heating system). Denmark has potential of geothermal sources to be exploited, which could be one way to further develop LTDH in the country.

9.4.2 Availability of technical components, installers and operators

The components for LTDH are widely available, as it has been a trend during the last years to sharpen the standards when dimensioning the heat installations at the end users. The national standards (DS 469) as well as the recommendations from the Danish District Heating Association and the individual contractual terms among the +400 Danish DH companies foresee lower forward temperatures in the future.

There has been a tendency to be "on the safe side" when dimensioning DH components, so the end users will not experience too low temperatures at any given time. In general, many installers lack knowledge of LTDH, and operators also tend to like to be on the safe side with regards to tenants and e.g. schools and institutions. The same situation occurs in the DH supplies, where end users call in if they lack heat – resulting in the operators giving the forward temperature a few extra degrees.

Comfort cooling is relatively new in Denmark, only a very small part of the Danish housing stock has been prepared for cooling. Most common are individual solutions. DC has been present since 2008 in Copenhagen. The HOFOR District Cooling Company targets larger customers in Copenhagen – and the technical components needed for DC are available. The number of suppliers is limited, but the potential for expanding the DC market seems large, and in recent years more and more DC suppliers have been established around Denmark. As in Copenhagen, the suppliers target customers with a large cooling demand.

9.4.3 DHC solution replicability

In general, regarding replicability of solutions, LTDH can supply enough heat to secure indoor comfort in new houses and houses where continued improvements have been done over the years regarding energy efficiency (e.g. insulation, windows). A challenge can be found in buildings that are less prepared for LTDH. These could be historical buildings or houses where no improvements have been done in the latest 30-40 years and where other heating systems, e.g. conventional high temperature DH, have been used. For these cases, technical solutions need to be found regarding back-up heating systems. Studies and evaluations are needed in the specific cases on how to keep a solid and comfortable indoor temperature even during the coldest hours of winter. The current building norm in Denmark entails that new houses are constructed as low energy buildings, which is a good prerequisite when developing LTDH.

If smart metering and monitoring are used in the buildings, this could ease detection of eventual maintenance issues and increase the knowledge of how the buildings react on different outdoor temperatures. The continuously given data can also increase the transparency for both the heat supplier and end user.

9.4.4 Heat pumps

HPs are recognized in Danish legislation and is the preferred option in less populated and rural areas. In more dense areas where district heating or gas grids exist, they are the preferred heating system. HPs are not included in national statistics and data is only collected by the Danish Heat Pump Association. The interest of DHN to include large HPs and to renovate the networks to lower temperatures are driving the development of large HPs in Denmark.

Actors on the market, such as planners, architects and installers, are skilled and knowledgeable about HPs but mistakes are still made that could be avoided if the level of education increased. There is currently a debate as to whether installers should be required to be certified. Policy makers and customers need to become more informed about HPs for market expansion. The HP technology is available for all segments. Typically, the developer of a building would decide on the heating system, alternatively the installer would decide.

The primary energy factor provides an advantage of district heating over HPs and the electricity price is considered high. The Danish government recently agreed to reduce the electricity tax for heating purposes and to phase out individual gas and oil boilers and replace them with district heating and HPs. The Danish district heating associations long-term forecast is that about 30-40% of the heat production in DHN will be produced by HPs.

9.5 Legal factors

In Denmark the municipalities are responsible for heat planning, but there is a lack of national guidelines to fulfil the role. The heat planning regulation often favours natural gas to DH, when the natural gas prices are low. In recent years the price of natural gas has been low making it difficult to change the way of heating areas in the municipalities. Further legal aspects in Denmark include that the national building regulations lead to buildings with a smaller heat demand. DH is cheaper when the demand is high and concentrated, and the DH supply companies need to be innovative and become cheaper and more efficient.

9.5.1 Planning and permission

In Denmark the heat planning is a task for the municipalities (Lovbekendtgørelse nr. 120 af 6. februar om varmeforsyning, §3 (Law about district heating supply). The municipalities have the right to do heat planning, however they are not obliged to do so. Heat and energy planning by the municipality involves both strategic planning (transportation, production, land use, etc.) and local heat planning deciding on heating solution for an area. Large investments with a long perspective payback, for the municipality, for house owners and for private businesses, are not an easy task for politicians elected every four years. At the same time few municipalities have the knowledge in-house to do energy planning; the municipalities lack guidelines from the national level in order to fulfil their role as a heat planner (KL, 2020, Energibureauet, 2020, Storm Simonsen, 2020).

The heat planning regulation (Bekendtgørelse nr. 1792 af 27. december 2018 om godkendelse af projekter for kollektive varmeforsyningsanlæg (Regulation about the approval of projects about collective heat supply) often favors natural gas to DH. In order to change an area from being heated by natural gas two requirements need to be fulfilled: 1) a positive economy for the society, 2) a positive economy for the end user. For several years the price of natural gas has been low, why it has been difficult to change the way of heating areas. At the same time CO_2 has had no costs, so a green alternative to natural gas is just an alternative with no value, which is contradictory to the political wish for less emissions.

9.5.2 Heat and cooling market

The development of the heating market in Denmark is influenced by individualism contra collectivism. Traditionally, DH has been regulated as a natural monopoly, leading to lower prices the more customers that are connected. This led to the possibility of municipalities forcing building owners to be connected to DH in areas appointed as DH areas in Denmark (if the above-mentioned conditions are fulfilled). Before 2019 the municipality could force buildings to be connected to a local DH network by "local area plans" or by local heat plans through the regulation about being connected to collective DH networks.

The monopoly has led to large investments from the municipalities. However, in recent years the monopoly has been challenged by national legislation and it is no longer possible to force building owners to use DH in new housing areas, according to Lov nr. 1712 af 27. ecember 2018 om ændring af lov om varmeforsyning og lov om planlægning (Law about the change of the law of district heating supply and the law about planning). It has led to a vacuum, with experts agreeing upon the possibilities with DH supporting the green transition and at the same time short sighted investors neglecting DH when building new buildings. The belief that more efficient heating will be achieved if competition, regulation and more professional leadership is introduced, is contradicted by statistics showing that the cheapest DH in Denmark is supplied by non-profit consumer-owned DH (Forsyningstilsynet, 2020).

9.5.3 Buildings and indoor climate

The Building Regulation Act, Bekendtgørelse nr. 1399 af 12. december 2019 om bygningsreglement 2018 (BR18) – national regulation providing the situations, when the Building Regulation Act (BR18) are to be fulfilled, in Denmark leads to buildings with a smaller heat demand. Traditionally, DH has high costs both concerning supply of DH with pipes in the ground and installations in the buildings with waterborne heat systems; DH becomes cheaper when the demand is high and concentrated. The DH supply companies need to innovate and become cheaper and more efficient, which can be made by lowering the temperatures, leading to less heat loss and better opportunities for exploiting surplus heat and renewable energy efficiently. The heat loss is reduced linear with a smaller temperature difference between the pipes and the surrounding soil, and heat pumps work more efficiently the less temperature the heat pump shall deliver (Paaske, 2015).

Further buildings related legal conditions might also be implemented ahead. E.g. the government has come with a suggestion to stop using natural gas for heating by 2030 and is looking on a regulated way to calculate the benefits of different heating solutions compared to each other (Regeringen, 2020).

The Building Regulation Act furtherly sets out some standards or minimum requirements for new buildings and buildings under thorough refurbishment:

- The thermal indoor climate is not to exceed 26°C for more than a few hours, a national Danish Standard 474 (available at DS, Dansk Standard) sets the requirements to supplement the National Building Regulation.
- Each hour 50% of the air needs to be changed in homes
- There are specific requirements for kitchens and bathrooms
- The minimum requirement for added energy (for heating, ventilation, cooling and domestic hot water) to a house is 30 kWh/m^2 + 1000 kWh divided by the heated area
- A heat recovery system is required

9.6 Modelling results-based factors

The environmental key factors were assessed as barriers or opportunities based on the results of the TIMES optimization modelling, which are presented and briefly described below.

9.6.1 Specific cost of heat supply

Figure 32 shows the differences between the specific variable, fixed O&M, and capital costs of heat supply in the heating sector of Denmark in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be observed that all three types of costs are estimated to be lower in the future with developed LTDHC networks and utilization of LTH sources, as compared to the future with conventional DH.

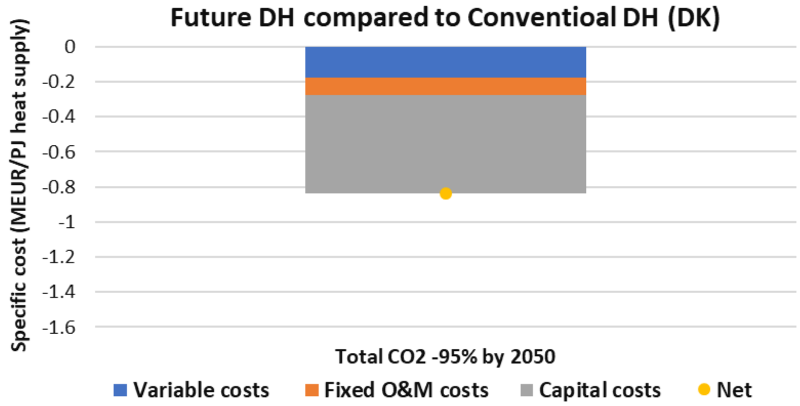


Figure 32 – The differences between the specific undiscounted Variable, Fixed O&M, and Capital (together with their total Net value) costs of heat supply in the heating sector of Denmark, averaged over the Years 2020-2050, in the FutureDH and ConventionalDH scenarios (with 95% CO_2 reduction by 2050).

9.6.2 Specific primary energy use

Figure 33 shows the specific primary energy use, divided into fuel use, electricity use and electricity generation, of heat supply in the heating sector of Denmark in year 2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). The modelling results indicate that with the development of LTDH networks and successful utilization of LTH sources the specific energy use of heat supply will be impacted insignificantly, as compared to the future with conventional DH networks.

Note: Specific primary energy use values for generated and used electricity were calculated using respective fuel use factors. Values for electricity generation are negative because generated electricity is assumed to be exported (from the heating sector) and substitute electricity generation in the electric power sector.

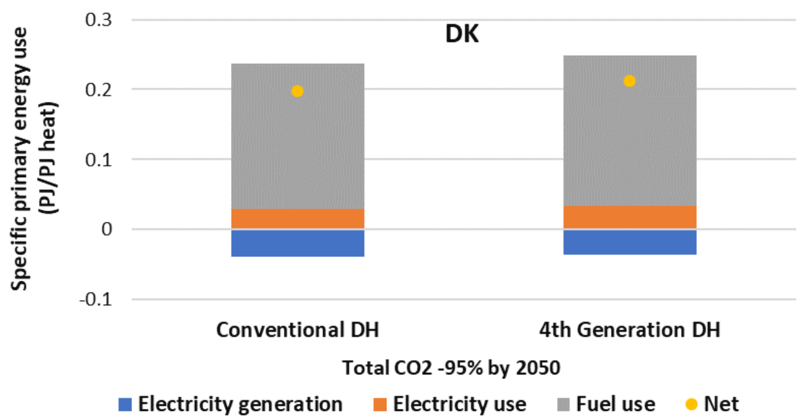


Figure 33 – The specific primary energy use, divided into fuel use, electricity generation and electricity use, of heat supply in the heating sector of Denmark in year 2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

9.6.3 Accumulated air pollutant emissions

Figure 34 shows the accumulated NOx, SOx, and PM2.5 emissions from the heating sector of Denmark over the period 2020-2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be noticed from the Figure that the replication of REWARDHeat solutions, i.e., development of LTDH networks and utilization of LTH sources, can lead to substantially lower air pollutant emissions in Denmark over the course of the next 30 years.

Note: Negative values in Figure 34 mean that electricity generated in the heating sector substituted emissions in the electric power sector and results in net negative total emissions of an air pollutant.

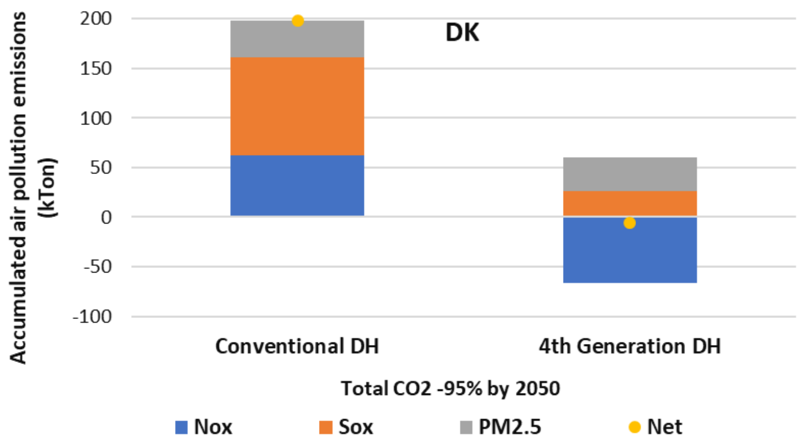


Figure 34 – The accumulated air pollutant emissions (NOx, SOx, PM2.5) attributed to heat supply in the heating sector of Denmark over the period 2020-2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

10 Annex: PESTLE Croatia

Croatia is in the central, south-east Europe with a coastline to the Adriatic Sea. The population as of 1 January 2019 was approximately 4.1 million (Eurostat, 2019c). The number of heating degree days in Croatia in 2018 was 2148 and cooling degree days 145 (Eurostat, 2019a). The energy consumption for heating in buildings (normal climate) in 2015 was 162 kWh/m^2 (Odyssee-Mure, 2019). The total primary energy supply in Croatia in 2018 consisted of 41.2% oil, 16.2% biofuels and waste, 5.6% hydro, 1.6% wind, solar etc, 30.6% natural gas and 4.8% coal (International Energy Agency, 2019b). The final energy consumption in 2017 was 79 TWh (Eurostat, 2019b).

Table 7 – Share of renewable energy in total energy, HC and electricity in 2017 (EuroStat, 2019d)

	RES in energy	RES in HC	RES in electricity	RES in transport
Croatia	27.3%	36.5%	46.4%	1.2%

10.1 Political factors

10.1.1 National energy and climate plan (NECP)

The energy development strategy for Croatia focuses on the three pillars; increased security of supply, ensure sustainable energy development and develop competitive energy systems. GHG emissions in the non-ETS sector are targeted to be reduced by at least 7% by 2030 compared to levels in 2005. The target for share of renewable energy in gross final energy consumption by 2030 is 36.4% and the specific target for transport is 13.2%

The energy renovation rate of the building stock of 0.7% per year is targeted to gradually increase to 3% over the period 2021-2030. Renovating the existing building stock, encouraging new building to be NZEB and set obligations of covering building energy demand with RES located in the building or in the proximity are part of the long-term strategy.

District heating systems have been identified as one of the priorities of the energy policy in Croatia with a focus on improving the energy efficiency of the existing infrastructure as well as integrating RES and heat pumps. There is an ongoing trend of customers disconnected and improving the network is a measure to reverting the trend. Integrating RES into the DHN is believed to increase the competitiveness of such systems and could result in new infrastructure. Especially geothermal energy is highlighted as something that could be exploited more in Croatia. The integration of RES in the DHN will be supported by measure under the ENU-17 "Increasing the efficiency of the heating system". Decreasing losses in the system due to old infrastructure is brought forward as something that could be achieved by shifting the technology to fourth and fifth generation. The shift in technology is also highlighted as one of the topics for research and development. The measure will include the introduction of advanced metering at end-user level.

The potential for high-efficiency cogeneration and efficient district heating and cooling was estimated according to Article 14 (1) of Directive 2012/27/EU. The potential was estimated as shares of future consumers of DH systems with high-efficient cogeneration by using two scenarios, one conservative and one optimistic. Between 30-55% of consumers have a theoretical potential to be connected to a high-efficiency cogeneration system (European commission, 2020c).

10.1.2 Political interest in REWARDHeat solutions

Low energy buildings are suitable for LTDHN and a political support for energy efficient buildings could provide an indirect support to the REWARDHeat solutions. Until 2020 in Croatia 10% of all new buildings had to be NZEB and from 2020 all new buildings must meet the requirements for NZEB (Ministarstvo graditeljstva i prostornoga urednja, 2018). Between 2021-2030 the plan is to renovate 3.5% of the existing building stock to NZEB standards (Ministarstvo zaštite okoliša i energetike, 2019). The existing DHN in Croatia (even with lower temperature) have too high PEF and not enough RES in the supply to be able to supply heat to NZEB.

In the energy strategy it states that RES in heat sector should be encouraged, mainly this refers to biomass and geothermal energy (EuroHeat & Power, 2017).

10.1.3 Financial support for REWARDHeat solutions

On national level there are support schemes available for RES in electricity or cogeneration purposes, not for heat production only (Ćetković, 2019). Electricity production from renewable energy sources and high efficiency CHP is supported by a sliding premium tariff. Only certain technologies apply, and a quota decides the support and to be eligible a call for tenders is issued at least once per year. As of 2019 no tenders had been issued because necessary additional legislation has not passed the required procedures (Musec and Kanceljak, 2019). Refurbishment of the existing thermal networks are often carried out using EU funding through the Operational programme competitiveness and cohesion 2014-2020. Zagreb and Osijek are two refurbishment projects that have been carried out.

10.2 Economic factors

10.2.1 Heating and cooling demand

The HC demand in Croatia was approximately 40 TWh in 2015 which is about 50% of the total energy consumption. As can be seen in Figure 35, the largest demand comes from the residential sector, mainly as space heating. Space heating is also the largest demand in the tertiary sector whereas process heating is most in demand for the industrial sector (Fleiter et al., 2017). Energy efficiency policies that are to be implemented have been evaluated from a heat demand perspective and found that the expected heat demand in the residential and commercial sector will decrease by 2030 and that the industrial sector will increase the demand by 2030 (Požar, 2015).

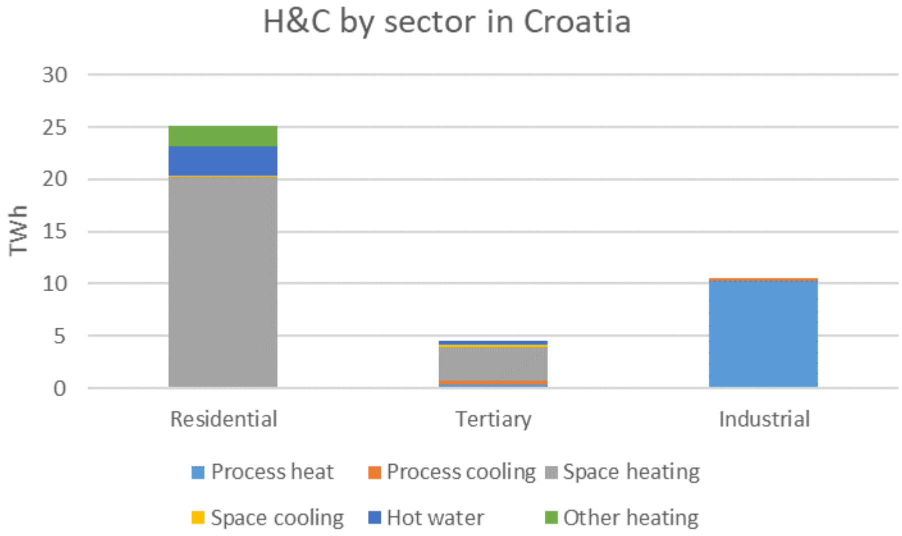


Figure 35 – HC by sector and country (Fleiter et al., 2017).

10.2.2 Heating and cooling supply

The HC demand in Croatia is mainly supplied by biomass (35%) and gas (30%), as can be seen in Figure 36 and Figure 37. Biomass is mainly used for space heating in the residential sector and gas mainly for process heating in the industrial sector and space heating in the residential sector. District heating supplied 3 TWh of the total HC demand, mainly as space heating to the residential sector (Fleiter et al., 2017).

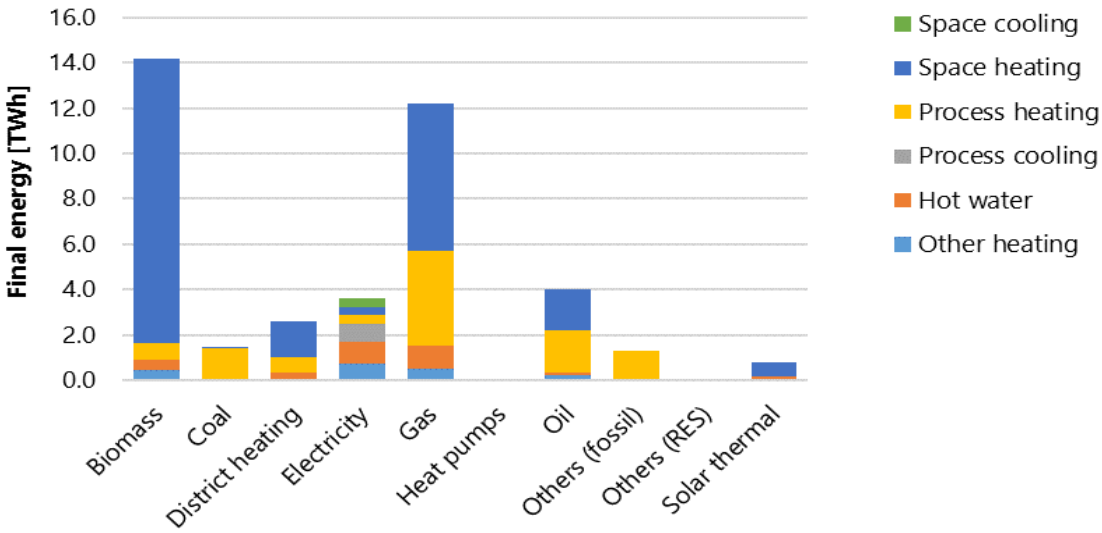


Figure 36 – Energy carrier for the final HC demand for all sectors in Croatia [TWh] (Fleiter et al., 2017).

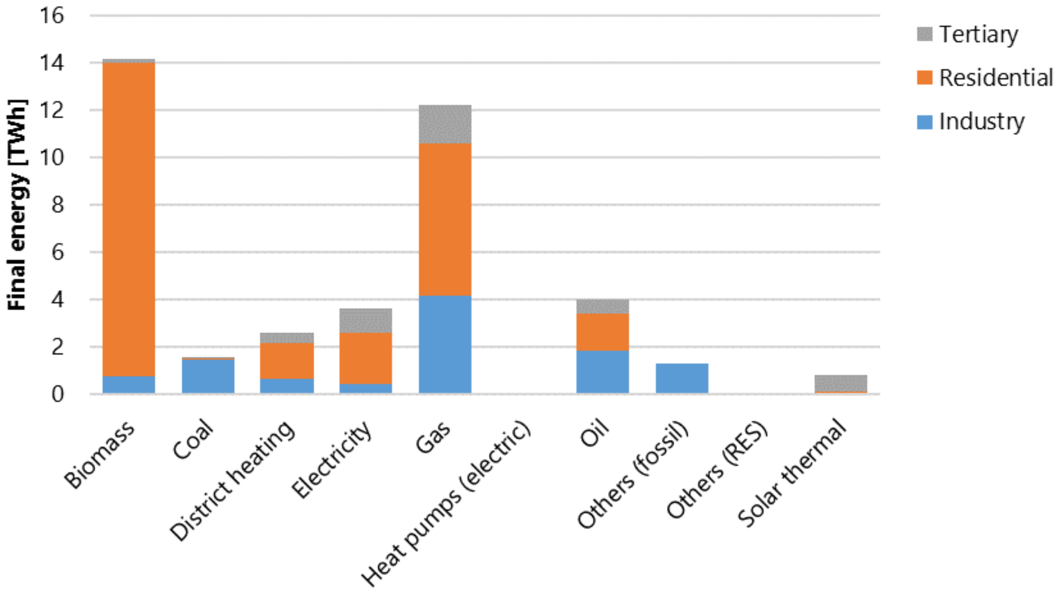


Figure 37 – Energy carrier split by sectoral demand in Croatia [TWh] (Fleiter et al., 2017).

10.2.3 District heating

There are about 104 DHN in Croatia. Most of the district heating (80%) is produced in CHP plants (EuroHeat & Power, 2017). The estimated share of cogeneration in the Croatian district heating and cooling systems is 79%. The DHNs in Croatia are often old and have high thermal losses and for further development of DHNs in Croatia the systems have to be renewed. Due to the building stock in Croatia lacking proper heating insulation in many places, supply temperatures must be above 100 degrees (e.g. in Zagreb) (Puksec and Duic, 2016), and refurbishment of the building stock is necessary to transition to LTDHN. Natural gas is the main competitor for district heating, and the main source for producing district heating at 74.5% of the fuel supply, followed by heat oil and very small portions of geothermal and biomass (EuroHeat & Power, 2017).

The Croatian Energy Regulatory Agency (HERA) is the agency that oversees the heat market. The Environmental Protection and Energy Efficiency Fund is the central point for collecting and investing extra budgetary resources in the programmes and projects that relate to environmental and nature protection, energy efficiency and use of renewable energy sources. The Ministry of environment and energy are the lawmakers in the energy sector. The Renewable Energy Sources of Croatia is an interest association that covers 70% of all electricity produces from renewables (Maras and Šimek, 2018).

The business set-up of DHN is typically business-to-business. About 85% of the district heating market is owned by a state-owned sister company to the national power company, HEP Toplinarstvo. In some cases, such as the REWARDHeat demo site In Croatia, the heat networks are owned by the local public authority. Some corporately owned CHP plants exist but the thermal energy is then used in the local industry process and rarely for DH purposes (EuroHeat & Power, 2017).

In Croatia the price per kWh for household consumers is 0.04€ for both DH and natural gas. Given that the price per unit is the same and the fact that customers are aware of problems involved with

DH, old networks, frequent distribution disruptions and high heat losses in the system, natural gas is often preferred (Eurostat, 2020b).

Geothermal energy is used in district heating systems in three locations in Croatia and the installed capacity is 42 MW_{th} (Živković et al., 2019). Solar thermal has been integrated into one network in Croatia.

10.2.4 Potential for waste heat and renewable energy sources

The practical utilization potential for annual available urban waste heat from four studied categories identified a potential of 8.1 PJ (or 2.2 TWh) in Croatia (Persson and Averfalk, 2018). The respective potential of the categories was data centres (1.5 PJ), metro stations (0 PJ), service sector buildings (2.6 PJ) and wastewater plants (4 PJ). The industrial waste heat recovery in the country has been estimated at 1 (Papapetrou et al., 2018a) - to 5.3 TWh/year (Persson, 2015).

Geothermal energy has a long tradition in Croatia as a heating source for bathing. Out of the 28 geothermal fields, 18 are being utilized today. The identified thermal capacity is 740 MW_{th}, of which 114 MW_{th} are utilized today. The geothermal temperature gradient in Croatia indicates a higher potential in the Panonian basis to the north-east inland side of the country and in the Dinarides to the south and towards the coast (Živković et al., 2019). Installed capacity of solar thermal in 2017 159 MW_{th}. The installed solar PV capacity in Croatia in 2017 was 60 MW and produced 0.079 TWh (EurObserv'ER consortium, 2018). The potential for solar PV production is visualized in Figure 38 and show a higher potential along the Adriatic coastline, especially in the southern regions (SOLARGIS, 2020).

Figure 38 – The photovoltaic power potential in Croatia (SOLARGIS, 2020).

10.3 Social factors

In Croatia responses for the survey were collected by going door-to-door with customers connected to the REWARDHeat demonstration site in Topusko. 10 responses were collected, 5 end-users and 5 professional customers. The respondents were all connected to a DHN today.

10.3.1 General opinion of DHN

Respondents have a generally very positive opinion about the technology. Respondents are also very positive towards DHN being a convenient, resource- and cost-efficient solution (Figure 39).

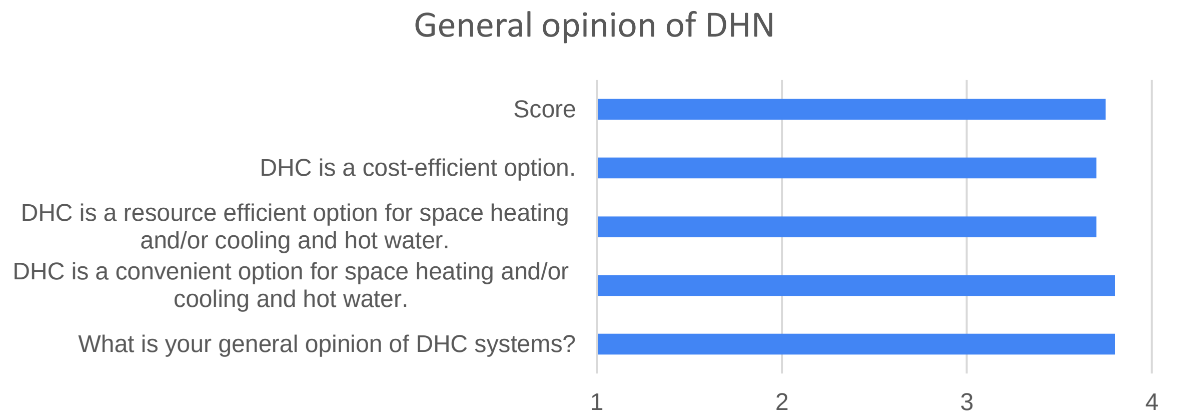


Figure 39 – Mean values of the respondents on their general opinion about DHC (Croatian demo site), as well as the resulting score. The respondents answered on a 4-degree Likert-scale were 1= I don't agree, or very negative, and 4= I agree completely, or very positive.

10.3.2 Awareness of technology

All respondents are familiar with DHN and all, but one respondent, perceives that it is available in most cities in Croatia. 70% of respondents had heard about LTDH and 90% had heard about waste heat integration. None of the respondents knows about of DHN with RES integration. Respondents think that they know very well how a DH system works (Figure 40).

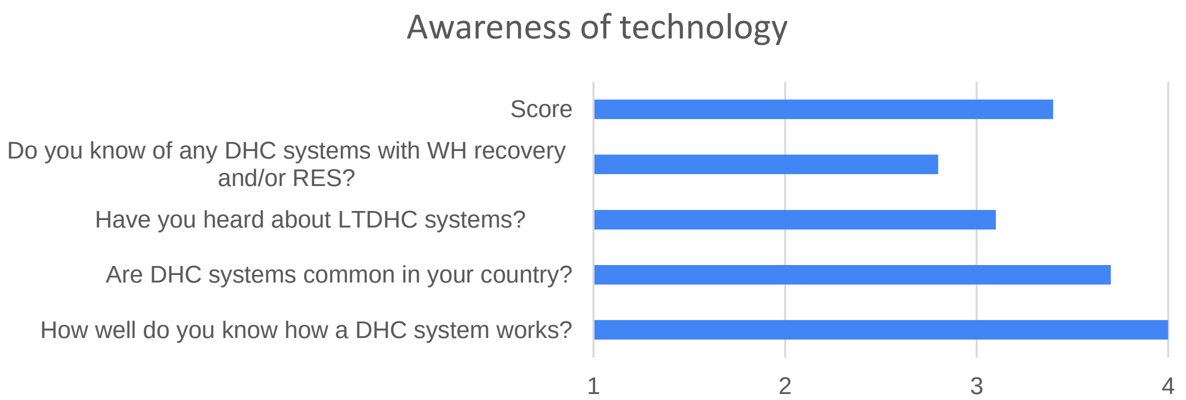


Figure 40 – Mean values on the awareness of the technology, as well as the resulting score (Croatian demo site).

10.3.3 Risks and benefits

With regards to risks and benefits, respondents foresaw two main benefits of having a LTDHN; energy savings and environmental benefits. Two residents believe that there is a risk of high-water consumption and one building owners find the main risk to be that the technology has high investment costs. All residents mentioned the environmental aspect as the main benefit of integrating of RES and excess heat whereas the building owners mainly sees financial savings followed by energy savings and environment aspects (Table 8).

Table 8 – Perceived risks and benefits of the REWARDHeat technologies by respondents as well as the resulting score (Croatian demo site). Respondents answered in open text fields and could write as many benefits or risks as they wanted. The number displayed in the parenthesis is how many respondents stated the risk/benefit.

	Benefits LTDHN	Risks LTDHN	Benefits RES & WH	Risks RES & WH
Professional customers	Energy savings (5)	High investment costs (1), don't know (4)	Energy savings (1), environmental (1), financial savings (2), don't know (1)	No risk (2), don't know (3)
End-users	Energy savings (3), environmental (3)	High water consumption (2), no risk (3)	Environmental (4), lower CO_2-emissions (1)	No risk (3)

10.3.4 Environmental consideration

Professional customers are somewhat more concerned than end-users about climate change and to a larger extent thinks that the forecasted effects are certain. All respondents consider climate change when using energy for heating and/or cooling and all respondents believe that including RES and excess heat is beneficial for the environment (Figure 41).

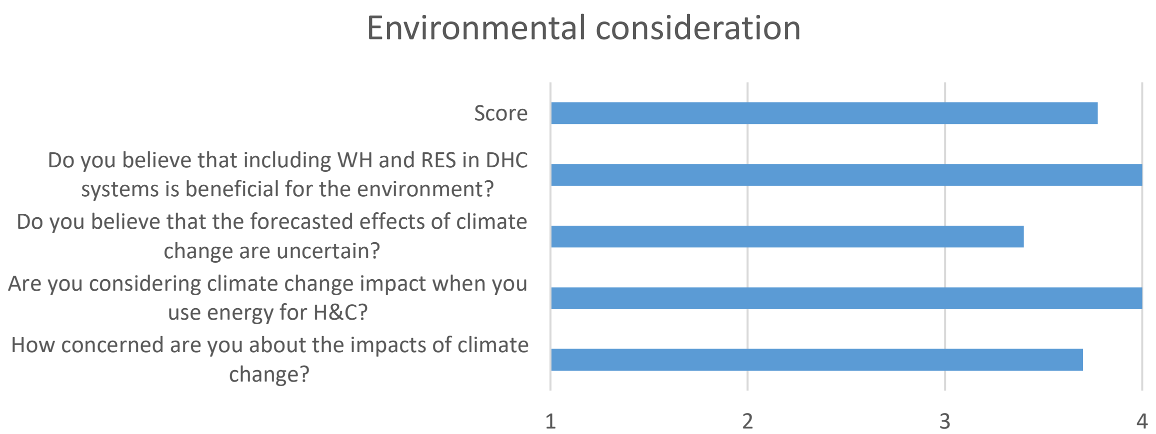


Figure 41 – Mean values on the environmental consideration, as well as the resulting score (Croatian demo site)

10.3.5 Cost expectancy

All respondents think that having a LTDHN or integrating excess heat or RES into a DHN result in a less expensive energy bill compared to conventional DH (Figure 42).

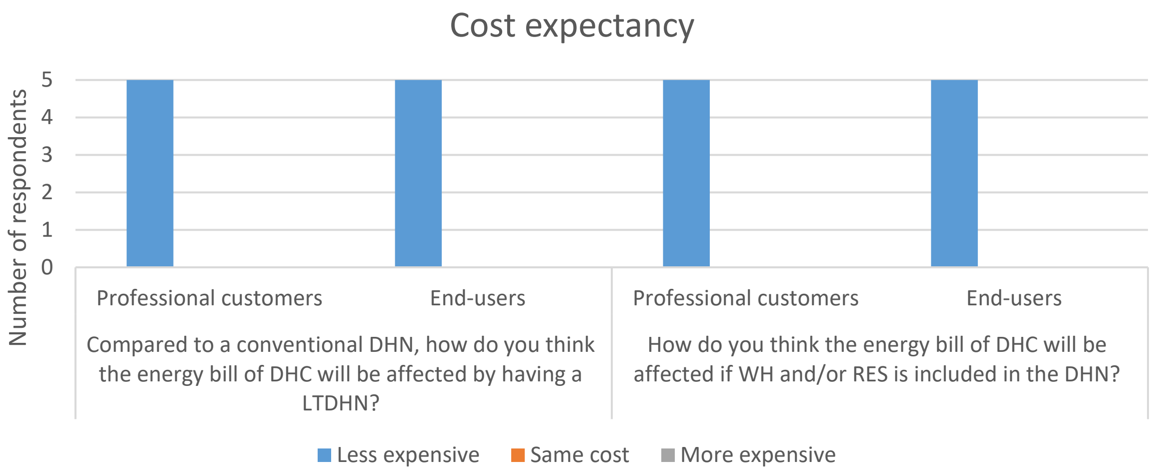


Figure 42 – Cost expectancy of end-users and professional customers (Croatian demo site)

10.4 Technical factors

In Croatia there are about ten large conventional DHN, low or neutral temperature DHC is unusual. The demand of alternatives and availability of control systems for district heating systems are covered by the market of European companies. The availability of companies performing the installations of innovative technical solutions in the specific projects and locations are generally more challenging.

10.4.1 Level of maturity of the DHC network technology

In Croatia the heat market is dominated by one single national heat company. There are about ten large district heating networks in the country, located in the major cities. The biggest network is in Zagreb, connected with two co-generation units. Conventional DHN are the most common and it is rather unusual with low or neutral temperature DHC. One example of a low temperature network is the REWARDHeat demo site in Topusko, where geothermal energy has provided heat to the local district heating through a single supply line for 30-40 years. There are also some cases with steam systems connected to small industrial consumers in the country. In Vukovar city a small 3rd generation district heating system is operated which utilizes large-scale solar thermal energy. This is the first such system in Croatia.

10.4.2 Availability of technical components, installers and operators

Depending on the technical solution of the low or neutral temperature district heating the availability of technical components, installers and operators vary. Regarding alternatives and availability of control systems for district heating systems the market with different European companies covers the demand. The availability of companies performing installations of the innovative technical solutions in the specific projects and locations are generally more challenging. District heating network pipes are usually provided by EU manufacturers such as ThermalFlex and Isoplus.

10.4.3 DHC solution replicability

The local prerequisites are important for evaluating replicability possibilities for certain DHC solutions. In general, a main current issue in Croatia regarding DH is old networks with substantial thermal losses. The major investments in heating systems are in repairing pipes or installing new ones, to increase the efficiency of the networks. In the case of Topusko the pipes also need regular maintenance due to corrosion resulted by the chemical composition of the geothermal water. The technical solution at the Topusko demo site is very site specific due to the geothermal heat resource and could only be replicable at other sites with the same conditions.

One other factor that impacts the development of DH is that in 2020 all new buildings will be near zero energy buildings. The regulations have three criteria (primary energy, share of RES and ventilation properties) and the calculations for a building is based on country level data. With the country level data of today, DH is less favourable to achieve the zero-energy building norm compared to e.g. brown coal or natural gas. This is a challenge in the development of district heating (such as technical solutions for low and neutral temperature), if less of the new building stock can connect to it. Nevertheless, in the Croatian National Energy and Climate Plan it is mentioned that development of new DH systems is crucial for meeting energy and climate goals in 2030.

10.4.4 Heat pumps

HPs are recognised in the legislation in Croatia as a measure for achieving energy efficiency and climate reduction targets. HPs are expected to increase as more renovation projects to NZEB are foreseen. Large capacity HPs in district heating systems are also expected to increase. The Croatian Ministry of Environment and Energy provide statistics on HPs but only as heat energy produced, no data on number of HPs installed in different sectors is provided.

HPs are dominating in new buildings for commercial purpose (especially tourism) where cooling is essential and frequently occurring in other newly built residential areas (especially in more attractive areas). There is a growing interest for HPs in DHN as well as in the industrial sector where HPs are mainly utilised for waste heat recovery. Generally, the building developer and the individual building owner makes the decision on heating system and the architect influences the decision.

Actors in the markets, such as installers, planners and architects, are considered knowledgeable to both recommend and install HP systems but there are not enough qualified actors. Often situations that are negative for the HP market occur due to faulty HP systems. Various explanations are identified; unqualified installer, lack of appropriate control system, installation and sizing is not properly documented or a general lack of knowledge. HPs are in strong competition with other heat sources in Croatia. In areas where the gas grid is available HPs cannot compete with gas boilers, neither in investment nor operating costs. In rural areas wood and biomass is expected to remain the dominant heat source for low- and medium-income households.

10.5 Legal

In Croatia the heat sector is regulated by several laws; Heat market law, Renewable energy sources and highly efficient cogeneration law, Energy efficiency law and Energy law. The heat market law states that DHC systems play a crucial role to achieve national energy efficiency goals and the responsibilities of the municipalities for the systems. The energy efficiency law defines an efficient DHC network as at least 50% of heat from RES or WH or 75% of heat from co-generation or 50% of heat from a combination of these heat sources. The energy law states that DHN owners are obligated to maintain and modernize the systems (Puksec and Duic, 2016).

10.5.1 Planning and permission

Before constructing energy production projects (such as DHC networks) in Croatia several licenses and permits are needed. Gathering the permits can take more than a year (e.g. in the case of the DHC network in Topusko the process took six years, and building the system took six months). Projects within DHC networks can be public, private or built in public private partnership. In a public private partnership, a document between the public institution and the private company is signed and then conceptual design is selected. The next step is to obtain location permit, building permit and ecologic permit. After this public procurement is made. Projects financed by EU funds acquire additional documentation. In order to receive feed-in-premium tariffs for electricity production in CHP plants additional documentation is needed in five different main procedure steps (Puksec and Duic, 2016).

10.5.2 Heat and cooling market

The heat market law defines in detail all DH network participants, their obligations and guidelines for different procedures connected with DH networks. The key heat market participants are heat producers (producing heat in heat facilities), heat distributers (distributing produced heat through the distribution network), heat suppliers (buying heat from heat producer(s) and making a contract with heat distributor(s) for distribution of heat in order to sell it to the heat buyers), heat buyers (buying heat in the name of owner(s) of the house/building), end buyer (buying heat from the heat buyer for their own consumption) (Puksec and Duic, 2016). The heat producers sign a contract with the heat distributers in order to distribute heat, and contract for the sale of heat energy with the heat supplier. The heat supplier establishes a heat distribution agreement with the heat distributer, together with a supply agreement with the heat buyer and a supply contract with the end buyer. The heat buyer finally signs a heat consumption agreement with the end buyer (Krklec, 2015).

Furthermore, the heat market law describes the calculation methodology of all fees and tariffs paid by heat market participants. The fee for concession for heat distribution is 0.05% of the revenue from the heat distribution the previous year, or 0.05% of the planned income from heat distribution if the distributer did not operate the previous year. The tariffs are divided between the residential and non-residential sector and between energy and capacity (with town specific values) (Republic of Croatia Ministry of Environment and Energy, 2018). The law states the amount of the tariff paid by the heat producer if the heat production of the DH network is a public service. It also determines the allowed revenue for the producer or distributor to cover expenses for the heat production or distribution. Additionally, the regulation states all heat buyer's payment obligations and the amounts that should be paid for heat in the DH network.

10.5.3 Buildings and indoor climate

From 2020 all new constructed buildings in Croatia must be NZEB. "Technical regulation on rational use of energy and thermal protection in buildings" is the core regulating document with requirements for construction of new buildings and renovation of existing ones (Ministarstvo graditeljstva i prostornoga uređenja, 2018). The total area of privately-owned buildings is around $179*10^6$ m^2 and the area of publicly owned buildings around $14*10^6$ m^2. If 3.5 % of the stock is renovated according to NZEB standard per year, there is a significant area eligible to connect to LTDH. In 2016 the total area of new constructed buildings was $2.6*10^6$ m^2. If the same construction rate would continue, more than $2.5*10^6$ m^2 per year of NZEB could be eligible for LTDH (Ministarstvo graditeljstva i prostornoga urednja, 2018). Most of the existing buildings are not energy-efficient and require high temperature heating. By implementing the NZEB standard the heat demand will decrease, which could stimulate DH owners and potential investors to shift to LTDH. One issue, according to document Primary energy factors and CO_2 emissions, is that DH networks in Croatia have high primary energy factors which means that NZEB buildings will not be able to meet 30% energy consumption from RES if connecting to current DH networks (Ministarstvo graditeljstva i prostornoga urednja, 2017).

Further legal requirements are set for thermal systems and indoor climate. E.g., indoor temperature should be 18°C or more. Specifically, for family houses located in continental Croatia internal temperature should be 24°C during the winter season, while family houses in coastal Croatia should have internal temperature of 22°C during winter season. The heating season should start at least by 15th of September and last, at least, until 15th of May next year. The operating hours should be 05:00-22:00. During night regime, the DH operator must secure an internal room temperature of 15°C. Production of domestic hot water is also required to be at specific temperatures. The required temperature is at 43°C after the heat exchanger or at the outlet of the thermal storage (Hrvatska energetska regulatorna agencija, 2014) (Sveučilište u Zagrebu Fakultet strojarstva i brodogradnje, 2017).

10.6 Modelling results-based factors

The environmental key factors were assessed as barriers or opportunities based on the results of the TIMES optimization modelling, which are presented and briefly described below.

10.6.1 Specific cost of heat supply

Figure 43 shows the differences between the specific variable, fixed O&M, and capital costs of heat supply in the heating sector of Croatia in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be observed that all three types of costs, but mainly the variable cost, are estimated to be lower in the future with developed LTDHC networks and utilization of LTH sources, as compared to the future with conventional DH.

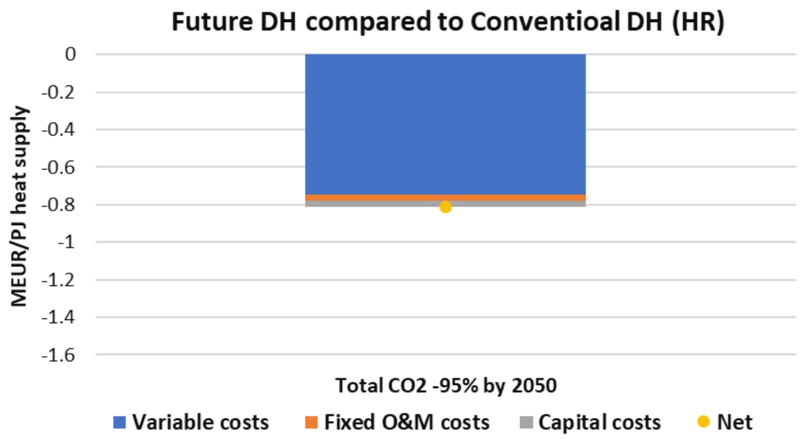


Figure 43 – The differences between the specific undiscounted Variable, Fixed O&M, and Capital (together with their total Net value) costs of heat supply in the heating sector of Croatia, averaged over the Years 2020-2050, in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

10.6.2 *Specific primary energy use*

Figure 44 shows the specific primary energy use, divided into fuel use, electricity use and electricity generation, of heat supply in the heating sector of Croatia in year 2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). The modelling results indicate that with the development of LTDH networks and successful utilization of LTH sources the specific energy use of heat supply will be impacted insignificantly, i.e., decreased by more than 50%, as compared to the future with conventional DH networks.

Note: Specific primary energy use values for generated and used electricity were calculated using respective fuel use factors. Values for electricity generation are negative because generated electricity is assumed to be exported (from the heating sector) and substitute electricity generation in the electric power sector.

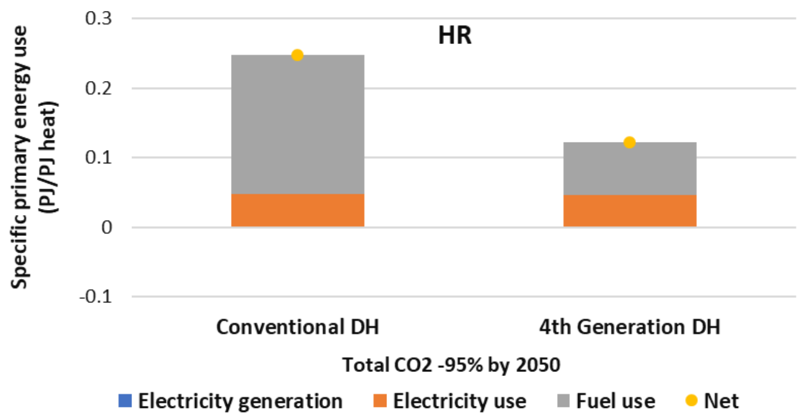


Figure 44 – The specific primary energy use, divided into fuel use, electricity generation and electricity use, of heat supply in the heating sector of Croatia in year 2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

10.6.3 Accumulated air pollutant emissions

Figure 45 shows the accumulated NOx, SOx, and PM2.5 emissions from the heating sector of Croatia over the period 2020-2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be noticed from the Figure that the replication of REWARDHeat solutions, i.e., development of LTDH networks and utilization of LTH sources, can lead to lower air pollutant emissions in Croatia over the course of the next 30 years.

Note: Negative values in Figure 45 mean that electricity generated in the heating sector substituted emissions in the electric power sector and results in net negative total emissions of an air pollutant.

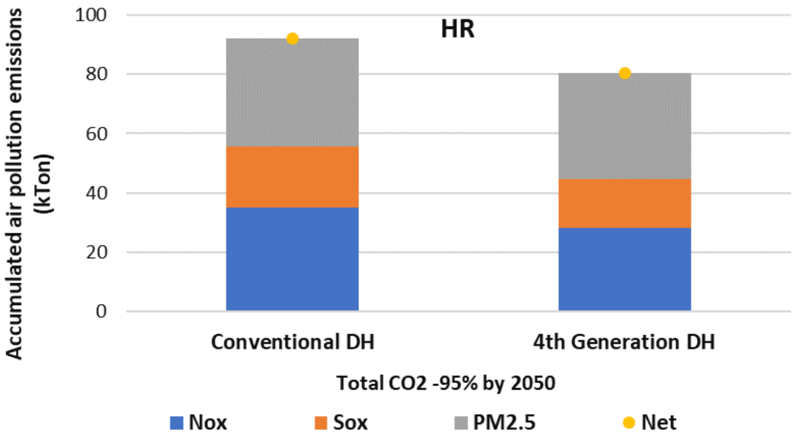


Figure 45 – The accumulated air pollutant emissions (NOx, SOx, PM2.5) attributed to heat supply in the heating sector of Croatia over the period 2020-2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

11 Annex: PESTLE Germany

Germany is located in western Europe with a coastline in the north to the North Sea. The population as of 1 January 2019 was approximately 83 million (Eurostat, 2019c). The number of heating degree days in Germany in 2018 was 2775 and 51 cooling degree days (Eurostat, 2019a). The energy consumption for heating in buildings (normal climate) in 2015 was 128 kWh/m^2 (Odyssee-Mure, 2019). The total primary energy supply in Germany in 2018 consisted of 32.4% oil, 9.9% biofuels and waste, 0.5% hydro, 6.5% nuclear, 4.8% wind, solar etc, 23.6% natural gas and 22.2% coal (International Energy Agency, 2019b). The final energy consumption in 2017 was 2379 TWh (Eurostat, 2019b).

Table 9 – Share of renewable energy in total energy, HC, electricity and transport in 2017 (EuroStat, 2019d)

	RES in energy	RES in HC	RES in electricity	RES in transport
Germany	16%	13%	34%	7%

11.1 Political factors

11.1.1 National energy and climate plan (NECP)

The German energy policy centres around security of supply, environmentally friendly and affordability. Using energy more efficiently, reducing the primary energy consumption and increase the amount of renewable energy. GHG emissions to be reduced by at least 55% by 2030 compared to 1990 and to be largely GHG neutral by 2050 including a virtually climate-neutral building stock.

Share of renewable energy in gross final energy consumption to be 30% by 2030, focusing on both electricity, heating and cooling as well as transport. 65% of the electricity mix should be renewable energy by 2030, 27% of the heating and cooling sector and 27% in the transport sector. Coal in electricity production to be phased out by 2038 at the latest. Coal-fired power plants are still the dominant source of energy in Germany.

Through the Energy Efficiency Strategy 2050 (EffSTRA) the primary energy consumption should be reduced by 30% by 2030 compared to 2008. In all sectors the main idea is to promote "Efficiency First", the second priority is the direct use of renewable energy and the third option is to use electricity generated by renewable sources. For the building stock this entails that measures such as insulation, efficient windows and other building envelope enhancing measures are prioritised as well as efficient systems for heating, cooling and light, a 3% renovation rate of the building stock is required. Further integrating the electricity, heating and transport sector is a target for the internal energy market.

The renewable energy target for the heating and cooling sector by renewable heat technologies and decarbonized district heating. Heat pumps are expected to increase, especially in new buildings. District heating supply will change drastically in the coming years when moving from coal-fired CHP to renewable energy sources. A large expansion of low temperature heating network, and refurbishment of existing networks, is expected and encouraged to be developed in order to increase the share of energy from renewables and excess heat. In Germany these types of networks are denoted Heat network 4.0 and often include a large thermal storage. Heating networks in Germany have a specific target of 30% renewable energy in supply.

Carbon pricing will be introduced to the heating and transport sector to further drive decarbonization (European commission, 2020c).

11.1.2 Political interest in REWARDHeat solutions

Climate Change Action Plan 2050 mentions LTDHN with a high degree of renewables as an important part of reaching an almost climate neutral building stock. DHN, in combination with more energy efficient buildings and integration of renewable energy on individual houses (Federal Ministry for the Environment, 2016).

There is no definition of low-energy houses, the international standard value for maximum heating requirement of a low-energy house is a maximum of 70 kWh/m^2. Since the Energy Saving Ordinance 2009, all new buildings must meet this requirement and as such every new building is a low-energy house. There are about 10,000 passive houses (may not exceed 15 kWh/m^2) in Germany.

One of the key energy efficiency measures for the industry sector in the *Climate Change Action Plan 2050* is to reduce or reuse the waste heat produced in many industrial processes at all temperature levels, both within the industry or in nearby residential areas using local and DHN. These aspects will be considered in upcoming programs and measures. Integration of large-scale heat pumps and solar thermal systems to the DHN is also encouraged in the policy. The policy aims to make it more attractive for the building sector to phase out of fossil-fuels in the heating systems and replace with efficient new heating systems using renewable energy (Federal Ministry for the Environment, 2016).

One of the action points in the *National Energy Efficiency Action Plan (NEEAP)* is to perform an inventory and label and potentially upgrade old heating systems based on heaters or boilers (International Energy Agency, 2019a). As a part of the NEEAP an energy efficiency fund was established to promote economic use of energy (Odyssee-Mure, 2019). To increase the share of RE in the HC system the *Renewable Energy Heat Act (EEWärmeG)* set binding targets for some categories of buildings that must cover part of their energy consumption used for HC with RE by 2020 (International Energy Agency, 2019a). Energy standard for building will be gradually updated by 2030 (Federal Ministry for the Environment, 2016).

11.1.3 Financial support for REWARDHeat solutions

Funding at system level for heat networks is provided since July 2017 under the *Pilot Project Heating Networks 4.0* where fourth generation DHNs can receive funding. Fourth generation is described as lower temperatures, renewable and waste heat integration. Heat pumps, seasonal storage and flexibility towards the electricity system are encouraged in the funding for heating systems. To be eligible for funding the systems must have 50% of annual heat consumption provided by renewable energy and only 50% of the RE share can come from biomass. DHN with supply temperatures of 20°C are also foreseen to receive support (Federal Ministry for Economic Affairs and Energy, 2017, Bröer, 2017).

Financial support to renewable heat generation is stipulated in the *Market Incentive Programme (MAP)* and some investment support is available both for individual heat installations and district heating systems (*BAFA and KfW*). Technologies supported by the support scheme is biogas, biomass, geothermal energy and solar thermal. Support can be given to low temperature district heating networks (Sternkopf, 2019). KfW's funding program Renewable Energy (Erneuerbare Energien) section Standard provides low-interest loans for investments in installations for electricity production in accordance with the EEG, cogeneration plants and for small heat production installations. In program section Premium low interest loans with repayment subsidies are granted for renewable energy heat produced in large installations. KfW funding programs for energy-efficient construction and renovation (CO_2 building renovation program), which promote the development of renewable energies, are Energy efficient Construction (Energieeffizient Baue), Energy Efficient Renovation (Energieeffizient Sanieren) or Energy-efficient Renovation – Local Authorities (Energieeffizient Sanieren – Kommunen) and Social Investment - Building Refurbishment (Sozial Investieren- Energetische Gebäudesanierung).

In the 7th Energy Research Programme of the Federal Government defines funding priorities for the energy transition. In the new field "Cross-system research topics for the energy transition" covers REWARDHeat solution (Federal ministry for Economic Affairs and Energy, 2018).

The Heat-and-power Cogeneration Act (KWKG) regulates the funding of old and new combined heat and power (CHP) plants and the development and construction of heating networks into which heat from CHP-plants is fed. Guidelines on the promotion of mini-CHP plants promote through investment grants the new construction of CHP - plants up to 50 kW_e. The Energy Tax Act (*EnergieStG*) provides tax relief for energy products used for combined heat and power production if the CHP plant has a monthly or annual efficiency of at least 70%. There is also a tax exemption for biogas which is combusted immediately after production or is used in a CHP plant.

Electricity produced by any renewable energy is supported by a market premium scheme which is the main support scheme for promoting renewable energy as stipulated in the EEG 2017. Smaller installation <100kW, regardless of renewables source, are supported by a feed-in tariff stipulated in the EEG 2017 (Sternkopf, 2019). Under the Renewable Energy Sources Act (EEG), sector-specific tariffs are set for electricity from renewable energies fed into the public supply grid. The amount of compensation follows the principle of cost-covering compensation and is based on the specific electricity production costs of the specific sectors.

11.2 Economic factors

11.2.1 Heating and cooling demand

The HC demand in Germany reached 1384 TWh, approximately 56% of the total energy demand (Paardekooper et al., 2018a). As shown in Figure 46, the residential sector has the largest demand and most of the demand is space heating. The industrial sector mainly demands process heat and the tertiary sector is mainly in demand for space heating (Fleiter et al., 2017).

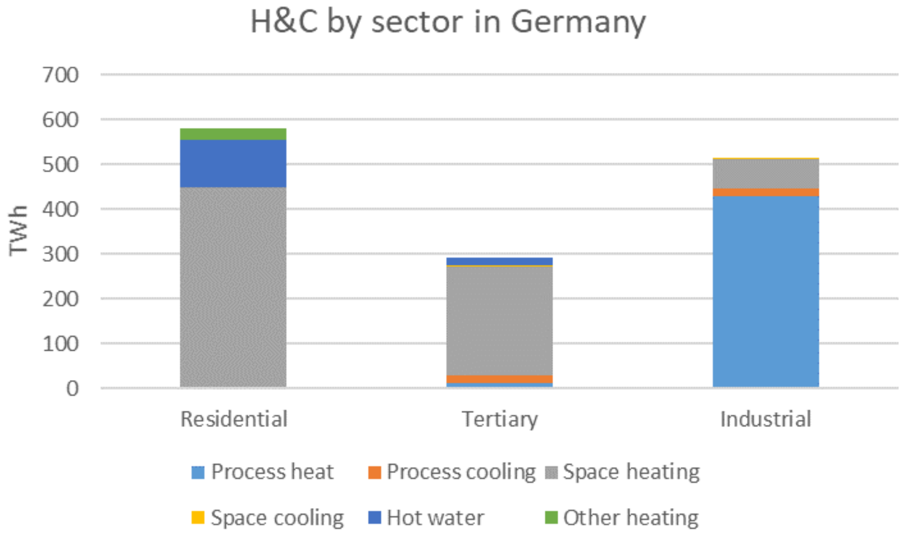


Figure 46 – Heating and cooling by sector and country (Fleiter et al., 2017).

In the Heat Roadmap for Germany the current policy which is mainly focusing on space heating is expected to lead to an 18% decrease in HC demand. Space heating is expected to decrease by 29%, hot water and process heating decrease by 1%. Demand for space cooling is expected to more than triple from 2015 to 2050, mainly in the service sector. Process cooling is expected to remain at the same levels as 2015. The space and process cooling are not expected to represent more than 13% of the total HC demand in Germany in 2050 (Paardekooper et al., 2018a)

11.2.2 Heating and cooling supply

The HC demand in Germany is mainly covered by gas (42%), shown in Figure 47 and Figure 48. Gas is used for space heating; process heating and hot water and gas is used in all three sectors. District heating is supplying 10% of the HC demand and mainly for space heating and DHW to the residential and industrial sector (Fleiter et al., 2017).

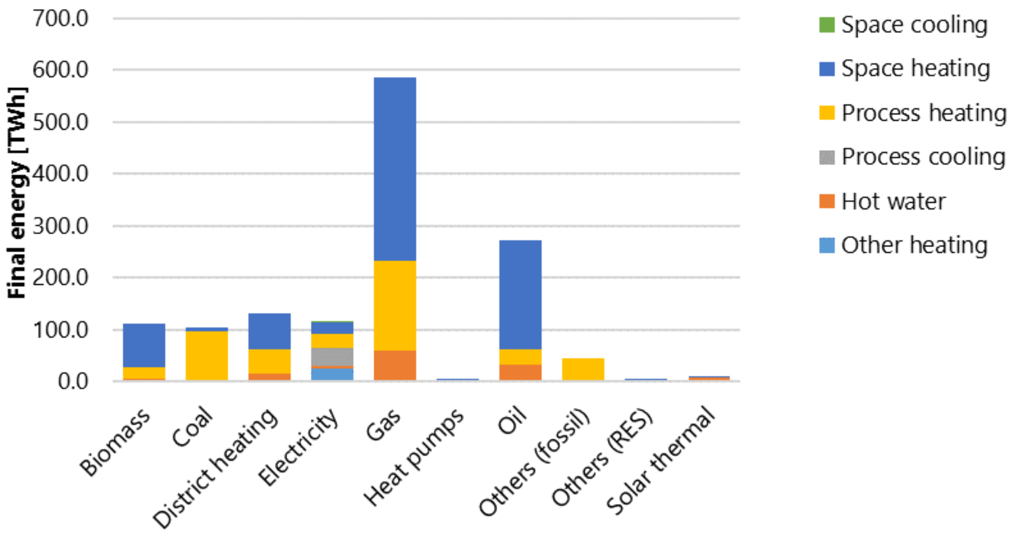


Figure 47 – Energy carrier for the final HC demand for all sectors in Germany [TWh] (Fleiter et al., 2017).

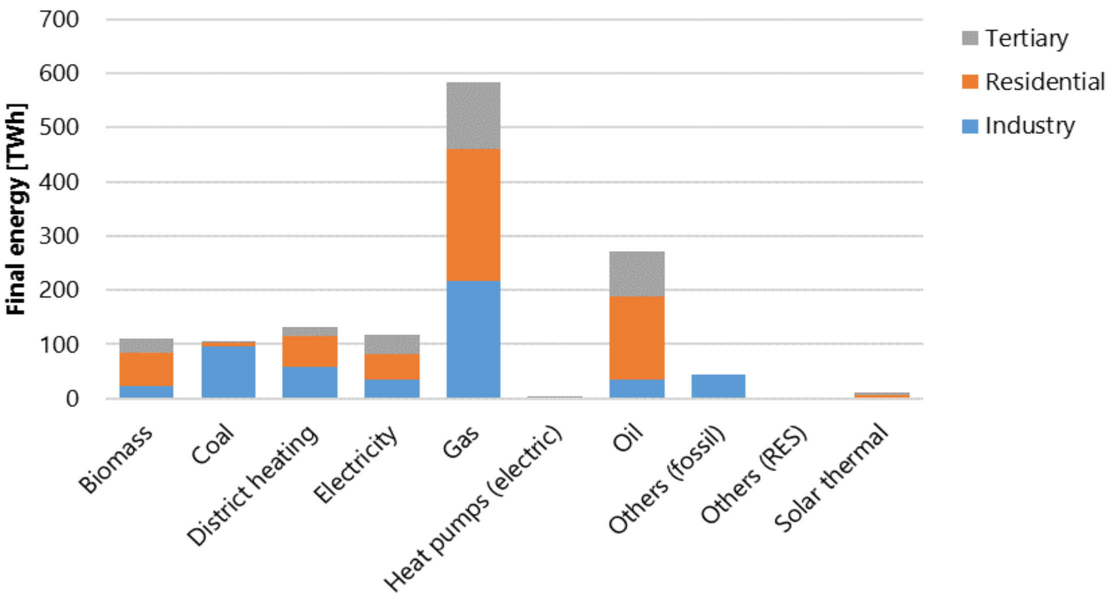


Figure 48 – Energy carrier split by sectoral demand in Germany [TWh] (Fleiter et al., 2017).

11.2.3 District heating

DH has been present in Germany since the end of the 19th century and the acceleration started after the oil crises in the 70's and with the German energy transition taking off in 2010 it has boosted the development of DHN (Lutsch and Werner, 2017). Germany has about 1372 DHN. Most of the heat in the DHN (83% in 2015) is generated in CHP plants (Fleiter et al., 2017). Germany's DHN is mainly supplied by fossil fuels. In 2015 coal supplied 47% of the production and natural gas 39% (EuroHeat & Power, 2017). The district cooling capacity was 161 MW_{th} in 2011. Germany has some LTDHN in operation today (Fleiter et al., 2017) with temperatures down to 8-20°C. District cooling is available for example in München and Dresden.

The German District heating association (AGFW) established in 1971, covers nearly 100% of all DH in Germany and works to promote energy efficiency, heat from renewables, storage, HC and CHP at national and international level (Lutsch and Werner, 2017). The BDEW Federal Association of the Energy and Water Industries members account for 95% of Germany's electricity and gas networks and 78% of its heating and cooling networks. The German Cogeneration Association (Bundesverband Kraft-Wärme-Kopplung e.V. (BKWK)) promotes the technical organisational principle of cogeneration, irrespective of the type and size of the plants, the area of application and the energy source used. The aim of the association is to increase the efficiency of energy conversion in order to conserve resources and reduce environmentally and climate-damaging emissions.

On a higher level there are many organisations (think-tanks, agencies, centre of expertise, associations etc) with the purpose the enable and drive the energy transition in Germany. Some examples are Agora Energiewende, The Federal Association of Energy and Climate Protection Agencies in Germany (eaD), Deutsche Energie-Agentur (dena), The Federal Office of Energy Cooperatives, The KEA Klimaschutz- und Energieagentur Baden-Württemberg GmbH, The Renewable Energies Agency ("Agentur für Erneuerbare Energien e. V., AEE") and The Verband kommunaler Unternehmen e.V. (VKU).

Most DH plants in Germany are partially private and partially publicly owned (Scabell et al., 2015). Many factors of the local heating networks affect the profitability such as, temperature, fuels, heat generation and consumers. As a guideline for the pay-back period of a newly planned network in a new or existing area, a local network operator approximates 15 years. The cost of heat production (distribution excluded) can for example be 15 €/MWh for a waste incineration plant and 30-45 €/MWh for a CHP plant fuelled by conventional or renewable gas. Heating networks require high investment volumes and investment support is very important for these high investment amounts.

A problem for investors, especially in the case of new development areas, is the uncertainty about the development of the affected area or the uncertainty about how much energy will be needed and how many households would connect to the local heating network. The risk here is to have to run the local heating network temporarily or even in the long term without making a profit. The conditions for customers differ depending on the location and other factors. However, the targeted establishment of local heating networks can generate synergy effects and thus achieve cost savings, which could increase acceptance on the customer side and favour a positive return. It has also been forecasted that the heat demand from locally produced heating is expected to increase in the long term (forecasted until 2050) which would favour a positive return in the long term (Deutsches Zentrum für Luft- und Raumfahrt et al., 2009).

Industrial heat recovery to the DHN occurs but at a small scale (<0.1TWh per annum) (Persson, 2013). Geothermal energy heat production in the DHN in 2017 was approximately 0.5 TWh (Dumas and Bartosik, 2014) from 29 larger installations and the number of geothermal heating plants supplying DHN is growing (Weber et al., 2019).

11.2.4 Potential for waste heat and renewable energy sources

The practical utilization potential for annual available urban waste heat from four studied categories identified a potential of 213 PJ in Germany (Persson and Averfalk, 2018). The potential for each category was identified as data centres (58.6 PJ), metro stations (7.2 PJ), service sector buildings (26.5 PJ) and wastewater plants (121.2 PJ). The industrial waste heat recovery in the country has been estimated at 75 (Papapetrou et al., 2018a)- 157 (Persson, 2015) TWh/year.

The geothermal heat production in 2017 reached 0.9 TWh (Dumas and Bartosik, 2014) At the end of 2018 there were about 180 larger direct geothermal installations supplying heat either for district heating or thermal spas in combination with space heating. In addition, more than 380 000 geothermal heat pumps were operational and supplying heat mainly to individual houses (Weber et al., 2019). In a study from 2014 the potential for geothermal energy was assessed as a percentage of the population that can be reached by geothermal district heating and found that it is possible for almost 50% of the German population. 38% can be reached by low temperature source at 60-100°C at 1000 meters depth and the rest with heat above 100°C at 2000 meters (Dumas and Bartosik, 2014).

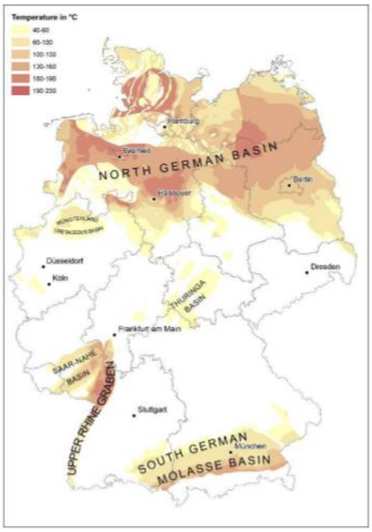


Figure 49 – Regions with geothermal potential in Germany (Weber et al., 2019)

In the Heat Roadmap for Germany the geothermal energy potential in the district heating supply was estimated at 8%. Solar thermal estimated potential of district heating supply was estimated at 2% (Paardekooper et al., 2018a). Installed capacity of solar thermal in 2017 was 13.4 GW_{th}. The installed solar PV capacity in Germany in 2017 was 42.3 GW and produced 39.4 TWh (EurObserv'ER consortium, 2018). The potential for solar PV production is visualised in Figure 50 (SOLARGIS, 2020).

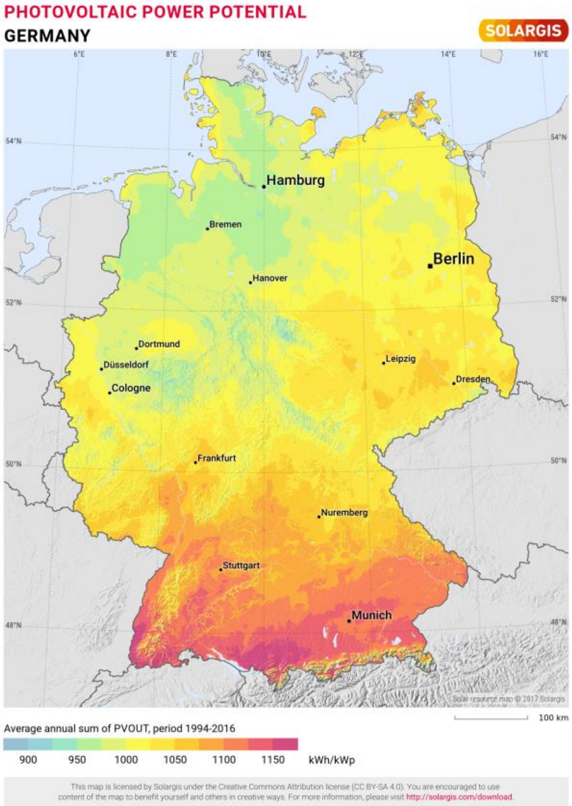


Figure 50 – Solar PV power potential in Germany (SOLARGIS, 2020).

11.3 Social factors

Responses for the survey in Germany were collected by distributing the survey via email. Because the demo site in Hamburg under construction there were no end-users connected to the demo site and instead an approximation for customers had to be made. 8 responses were collected, four end-users and four professional customers. Five of the respondents are connected to DHN today, one did not know and two are supplied with natural gas.

11.3.1 General opinion of DHN

The general opinion towards DHN among respondents is positive. The lowest rating was received on DHC being a cost-efficient solution.

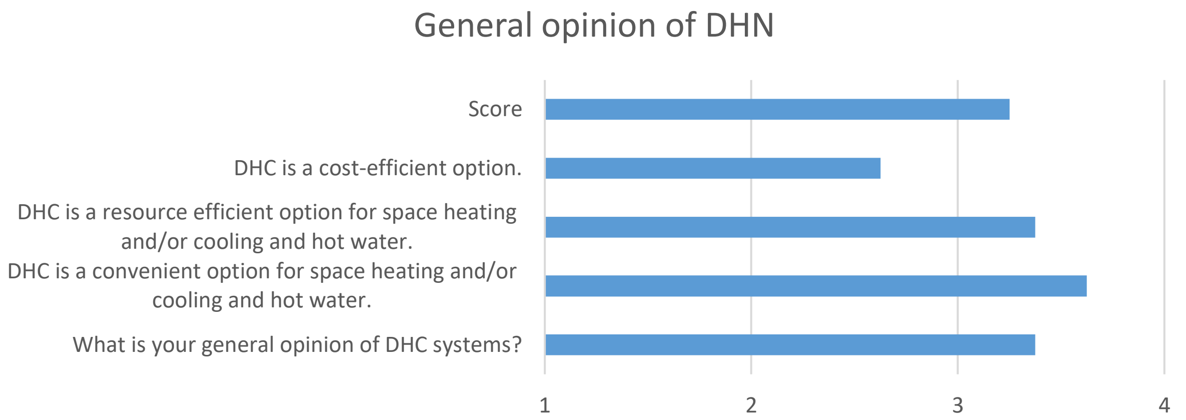


Figure 51 – Mean values of the respondents on their general opinion about DHC (German demo site), as well as the resulting score. The respondents answered on a 4-degree Likert-scale were 1= I don't agree, or very negative, and 4= I agree completely, or very positive.

11.3.2 Awareness of technology

Respondents are not so knowledgeable on how a DHC system works. 75% of respondents say it is available in most cities. Only one respondent has heard about LTDHN but five of the respondents have heard about integrating waste heat into DHN. The technology awareness level is higher among professional customers (Figure 52).

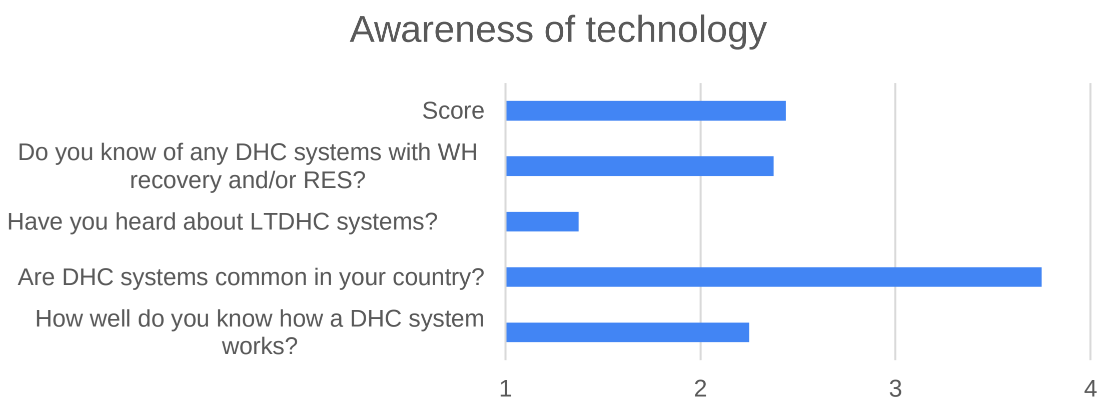


Figure 52 – Mean values on the awareness of the technology, as well as the resulting score (German demo site).

11.3.3 Risks and benefits

Energy savings is identified as the main benefit of having a LTDHN but 3 out of 8 respondents had no idea about possible benefits. The identified risks of LTDHN varied. Energy savings and environmental benefits are seen as the main benefit of integrating WH and RES into the DH supply whereas the identified risks are again diverse (Table 10).

Table 10 – Perceived risks and benefits of the REWARDHeat technologies by respondents as well as the resulting score (German demo site). Respondents answered in open text fields and could write as many benefits or risks as they wanted. The number displayed in the parenthesis is how many respondents stated the risk/benefit.

	Benefits LTDHN	Risks LTDHN	Benefits RES & WH	Risks RES & WH
Professional customers	Energy efficient (1), use several energy sources (1), don't know (1)	High investment cost (1), bacteria (1), performance issues (1), don't know (1)	Energy efficient (1), lower primary energy (2)	High investment costs (1), vulnerable technology (1), no risk (1)
End-users	Energy savings (2), use several energy sources (1), integrate RES (1), don't know (1)	Competition (1), difficult to expand to urban areas (1), no risk (1), don't know (1)	Flexible (1), environmental (2), don't know (1)	Less transparency of cost (1), risk of losing heat supply (1), no risk (1), don't know (1)

11.3.4 Environmental consideration

All respondents believe that integrating WH and RES in the DH supply is beneficial for the environment. Respondents are in general concerned about the impacts of climate change and all, but one professional customer, consider climate impact in relation to HC. Customers believe that the forecasted effects of climate change are uncertain which can lead to a more passive behaviour (Figure 53).

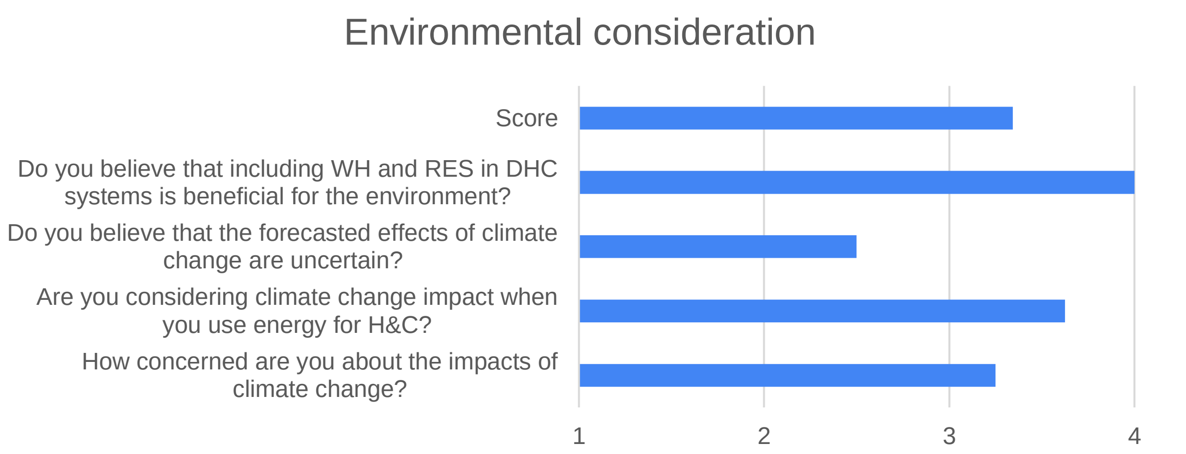


Figure 53 – Mean values on the environmental consideration, as well as the resulting score (German demo site)

11.3.5 Cost expectancy

Most respondents believe that the REWARDHeat technology will result in a lower energy bill compared to a conventional DH supply (Figure 54).

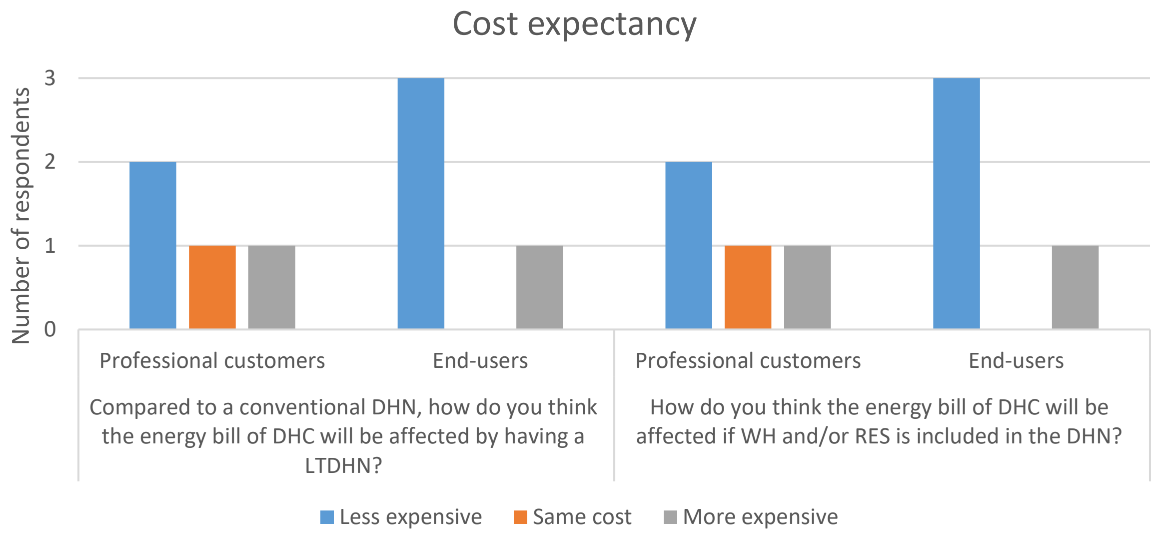


Figure 54 – Cost expectancy of end-users and professional customers (German demo site)

11.4 Technical factors

In Germany DHN is quite common and, by being a mature technology, experiences of further development potential of specific technical issues, e.g. related to piping and fluid mechanics, have been identified. In general, the availability of necessary technical components is good, but it is more challenging to find available experienced installer companies to involve in the projects. There are good opportunities when constructing new quarters and building areas to consider integration of other local heat sources than the conventional DHN.

11.4.1 Level of maturity of the DHC network technology

In Germany there are several DHN but representing a smaller part of the heat supply compared to gas, which is the largest heat source. Gas is used for approximately 40% of the household heating, while the corresponding share for DH is 7.7%. In big cities, this DH share is occasionally higher, e.g. 22% in Hamburg.

Within the field of DHN there are different relevant technical potential topics for developing the systems furtherly. For example, aspects as improving diagnostic systems for existing pipes (e.g. measuring above ground the thickness of pipes underground) for evaluating the pipes and predicative maintenance. In the area of fluid dynamics there is potential to gather, exploit and interpret more information of the real systems, e.g. how fluid behave realistically and how the correlation is between pressure, temperature and outgassing. Interesting studies can be made on this in order to develop realistic, detailed and precise simulation tools, and to avoid risk supplements in the planning and implementation phase. Another issue is economic and ecological optimization of pipe insulation. A final example of is long-term investigation of plastic pipes e.g. lifecycle costs and cradle-to-cradle consideration, diffusion problems and oxygen input.

11.4.2 Availability of technical components, installers and operators

In general, the availability of technical components needed to transfer low temperature heat to the network (for example heat exchangers, control systems and basic technology needed in the stations) is good. It is furtherly crucial to apply to a proper installer company when installing complicated systems, and there may be a lack of available experienced companies to involve in these types of projects.

11.4.3 DHC solution replicability

Regulations in Germany states that if an existing building has its own heating source the district heating is not allowed to be more expensive. E.g. with an existing gas boiler, the comparison is made with the gas price (without the cost of installation and equipment), and in many cases the expanding DHN can have issues to be competitive with it. Due to this it is generally more common that DHN connects to new buildings than to the existing building stock.

The possibilities to use waste heat in the district heating networks are good – depending on the waste heat temperatures. One potential issue to consider is how to balance the demand and supply of heat e.g. in the summer when the potential volume of heat supply (e.g. excess heat from industries and waste incineration) is bigger than the heat demand. This issue may also relate to heat sources as solar thermal, since the heat demand is lower in the summer.

It is more expensive and complicated to integrate low-temperate local sources to the conventional DHN. A lot of technical requirements need to be met to integrate it with a high temperature DHN; thereby it is easier to keep this within subnetworks. When building new quarters and building areas there is a good opportunity to consider integration of other local heat sources than the normal DHN.

The local prerequisites are important when deciding on the technical solution. Regarding the replicability of local low temperature geothermal heat sources, it is essential that the drilling is done with high quality to enable the energy for a long period of time. It is crucial with professional and competent companies and engineers, with knowledge of the geological conditions of the soil, to execute the work. When comparing different technical solutions for the local case, one of many factors could be that e.g. solar thermal is less complicated in regard of access if technical problems occurs and in terms of maintenance, compared to geothermal sources. Geothermal heat sources are covered and can be more difficult to access for maintenance when the surface is used for other activities and purposes.

11.4.4 Heat pumps

Legislation in Germany is striving towards technology neutrality and to let market mechanisms decide. Policy makers are however more positive towards HPs today than before and to a larger extend understand the technology and consider it to be reliable. A CO_2 price on heating is expected to drive the shift from fossil fuels in the heating sector with the largest impact foreseen in 2026-2027. The Ministry of Environment is responsible for collecting energy statistics and the statistics covers also HPs.

HPs are mostly in demand with new buildings but buildings undergoing renovation is a growing segment. HPs in district heating is not covered specifically in the statistics but known to exist in some projects, for example in Berlin. HPs are available for all sectors and the largest potential is identified in renovation projects as well as multifamily buildings. A variety of professionals can be involved with influencing the decision for heating system in a building, builder, building owner, project developer or energy consultant. In principle actors on the HP market, such as installers, planners and architects are knowledgeable about HP systems. Installers of traditional boilers can typically also install HPs and if the demand were to increase installer could quickly re-skill themselves. Manufacturing capacity is available to see an increased demand.

In Germany the gas versus electricity price ratio is still negative for HPs. The high electricity price in Germany compared to oil and gas prices causes operational costs for HPs to be less advantages than fossil combustion. The CO_2 price that will be introduced to the heating sector is expected shift the operational costs as the proceedings for the CO_2 price will be used to reduce the electricity price.

11.5 Legal

For Germany, legal prerequisites that impact DHC systems include ordinances on prices and costs as well as low-energy performance for buildings, municipalities' legal means concerning DH use, tax acts and legislation for renewable energy with impact on DH system fuel mix.

11.5.1 Planning and permission

A federal-level regulation in Germany in this legal field is the Ordinance on General Conditions for the Supply of DH (AVBFernwärmeV) (Bundesministerium der Justiz und für Verbraucherschutz, 2020), which is a set of responsibilities and rights for DH suppliers and customers. It covers aspects affecting the planning of DH facilities and networks such as pricing structure, connection costs and price escalation clauses. A wide analysis of its effect on the use of DH cannot be covered in this task, but the DH industry has been seen to view the ordinance as an important part of the legal framework, and that preserving it is important for the envisioned development of DH in Germany (Snodin and Garside, 2019). From a planning and permission perspective, it can furtherly be noted that German municipalities through their legal means occasionally make DH connections mandatory.

From the point of view that co-generation of heat and electricity is desired, the German KW-Koppelungsgesetz (Combined Heat and Power Act) is also of significance providing a framework for the operation of these plants. Legal influences by the Erneuerbare-Energien-Gesetz (Bundeministerium det Justiz under für Verbraucherschutz, 2014), EEG (Renewable Energy Sources Act), have also been seen as an important factor for the use of biogenic, renewable fuels. A reduced promotion of these technologies has been displayed and parts of the plant stock using these fuels can no longer be operated economically from a monetary point of view. This leads to plants being converted to combustion of natural gas and planning of new plants carried out without taking these fuels into account (Umwelt Bundesamt, 2019, Informationsdienst, 2010, Shell, 2017, Von Ulrich).

11.5.2Heat and cooling market

The operation of local heating networks is highly influenced by federal electricity tax legislation (Stromsteuergesetz), as these levies have a considerable impact on the price of electricity from CHP plants. National legislation also influences the use of fuels e.g. through the Energy Tax Act (Energiesteuergesetz). It provides a tax relief for energy products used for CHP production if the plant has a monthly or annual efficiency of at least 70%. There is also a tax exemption for biogas that is used in a CHP plant.

Special heat legislation at regional state level, as in Baden-Württemberg, is an example that provides a certain proportion of renewable energy sources when replacing an existing plant or planning a new one (Ministerium für Umwelt Klima und Energiewirtschaft Baden-Württemberg, 2015, Ministerium für Umwelt Klima und Energiewirtschaft Baden-Württemberg, 2008). This type of legislation is viewed as a positive development by DH network operators. As a rule, these requirements can be met more economically with centralized heat generation systems rather than with individual household systems. The legislation thus helps operators to gain more household customers in a connection area for local heating supply.

11.5.3Buildings and indoor climate

Requirements for buildings and indoor climate are set in several standards. The German standard DIN 4108 sets thermal and humidity standards while DIN 4109 determines the requirements between residential units. In addition, the international EN ISO 6946 standard, for uniform assessment of the thermal properties of building elements of the building envelope, is also applied.

Additional requirements are a result of the Energy Saving Ordinance (EnEV) (Bundesministerium für Wirtshaft und Energie), according to which every new building will have to be a low-energy house. A clear definition for low-energy houses is inquired, but an international standard value for maximum heating demand of a low-energy house at 70 kWh/m^2 is in application. How an exact definition can be made should have significant importance to the DH sector in terms of how the competing energy solutions are valued and favoured relative to each other.

Furtherly, the VDI 6022 standard sets requirements for technical systems (above all air conditioning systems), and DIN 1946-2 as well as DIN EN ISO 7730 define requirements for thermal comfort of users. For construction and operation of heat networks/plants, building permits must be obtained, which demonstrate the compatibility of the project with the requirements of building planning and building regulations. Infrastructure construction for heat supply also often involves the use of land or roads, paths and squares that are not solely owned by the project executer. Due to this, it is necessary to obtain a special permission of use or to regulate licensing agreements (Klima Initiative, 2019).

11.6 Modelling results-based factors

The environmental key factors were assessed as barriers or opportunities based on the results of the TIMES optimization modelling, which are presented and briefly described below.

11.6.1 Specific cost of heat supply

Figure 55 shows the differences between the specific variable, fixed O&M, and capital costs of heat supply in the heating sector of Germany in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be observed that all three types of costs, but mainly variable cost, are estimated to be lower in the future with developed LTDHC networks and utilization of LTH sources, as compared to the future with conventional DH.

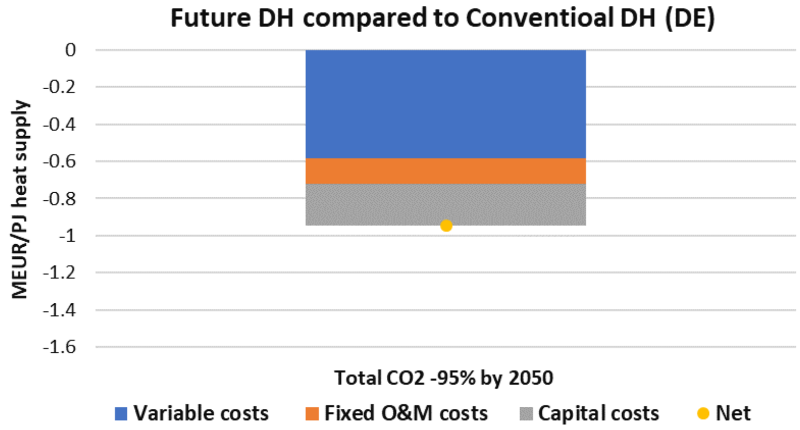


Figure 55 – The differences between the specific undiscounted Variable, Fixed O&M, and Capital (together with their total Net value) costs of heat supply in the heating sector of Germany, averaged over the Years 2020-2050, in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

11.6.2 Specific primary energy use

Figure 56 shows the specific primary energy use, divided into fuel use, electricity use and electricity generation, of heat supply in the heating sector of Germany in year 2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). The modelling results indicate that with the development of LTDH networks and successful utilization of LTH sources the specific net energy use of heat supply will be impacted significantly, i.e., reduced by around 40%, as compared to the future with conventional DH networks.

Note: Specific primary energy use values for generated and used electricity were calculated using respective fuel use factors. Values for electricity generation are negative because generated electricity is assumed to be exported (from the heating sector) and substitute electricity generation in the electric power sector.

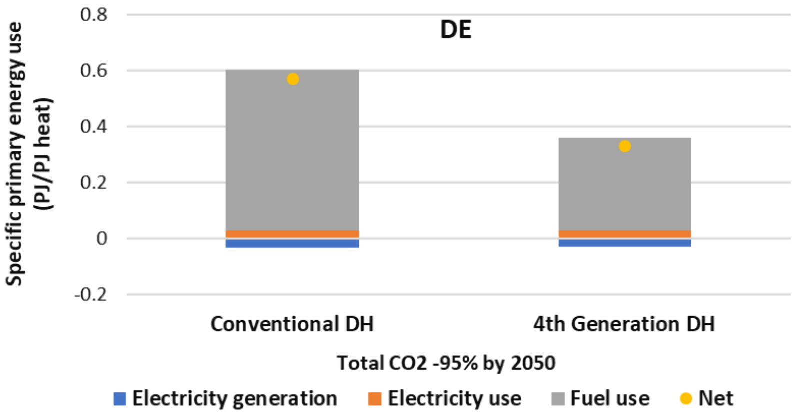


Figure 56 – The specific primary energy use, divided into fuel use, electricity generation and electricity use, of heat supply in the heating sector of Germany in year 2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

11.6.3 Accumulated air pollutant emissions

Figure 57 shows the accumulated NOx, SOx, and PM2.5 emissions from the heating sector of Germany over the period 2020-2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be noticed from the Figure that the replication of REWARDHeat solutions, i.e., development of LTDH networks and utilization of LTH sources, can lead to noticeably lower air pollutant emissions in Germany over the course of the next 30 years.

Note: Negative values in Figure 57 mean that electricity generated in the heating sector substituted emissions in the electric power sector and results in net negative total emissions of an air pollutant.

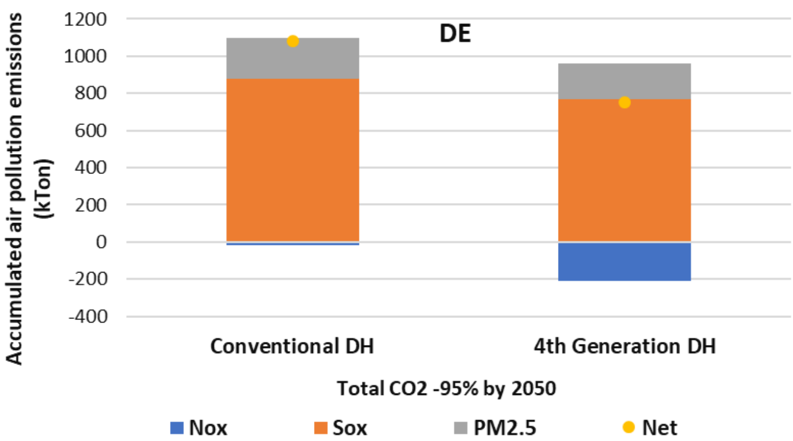


Figure 57 – The accumulated air pollutant emissions (NOx, SOx, PM2.5) attributed to heat supply in the heating sector of Germany over the period 2020-2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

12 Annex: PESTLE France

France is located in western Europe with a coastline both towards the Atlantic Ocean in the west and the Mediterranean Sea in the south. The population as of 1 January 2019 was approximately 67 million (Eurostat, 2019c). The number of heating degree days in France in 2018 was 2183 and 65 cooling degree days (Eurostat, 2019a). The energy consumption for heating in buildings (normal climate) in 2015 was 123 kWh/m^2 (Odyssee-Mure, 2019). The total primary energy supply in France in 2018 consisted of 27.9% oil, 7.1% biofuels and waste, 1.6% wind, solar etc, 2.2% hydro, 42.9% nuclear, 14.6% natural gas and 3.6% coal (International Energy Agency, 2019a). The final energy consumption in 2017 was 1640 TWh (Eurostat, 2019b).

Table 11 – Share of renewable energy in total energy, HC, electricity and transport in 2017 (EuroStat, 2019d)

	RES in energy	RES in HC	RES in electricity	RES in transport
France	16%	21%	20%	9,1%

12.1 Political factors

12.1.1 National energy and climate plan (NECP)

The overall target is to reduce GHG emissions by 40% between 1990 and 2030 and to achieve carbon neutrality by 2050. Primary energy consumption in France today is mainly driven by nuclear energy, oil and natural gas. Oil and natural gas are imported, and France is trying to diversify the energy supply to become less dependent on import.

The national target for renewable energy in the energy consumption by 2030 is 33%. 40% renewables in electricity production and 38% in heat consumption. Direct use of renewable heat receives some special focus with a goal of increasing by 50%. For the heating and cooling sector, the goal is to increase renewables by 1.3% per year and for heating networks the goal is 1% per year up to 60% by 2030. Heat recovery in heating networks is also forecasted to increase.

Reducing energy consumption is the first focus in France to enable the energy transition. The national target for final energy consumption is to reduce by 20% by 2030 compared to 2012 and by 50% in 2050. The entire building stock should be equivalent to low-energy building standards by 2050 and the focus is to improve the building envelope, have higher efficiency heating equipment and improve electricity devices.

Sectoral coupling between the electricity, gas and heat networks is promoted in the internal energy market dimension with power-to-gas and power-to-heat. Heating networks are seen as essential to increase the share of renewable and recovered energy in the energy system. Biomass, geothermal, solar, waste incineration and waste heat from industries can be utilized through heat networks. The target is to increase the share of renewable and recovered energy in heat networks five times by 2030 resulting in 39.5 TWh. It is estimated that the potential for heat networks is approximately 67TWh (an 8.5 multiple of 2012 level) (European commission, 2020c).

12.1.2 Political interest in REWARDHeat solutions

The national target for district heating is to go from 24.6 TWh of renewable and recovery energy in 2016 to 39.5 TWh by 2030. To reach the targets the government wants to create new DHN when feasible, extend current DHN and integrate renewable and recovered energy to replace fossil fuels (Reseaux de Chaleur et Territoires, 2018).

ADEME (the French Environment and Energy Management Agency) supports heat networks supplied with more than 50% renewable or recovered energy. Heat networks are described as the only way for large scale utilization of deep geothermal energy, solar thermal heat from collector fields, biomass plan, heat from waste incineration process and waste heat from industries as well as low temperature heat recovery from seawater, lake, river water or wastewater (ADEME, 2017b).

12.1.3 Financial support for REWARDHeat solutions

The Heating Fund managed by ADEME is a funding mechanism dedicated to RES and heat recovery DHCN projects. To be eligible, among others, projects have to ensure that at least 50% of the annual energy mix originates from renewable or recovered energy. Once the application process is approved, objectives on heat efficiency are contractual among the parties and this defines the amount of founding a project will receive: a percentage of the financing is released once the installation is delivered, the remaining part is released in proportion of the overall achievement of the stated objective of "heat efficiency". This is simply measured in MWh, after 1 or 2 years depending on the size or complexity of the project. For all projects above 12 GWh/year, verification is done through "remote monitoring", so such systems have to be connected to ADEME's information system. Thus, project owners have to ensure a proper metering and related ICT system and that the correct data are transmitted and conformed to the defined evaluation method. To notice, until recently, only "heating" was considered by the founding scheme nevertheless, "cooling" energy is integrated today (Galindo Fernández et al., 2019, ADEME, 2020).

District heating operators have the possibility to apply for the funds coming from the *PIA 3 – TIGA: Programme d'investition d'avenir - territoires d'innovation de grande ambition (Program for the investments for the future – Great Ambition Innovation territories)*.

The Energy Transition Law for a Green Growth, French law n° 2015-992 of 17 august 2015, promotes decentralised RES systems by imposing strong mid-term objectives for energy efficiency, carbon reduction and RES share (Ministére de la Transition Écologique et Solidaire, 2019).

The French Law n° 2017-227 of 24 February 2107, sets the ground for the self-consumption (PV) regulation followed by different financial policies supporting the development of the model – investment support and feed-in tariffs. If the installation is smaller than 100 kW_p, the smaller the PV installation the higher the share in investment received and the fixed feed-in tariff rate. If the installation is larger than 100 kW_p projects do not receive any more investment aids and the feed-in tariff rate is regulated via a call for tendering system. Furthermore, projects are classified in two families: individual and common self-consumption endeavours. The first ones, are exempt from distribution taxes (TURPE), as affecting only one meter (delivery point) and the installation is affecting only "private" infrastructure behind the meter while the others, have just a lowered rate (of about 12%), as affecting more meters (delivery points), yet connected among them by the public distribution grid (Commission de Régulation de L'énergie, 2020).

The public authority has the possibility to finance third party studies at different project stages through regional funds (typically engineering and consulting studies), if a CRET with specific clauses has been put in place *(CRET: Contrat Regional d'Equilibre Territoriale – Regional contract for the territorial equilibrium).* The latter can't be cumulated with other fundings.

12.2 Economic factors

12.2.1 Heating and cooling demand

The HC demand in France is 758 TWh (Fleiter et al., 2017), approximately 45% of France's final energy demand. Space heating is the largest type of HC in demand in France, mainly to the residential and tertiary sector as can be seen in Figure 58. The industrial sector is mainly using process heat. Space and process cooling is less than 8% of the total HC demand (Paardekooper et al., 2018f).

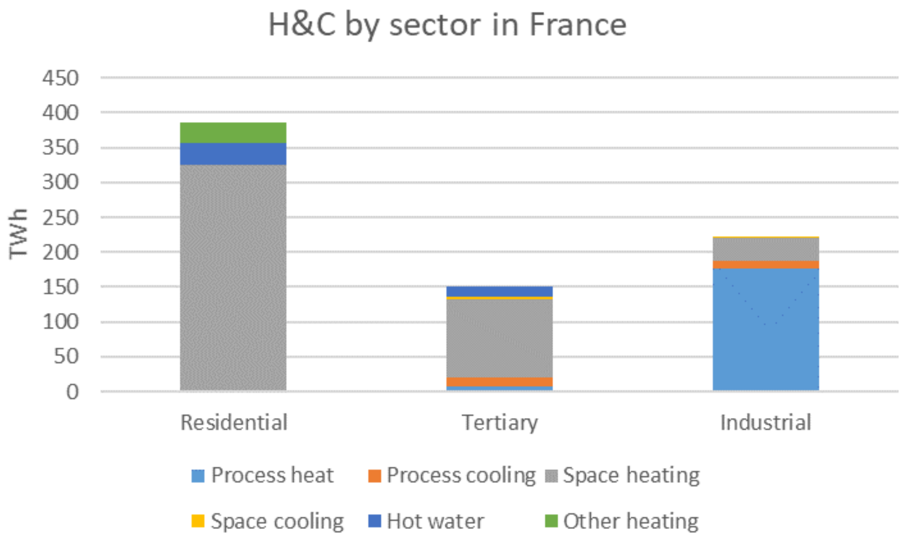


Figure 58 – HC by sector and country (Fleiter et al., 2017)

In the Heat Roadmap for France it was identified that with the current policy, which mainly focuses on space heating, a decrease in HC by 8% would occur till 2050. Space heating is expected to decrease by 24%, hot water and process heating is expected to increase by 4%. Space cooling is expected to triple in in demand until 2050 (from 20.7 to 68 TWh), mainly driven by the service sector. Process cooling is expected to increase by 40% to 2050. Space and process cooling could represent up to 27% of the total HC demand in France by 2050 (Paardekooper et al., 2018f)

12.2.2 Heating and cooling supply

The HC demand in France is mainly supplied by gas (42%). Gas is supplied to all sectors and used mainly for space heating and process heating. District heating supplies 3% of the total HC demand

and is used for space heating and DHW, shown in Figure 59, and supplies mainly the residential and tertiary sector, shown in Figure 59 (Fleiter et al., 2017).

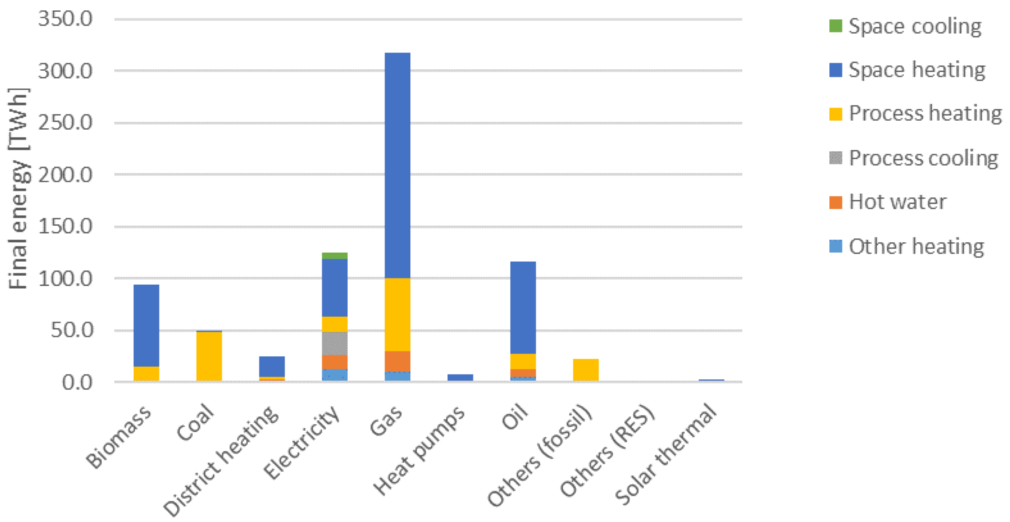


Figure 59 – Energy carrier for the final HC demand for all sectors in France [TWh] (Fleiter et al., 2017)

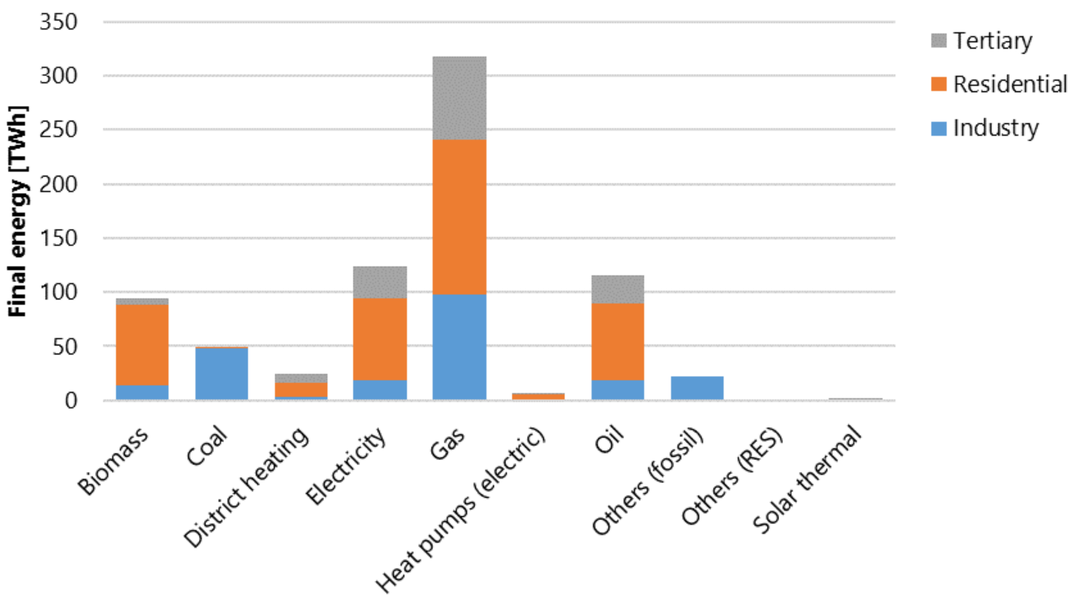


Figure 60 – Energy carrier split by sectoral demand in France [TWh] (Fleiter et al., 2017)

12.2.3 District heating

District heating in France developed mainly in the 1980's as a result of the oil crises in the 70's. The DHNs were built by the local authorities and provided as a public service. In the last 10 years, renewables and recovered energy in the DHN supply has increased (Reseaux de Chaleur et Territoires, 2018). In 2017 the official number of heating and cooling networks presented by ADEME was 761 heating networks and 23 cooling networks delivering 25 TWh of heat and 1 TWh cooling.

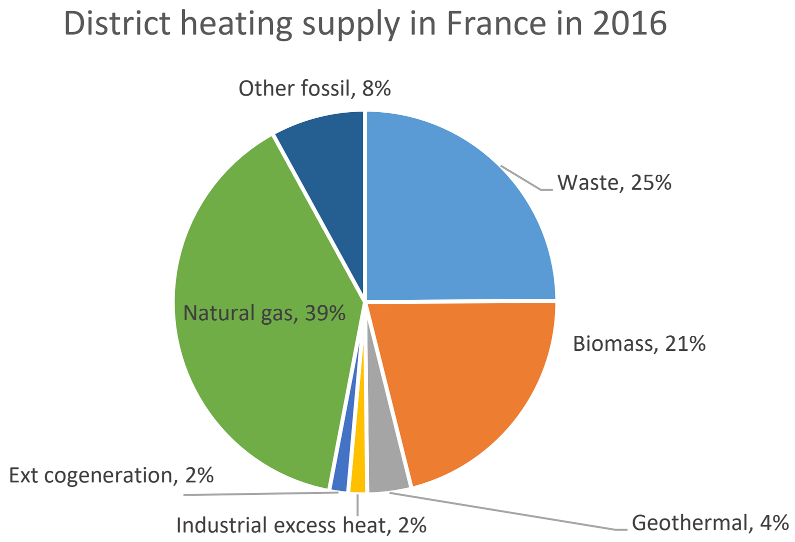


Figure 61 – District heating supply 2016 in France (Reseaux de Chaleur et Territoires, 2018)

About 1 % of the DHN in France have a temperature of less than 40°C. Both low temperature networks (45-60°C) and neutral temperature networks (15-25°C) exist in the country. Various professional associations exist in France that are indirectly connected to the DHCN market, focusing on biomass and geothermal energy systems or public housing amongst others.

The local authority is the responsible agent for the public district heating service. The local community (generally a commune or a public establishment for inter-municipal cooperation) is responsible for the proper functioning of the DHN. Depending on the contractual arrangement chosen for the DHN, the responsible agent may delegate a certain part of its responsibilities to a network operator. The community remains responsible for monitoring the service provided by the operator. Thus, if the operator has for e.g. made commitments towards the end-users on the proportion of RES used, it is up to the community to ensure that the commitments are fulfilled.

The Network operator is in most cases a specialised company responsible for the proper functioning of the DHN service towards the customers (operation and billing). A pure public/community service company is rare, as seldom local authorities have the needed resources and know-how for operating such facilities. The network owner's responsibility ends at the building-substation level or primary network, while the secondary network is managed by the *manager of a building*. The building manager is the most common direct customer of the DHCN responsible for paying the operator and billing end-users.

The most common business set-up for DHCN in France is the *DSP* (Delegation of public services) scheme with the creation of an "ad-hoc" company. By this, the public authority can impose a share of renewables and a certain tariff scheme. Another business set-up is the SPV (Special Purpose Vehicle) or a *SEM* (Society of mixed enterprises) where the public share is regulated among certain conditions. For the case of a DHN operation or a waste heat recovery company, the need of qualified personnel and engineering competencies make a 100% public model usually unviable.

A third business set-up option are privately operated endeavours, where there is no direct contractual relation with the public authority, between the heat sourcing and the service delivery to the end-users. The undertaking is completely steered by the private operator, sourcing the heat, whether from a private or public held source, and then sells it through an-hoc contracts to end-users. Public authority controls conformation to laws and regulations, as well as grants access to public spaces for the network piping and associated equipment, via permitting processes, of the public spaces needed for the network piping works and associated equipment. The risk and responsibility of the DHCN lies with the private operator.

Profitability of DHCN in France is hard to quantify due to risks and uncertainties involved with a 10-20 years' time frame but an internal rate of return is somewhere between 6-12%. Lower IRR are possible, while higher ones are rare.

The General Directorate for Energy and Climate (DGEC) is part of the "Ministry of Sustainable Development" and in charge of defining and implementing DHCN network related policies. Moreover, it has the role to coordinating policy related tasks with involved ministries. At a local level, the implementation of policies is supported by the DREALs (regional level) and the DDT / DDTMs (departmental level). Under the same ministry, falls the ADEME, a public institution participating in the implementation of public policies concerning environment, energy and sustainable development. It manages the heat fund and provides support to local authorities in terms of expertise and advice. *The National Syndicate of Urban Heating* (SNCU), member of the Federation of Environmental Energy Services (FEDENE), is the official representative of professionals in urban heating and in charge of conducting a national statistical survey on DHCN. SNCU further takes part in national and EU standardisation work.

The geothermal energy installations for DHN are located mainly in the Paris Basin and the Aquitaine Basin in southwest France (Dumas and Bartosik, 2014). Industrial waste heat recovery to the DHN occurs in France but in a small scale (<1TWh per annum) (Persson, 2013).

12.2.4 Potential for waste heat and renewable energy sources

The practical utilization potential for annual available urban waste heat from four studied categories was estimated at 192 PJ in France. The potential per category was estimated at data centres (12.7 TWh), metro stations (3.1 TWh), service sector buildings (14 TWh) and wastewater plants (23.8 TWh) (Persson and Averfalk, 2018). Another study from 2017 estimating two of the same categories and found the potential to be lower, wastewater treatment plants (0.4 TWh) and data centres (3.6 TWh) (ADEME, 2017a). The industrial waste heat recovery in the country has been estimated at 32 TWh/year (Papapetrou et al., 2018a). Another study estimated the potential to 89 TWh (Persson, 2015). A study from 2017 identified the potential for industrial waste heat in France to be 109 TWh of which half was below 100°C, however most of which is not in proximity to be recovered in a DHN (ADEME, 2017a).

In the Heat Roadmap for France the potential for geothermal energy integration in the DHN could supply 9% of the district heating production (Paardekooper et al., 2018f). In a study from 2014 it was estimated that geothermal energy between 60-100 degrees at 1000 meters depth can reach approximately 37% of the population (Dumas and Bartosik, 2014). The installed geothermal energy in 2017 was 509 MW_{th} and 17.1 MW_{e}. The role of solar thermal according to the Heat Roadmap is expected to supply about 1% of the district heating production in France (Paardekooper et al., 2018f). Installed capacity of solar thermal in 2017 2166 MW_{th}. The installed solar PV capacity in France in 2017 was 8610 MW and produced 9.6 TWh (EurObserv'ER consortium, 2018). The potential for solar PV is visualised in Figure 62, indicating a higher potential towards the Mediterranean coast (SOLARGIS, 2020).

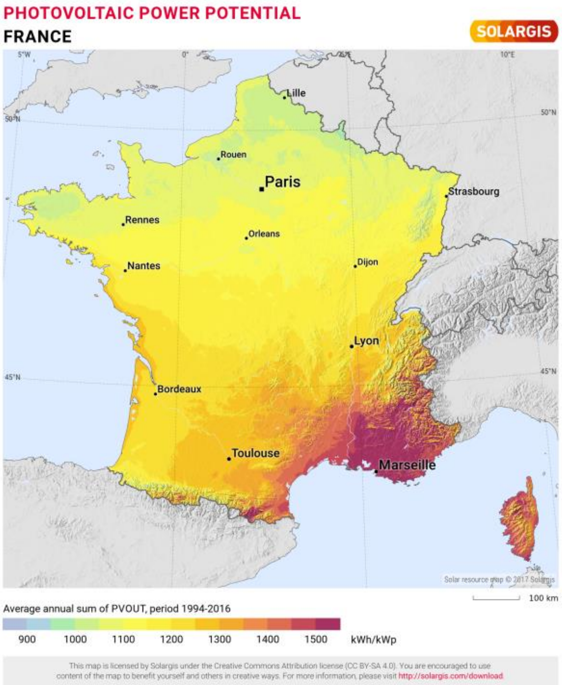


Figure 62 – Solar PV power potential in France (SOLARGIS, 2020).

12.3 Social factors

From the French demo site, 6 responses were collected via email distribution of the survey. 5 responses from end-users and 1 professional customer. Since only one professional customer responded to the survey the results for professional customers will be omitted from the deliverable as it might expose the professional customer. Hence all results, tables and figures in this chapter only includes end-users. 3 of the end-users were connected to a DHC network today and received space heating and cooling as a service. The other end-users had a heat pump as well as an electric boiler for hot water, one of them (living in a house) had a biomass boiler additionally.

12.3.1 General opinion of DHN

Respondents are generally positive towards DHC systems. DHC is seen as a convenient option for space heating, cooling and hot water with all but one respondent responding 4 (very positive). DHC as a cost-efficient solution received the lowest rating, at an average rate of 2.6 respondents are neither positive nor negative about the aspect (Figure 63).

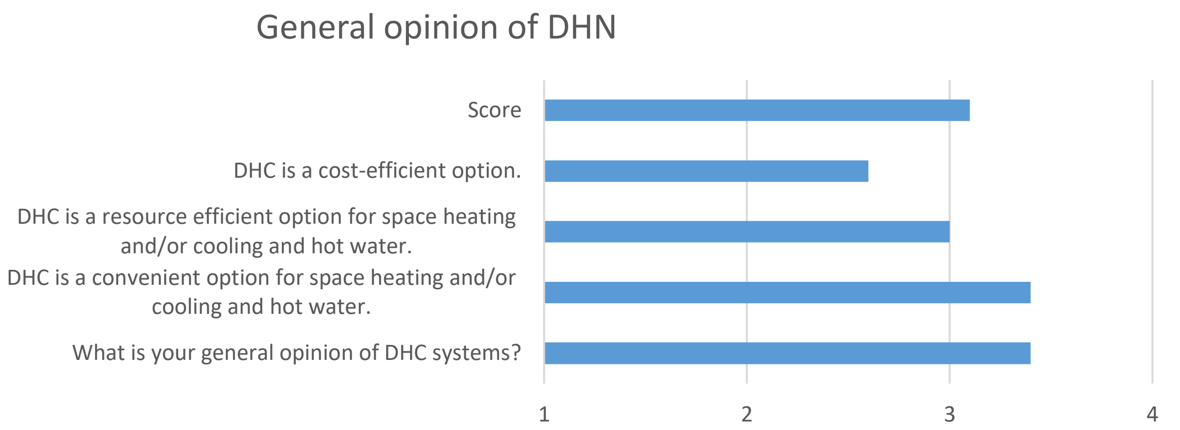


Figure 63 – Mean values of the respondents on their general opinion about DHC (French demo site), as well as the resulting score. The respondents answered on a 4-degree Likert-scale were 1= I don't agree, or very negative, and 4= I agree completely, or very positive.

12.3.2 Awareness of technology

Respondents have an understanding about how a DHC systems works but the perception is that DHC networks are uncommon in the country. 3 out of 5 respondents have heard about LTDHN and only 2 have heard about integrating RE or excess heat in the system (Figure 64).

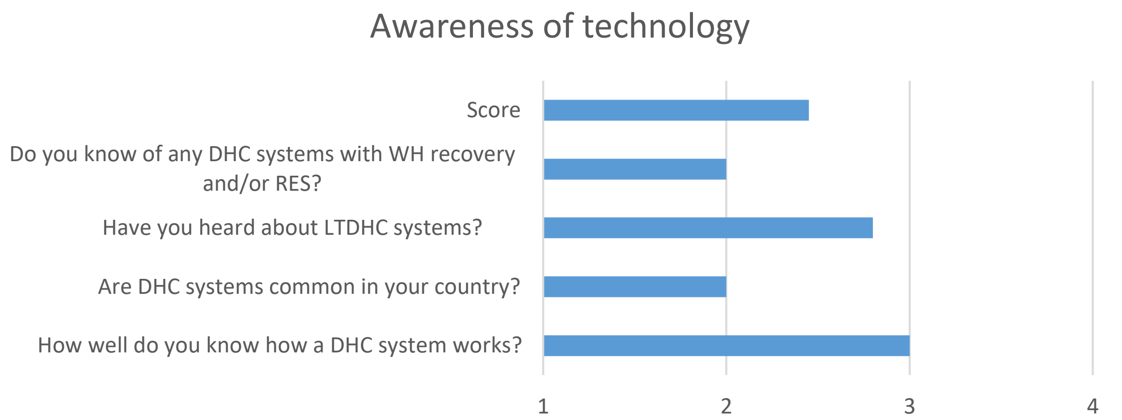


Figure 64 – Mean values on the awareness of the technology, as well as the resulting score (French demo site).

12.3.3 Risks and benefits

End-users in France perceive the main benefits of a LTDHN to be that it is energy efficient and that it can supply both HC. The main perceived risk is that not enough heating or cooling will be supplied for example during extremely hot or cold weather. Some respondents describe that it could be due to design error in sizing pipes or that the temperatures and seasons will change due to climate change. With regards to RES and WH in the DHCN identified benefits are environmental and energy savings. Risks are that it would be less flexible, or more difficult to control, that the HC demand are met (Table 12).

Table 12 – Perceived risks and benefits of the REWARDHeat technologies by respondents as well as the resulting score (France demo site). Respondents answered in open text fields and could write as many benefits or risks as they wanted. The number displayed in the parenthesis is how many respondents stated the risk/benefit.

	Benefits LTDHN	Risks LTDHN	Benefits RES & WH	Risks RES & WH
End-users	Environmental (1), energy efficiency (2), less material for insulation of pipes (1), possibility to supply both HC (2)	Not able to reach sufficient heat/cold (4), maintenance (1)	Environmental (2), energy savings (3)	More expensive (1), less flexibility/control in meeting the HC demand (2), No risk (1)

12.3.4 Environmental consideration

All respondents are concerned about the impacts of climate change, all respondents are considering climate change in relation to their usage of energy for HC and all respondents believe that including WH and RES in the DHCN would be beneficial for the environment. Only two respondents believe that the effects of climate change are uncertain (Figure 65).

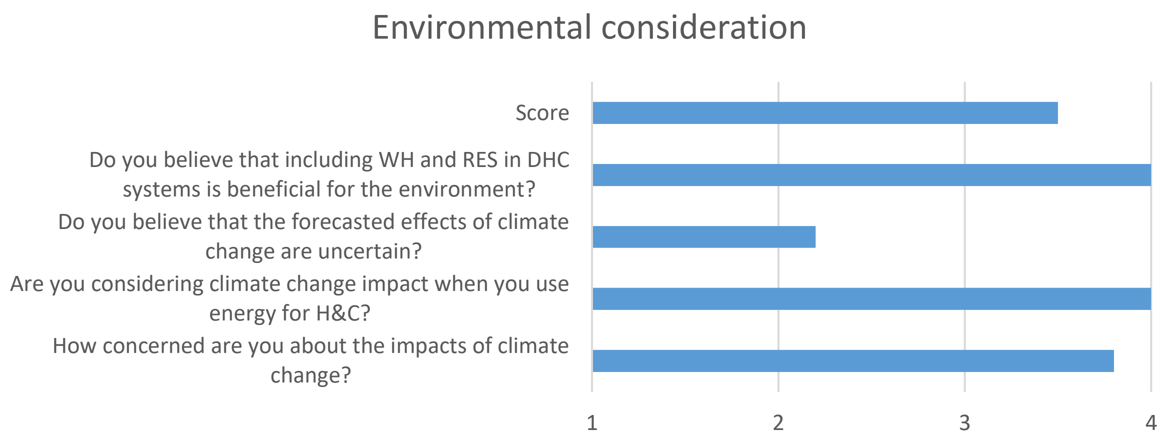


Figure 65 – Mean values on the environmental consideration, as well as the resulting score (French demo site)

12.3.5 Cost expectancy

Respondents are divided in their opinion as to how their energy bill will be affected by having a LTDHN or integrating WH and/or RE in the DHN. Most respondents had a different view on how the respective technologies would affect the bill, for example, one respondent believe that having a LTDHN will be less expensive but that including WH and/or RE would make it more expensive (Figure 66).

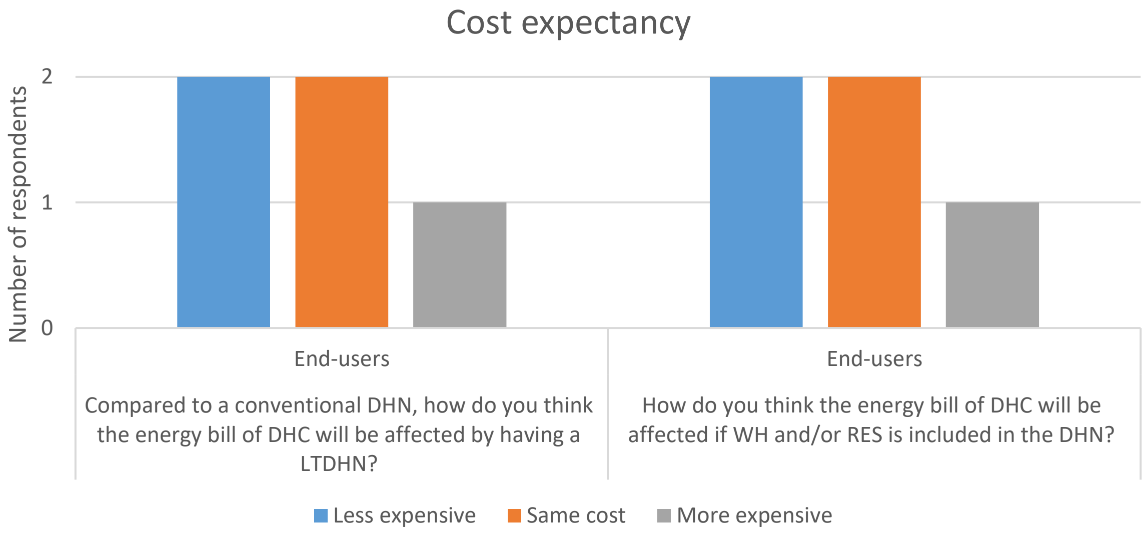


Figure 66 – Cost expectancy of end-users (French demo site)

12.4 Technical factors

Technical prerequisites that impact the DHC development in France concern mostly the generally limited adoption of DHN solutions. Other aspects are the variable geographical and meteorological conditions within the 3rd largest country in Europe: on one side, renewable resources are unevenly distributed within the territory and, on the other, demand side profiles vary greatly between the southern and norther latitudes. These aspects impact the opportunities to replicate and standardize DHC technical solutions.

12.4.1 Level of maturity of the DHC network technology

DHN are not common France today. This is opposite to cooling networks, which have been constantly developed in France. Most of the heat supply of France is based on electricity (e.g. electric heaters or electrical boilers) and on gas. The DH networks that are in operation are usually smaller compared with the northern European countries, so extensive systems based on "transport pipes" between cities or neighbourhoods are seldom used.

Pilot and research projects have in the last approximately 10 years developed mostly incineration, biomass and geothermal based district heating systems. The projects are now moving gradually towards low and neutral temperature systems in order to better source low temperature renewable or waste heat sources. The share of renewables and recovered energy has increased to 56% in 2017 and has more than doubled in 10 years. With the 2018 published "Energy Transition Law for Green Growth", France has identified DHC networks as one of the main vectors to decarbonize the heat sector in urban areas: DHC from renewable and recovered energy sources is assumed to have a fivefold increase by 2030, whereas cooling networks alone should triple their capacity by 2030.

12.4.2 Availability of technical components, installers and operators

The technical components and skills needed for constructing and operating DHC networks are available and active within the limited amount of DHC systems that are in operation in France.

In principle there is no technological barrier (from single components to their supply chains) noteworthy for the French context; all resources needed are judged as accessible and no issues within the topic are identified in this study.

12.4.3 DHC solution replicability

Moving from a model based on high temperature DHN, usually driven by a centralized CHP or heating plants, towards low and neutral temperature networks, integrating multiple local renewable energy sources and sinks, makes DH replication rather a challenge.

Local conditions in terms of source availability and seasonality, location in the urban area (green vs. brownfield) and composition of the potential customer pool, make ad-hoc studies and assessment unavoidable and "one fits all" solutions rather improbable in France. Although tools and methods for assessment and sizing of such systems are becoming always more powerful and performing, the adoption of DHC solutions in France is yet low.

With an ongoing decentralization of decisional power in terms of climate policies from the central government towards cities and metropolitan authorities, it is expected that DHC solutions might be able to gain popularity and acceptance by local stakeholders and wider public. Local authorities have here a major role to play ahead to ensure a coordinated development between urban planning/expansion and its energy and environmental roadmaps, so that DHC technique can be put at use where and when it is appropriate.

12.4.4 Heat pumps

HPs are becoming recognized in the French legislation through requirement on renewable energy and energy efficiency. HPs are included in the statistics as renewable energy from heat pumps are visual in the renewable energy statistics. In new single-family houses HPs are the dominant solution at 55% market share, for new multifamily houses the market share is between 5-10%.

Installers, architects and planners have enough knowledge to recommend and install HPs. There are 8000 certified companies of installers through the QualiPAC certification program. Improvement areas for building knowledge are for hybrid systems. The largest potential for increasing the market share is in multifamily buildings for heating and domestic hot water as well as HPs for cooling application in new buildings.

The decision for heating system in a building depends if it is a new building or renovation project. For new buildings the engineering offices would decide and for renovation in existing buildings the individual (owner) would decide. The electricity price in France is relatively low, however the challenge is that fossil fuels are priced equally low and this has been especially true in 2020 which has triggered fossil fuel boilers to increase at the expense of HPs.

12.5 Legal

For France, legal prerequisites that impact DHC systems include legal planning obligations e.g. when extending or building DHC grids (carrying out a *Master plan*). It also includes legal classifications of grids which can better ensure a DHC customer pool and regulations on the energy performance of thermal systems depending on CO_2 content, which has an impact on the viability of DHC solutions.

12.5.1 Planning and permission

Carrying out a *Master plan* is the first legal step for a public heating or cooling network operator in France to make changes for DHC systems (e.g. extension, densification or boiler room works) (ADEME, 2015). The obligation to carry out a master plan concerns any public authority (municipality, EPCI, department, region) that owns a heating network supplying a plurality of customers, with exception of the most recent networks and networks in the pipeline. The master plan has been applied since January 1, 2009. The objective of the master plan is to enable the DHC operator to carry out a projection exercise with a horizon until 2030. The master plan is required according to ADEME for requesting investment aid on existing DHC networks changes.

The aim of the plan is not simply to meet a regulatory obligation, but to co-construct with local players in the evolution of a DHC network in a long-term approach. This makes the master plan a tool for enabling long-term planning and investments.

Furtherly, regular permitting processes are also carried out for the DHC networks by the public authorities, which control a proper use of the public spaces needed for DHC network piping works and its associated equipment.

12.5.2 Heat and cooling market

Extension or new construction of DHC systems are long-term investments recovered over a long period of time and dependent on a customer pool reliability. In France, a *classification* or *filling* (defined by articles L712-1 to L712-5 of the Energy Code, articles 5 and 7 of law 80-531 of July 15, 1980, decree No. 2012- 394 of March 23, 2012) of a DHC network can be made according to the Energy Code. This is a legal mean for a public authority in France to identify a perimeter within which customers have the obligation to connect to a new or existing DHC network (Réseaux de chaleur et territoires, 2013).

The classification is thus an important possibility to get a viable customer pool for a DHCN undertaking, especially in cases where there are environmental motives for DHC but difficulties to compete on a pure commercial basis with other energy sources. Whether the individual buildings and facilities in the defined perimeter are relevant to the connection obligation is settled through a number of defined cases and conditions.

In accordance with the Energy Code, classification of the network is only possible if 3 conditions are met:

- the network is supplied at least 50% by renewable or recovered energy;
- metering of energy volumes by delivery point (i.e. the substation) is ensured;
- the financial balance of the operation during the amortisation period of the facilities is ensured.

12.5.3 Buildings and indoor climate

Thermal requirements for new buildings and at replacements of existing building heating systems are defined in the French building thermal regulation (RT 2012) and further descriptions in relation to DHC projects (Réseaux de chaleur et territoires, 2014). The requirements concern e.g. indoor temperature control and hot tap water systems (requirements for legionella prevention etc.). RT impacts how low-temperature DHC systems must be designed concerning e.g. heat supply reliability and capacity at peak loads. Low-temperature systems has the need of local boosting capacity at peak load periods or for certain customers. Having enough but cost-effective capacity is one of the challenges.

From 2020 RT is replaced by RE (Réglementation Environnementale 2020) and considers RES or waste heat based DHC networks particularly, by taking the RES and low-carbon energy mix into account when assessing the performance of a new building and favour such technological solution. These are valued through that the maximum authorised consumption depend on the CO_2 content of the network. This valuing of the environmental qualities of the network allows such networks to obtain a temporary approval of their CO_2 content. The application file for this is specified by the "Processing Note" of special cases in the RT 2012 for new buildings.

12.6 Modelling results-based factors

The environmental key factors were assessed as barriers or opportunities based on the results of the TIMES optimization modelling, which are presented and briefly described below.

12.6.1 Specific cost of heat supply

Figure 67 shows the differences between the specific variable, fixed O&M, and capital costs of heat supply in the heating sector of France in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be observed that all three types of costs are estimated to be lower in the future with developed LTDHC networks and utilization of LTH sources, as compared to the future with conventional DH.

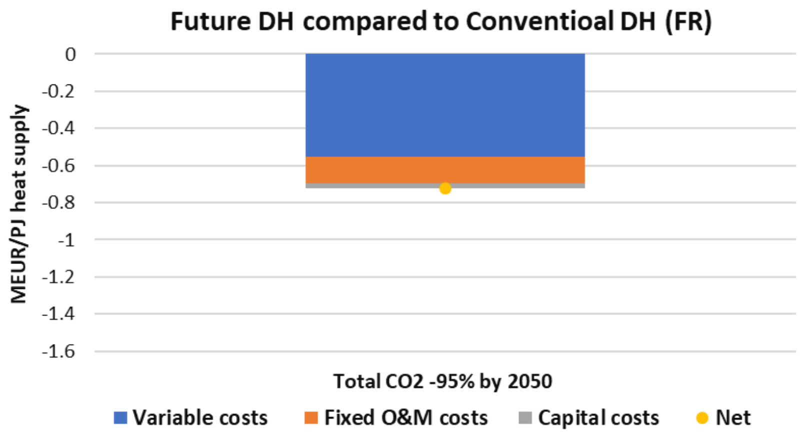


Figure 67 – The differences between the specific undiscounted Variable, Fixed O&M, and Capital (together with their total Net value) costs of heat supply in the heating sector of France, averaged

over the Years 2020-2050, in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

12.6.2 Specific primary energy use

Figure 68 shows the specific primary energy use, divided into fuel use, electricity use and electricity generation, of heat supply in the heating sector of France in year 2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). The modelling results indicate that with the development of LTDH networks and successful utilization of LTH sources the specific energy use of heat supply will be impacted insignificantly, i.e., reduced by around 60% (mainly from direct fuel use reductions), as compared to the future with conventional DH networks.

Note: Specific primary energy use values for generated and used electricity were calculated using respective fuel use factors. Values for electricity generation are negative because generated electricity is assumed to be exported (from the heating sector) and substitute electricity generation in the electric power sector.

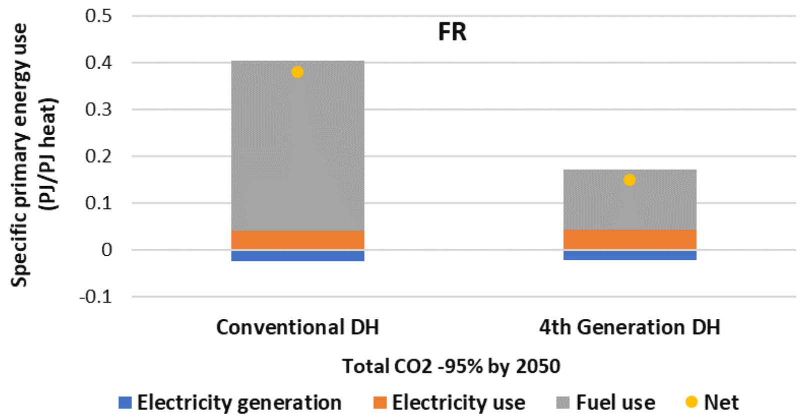


Figure 68 – The specific primary energy use, divided into fuel use, electricity generation and electricity use, of heat supply in the heating sector of France in year 2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

12.6.3 Accumulated air pollutant emissions

Figure 69 shows the accumulated NOx, SOx, and PM2.5 emissions from the heating sector of France over the period 2020-2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be noticed from the Figure that the replication of REWARDHeat solutions, i.e., development of LTDH networks and utilization of LTH sources, can lead to lower air pollutant emissions in France over the course of the next 30 years.

Note: Negative values in Figure 69 mean that electricity generated in the heating sector substituted emissions in the electric power sector and results in net negative total emissions of an air pollutant.

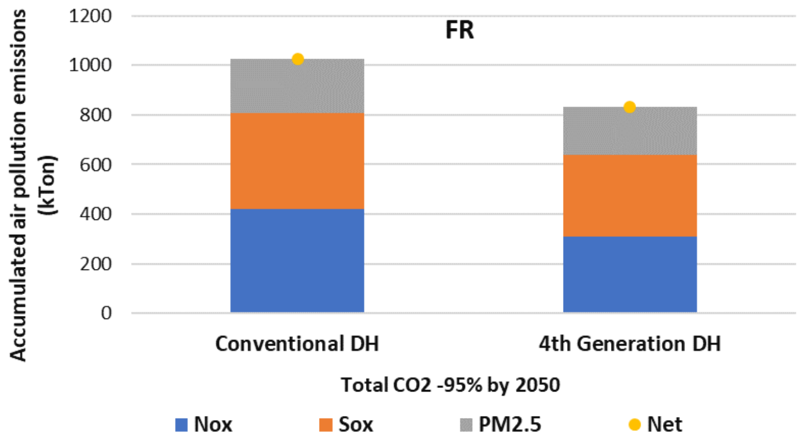


Figure 69 – The accumulated air pollutant emissions (NOx, SOx, PM2.5) attributed to heat supply in the heating sector of France over the period 2020-2050 in the FutureDH and ConventionalDH scenarios (with 95% CO_2 reduction by 2050).

13 Annex: PESTLE Italy

Italy, in the south-central part of Europe, is a peninsula in the Mediterranean Sea. The population as of 1 January 2019 was approximately 60.4 million (Eurostat, 2019c). The average number of heating degree days in Italy in 2018 was 1753 and 232 cooling degree days (Eurostat, 2019a). The energy consumption for heating in buildings (normal climate) in 2015 was 122 kWh/m^2 (Odyssee-Mure, 2019). The total primary energy supply in Italy in 2018 consisted of 34.7%% oil, 10% biofuels and waste, 6.2% wind, solar etc, 2.9% hydro, 40.4% natural gas and 5.8% coal (International Energy Agency, 2019a). The final energy consumption in 2017 was 1321 TWh (Eurostat, 2019b).

Table 13 – Share of renewable energy in total energy, HC, electricity and transport in 2017 (EuroStat, 2019d)

	RES in energy	RES in HC	RES in electricity	RES in transport
Italy	18%	20%	34%	7%

13.1 Political factors

13.1.1 National energy and climate plan (NECP)

Italy's overall energy goal is to achieve full decarbonization of the energy sector by 2050. The energy transition must be made in a way that is beneficial for citizens and businesses (particularly SMEs). Self-consumption of energy and renewable energy communities are promoted for this reason. The focus in Italy is towards self-generation systems, particularly in buildings, and to develop energy communities.

The 2030 targets for renewable energy in gross final energy consumption is 30%, in transport 22% and for heating and cooling the target is to increase by 1.3% yearly. Thermal solar energy is expected to have an increasing role, also integrated in district heating systems.

Extensive renovation of the existing building stock is expected to make the RES share towards heating easier to achieve. The number of nearly zero energy buildings (NZEB) was 1400 in 2018, 90% of which were new buildings for residential use. District heating and cooling is expected to increase. Energy subsidies measures will be implemented as tax credits on district heating networks fed by biomass and geothermal energy.

The sustainable growth potential for district heating was estimated in relation to the Article 14 (1) of Directive 2012/27/EU is approximately 4000 GWh and would be achieved by extending the current networks for heating and cooling by additional 900 km on top of the current network length of 4100 km. The potential for integrating solar thermal energy, waste heat and utilizing central heat pumps are recognised and will be assessed further as a solution for high-dense areas. Especially in relation to fourth generation networks. To realise this potential instrument will be made available that promote new constructions and expansion of infrastructure with the focus on heat production close to consumption sites and heat from RES, waste or cogeneration (European commission, 2020c).

13.1.2 Financial support for REWARDHeat solutions

District heating and cooling is not receiving much political support in Italy. Some support schemes have changed in recent years that have reduced the support for DHN. Residential customers supplied with heat produced by a CHP or heat from RES receive a reduced VAT (10% instead of 22%) and real estate tax deduction (Galindo Fernández et al., 2019). National incentives promoting investments in DHC projects are Decreto Marzano (Law 239/04) on heat from cogeneration for the use in DHN, also incentives on the electricity generated from high-efficiency cogeneration. Cogeneration from biomass is incentivised through Titoli di Efficienza Energetica (TEE). There are white certificates supporting large electricity and gas distributors to perform energy efficiency measures.

Renewable energy for HC and small interventions increasing energy efficiency receives support from the *Conto Termico 2.0. Conte termico 2.0* was effective as of 2016 and strengthens the previous *Conto Termico 1.0* from 2012. The policy aims to increase energy efficiency and the production of thermal energy from RE. Small-scale projects producing heat from RE and high-efficiency systems are eligible to apply for the annual budget. Heat pumps, biomass boilers, heaters, solar thermal and solar cooling are examples of eligible technologies (International Energy Agency, 2020).

Renewable electricity can be sold to the grid or net-metering can apply for prosumers. Net-metering (*scambio sul posto*) is applied on a yearly basis and only applies as long as the capacity of the installation does not exceed 500 kW, regardless of RE production type. A version of premium tariff applied to renewable electricity (*Ritiro dedicato*) is available where the producer can choose between selling electricity on the free market at market price or to Gestore Servizi Energetici (Manager of Electricity Services in Italy) for a minimum price (Schwarz, 2019).

13.2 Economic factors

13.2.1 Heating and cooling demand

The total HC demand in Italy in 2015 was 735 TWh, approximately 54% of total energy demand (Paardekooper et al., 2018b). Space heating accounts for the largest share of the demand, mainly in the residential and tertiary sector. Process heating is the second largest and supplies the industrial sector, as seen in Figure 70 (Fleiter et al., 2017).

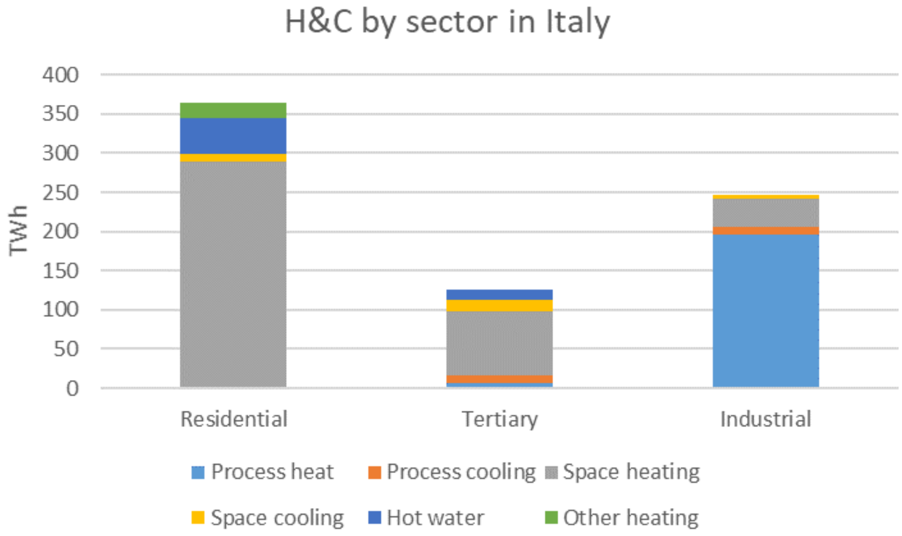


Figure 70 – HC by sector in Italy (Fleiter et al., 2017)

The total HC demand is expected to increase by 8% to 2050 according to the Heat Roadmap for Italy. Space heating is expected to decrease by 11%, hot water increases by 12% and process heating by 6%. Space and process cooling are the largest growing demand and is expected to represent around 32% of the HC demand. The demand for space cooling is expected to double by 2050 with the main growth in the service sector but also the residential sector (Paardekooper et al., 2018b)

13.2.2 Heating and cooling supply

The HC demand in Italy is mainly supplied by gas (51%) to all three sectors with the largest share going to residential sector for space heating as seen in Figure 71 and Figure 72. District heating supplied 6% of the total HC demand and mainly supplied the industrial and residential sector (Fleiter et al., 2017).

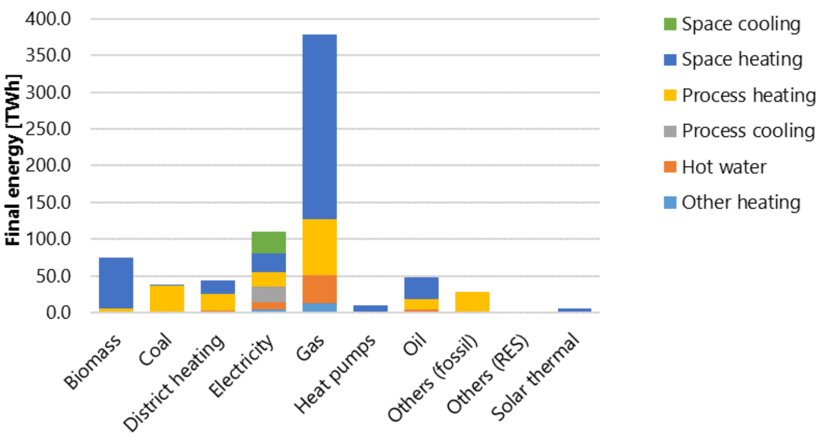


Figure 71 – Energy carrier for the final HC demand for all sectors in Italy [TWh] (Fleiter et al., 2017)

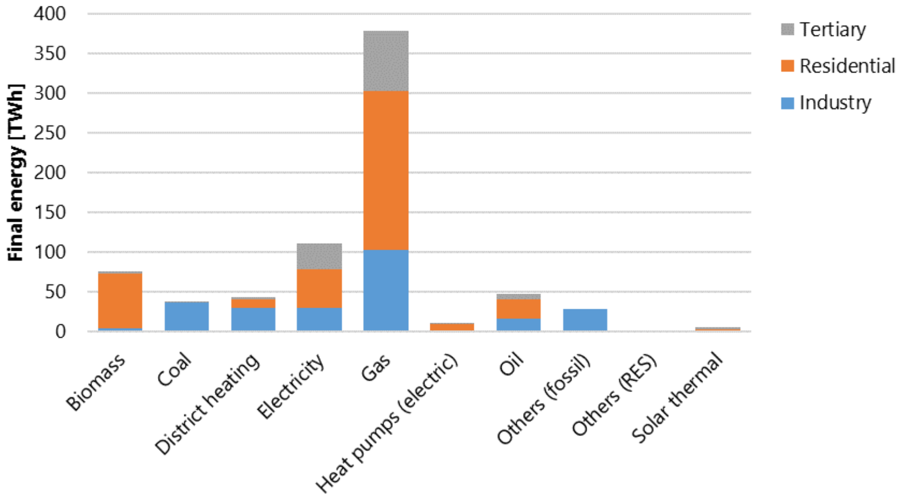


Figure 72 – Energy carrier split by sectoral demand in Italy [TWh] (Fleiter et al., 2017)

13.2.3 District heating

District heating has developed in Italy since the 70's. Italy has 303 district heating systems supplying 4.5 TWh in 2015. In 2015 68% of the district heating was produced in CHP plants, mainly supplying the industrial sector. Natural gas was the main fuel used for district heating production in 2015, followed by waste-to-energy at 13.6% and bioenergy at 8.3% (EuroHeat & Power, 2017). The growth in terms of pipe lengths in DH systems between 2009-2013 was 58%. The installed thermal capacity in DHN grew 24% between 2011-2015 (Rutz et al., 2019). The Italian heating and cooling market are dominated by individual solutions mainly based on natural gas and electricity and district heating is relatively new and only has 5.6% of the national market share in terms of final users. Industrial waste heat recovery to the DHN occurs in France but in a small scale (<0.1TWh per annum) (Persson, 2013). 237 GWh geothermal energy was supplied to DHNs (Manzella et al., 2019).

Italy has at least six identified LTDHN, three of which utilize sea water through a heat pump, two are ground water sources heat pumps and one has a mixture of fuels including solar thermal and ground sourced heat pumps. District cooling has seen some development in recent years and the installed capacity in 2013 was 182 MW_{th} (Galindo Fernández et al., 2019). At the end of 2017 32 district cooling networks were operating in 28 different municipalities in Italy.

The Italian District Heating Association (Associazione Italiana Riscaldamento Urbano) was founded in 1982 and works to produce guidelines, support and disseminate information on DH applications. The typical business set-up is that the company managing the DHC system is a public-private company or a private company operating under a concession of the local authority. DHC markets are only regulated through local contractual arrangements without central regulation.

Italy has some geothermal energy in the DHN (1.2% of supply) (EuroHeat & Power, 2017), the largest are in Pomarance (21.5MW_{th}) and Santa Fiora (17.2 MW_{th}) (Dumas and Bartosik, 2014). Solar thermal in the DHN exists in three locations in Italy but still make up a very small share of the supply (EuroHeat & Power, 2017).

13.2.4 Potential for waste heat and renewable energy sources

The practical utilization potential for annual available urban waste heat from four studied categories identified a potential of 135 PJ in Italy (Persson and Averfalk, 2018). The potential per category was identified at data centres (20.5 PJ), metro stations (5.8 PJ), service sector buildings (68.9 PJ) and wastewater plants (39.8 PJ). The industrial waste heat recovery in the country has been estimated at 30 TWh/year (Papapetrou et al., 2018a). Another study identified the potential at 95 TWh (Persson, 2015).

At the end of 2018 1424 MW_{th} geothermal energy was installed in Italy, producing 3 TWh. 915 MW_e electrical energy was installed. Space heating and thermal spas account for 84% of the thermal production (Manzella et al., 2019). In the Heat Roadmap for Italy the potential for geothermal energy integration in the district heating system is estimated at 3% of the district heating supply DHN and some increase of installed capacity is expected (Paardekooper et al., 2018b). In a study from 2014 the potential was assessed as a percentage of the population that can be reached by geothermal district heating and found that it is possible for almost 50% of the Italian population, at 60-100°C at 1000 meters (Dumas and Bartosik, 2014).

Installed capacity of solar thermal in 2017 2835 MW_{th} (EurObserv'ER consortium, 2018). Solar thermal potential is estimated at around 1% of the district heating supply according to the Heat Roadmap for Italy (Paardekooper et al., 2018b). The installed solar PV capacity in Italy in 2017 was 19.7 GW and produced 24.4 TWh (EurObserv'ER consortium, 2018). The solar PV potential for Italy is visualised in Figure 73 and shows increasing potential further south in the country (SOLARGIS, 2020).

Figure 73 – Solar PV power potential in Italy (SOLARGIS, 2020).

13.3 Social factors

In Italy responses were collected by distributing the survey via email to selected respondents. Professional customers chosen as the respondents are the customers that are foreseen to be connected to the REWARDHeat demo-sites. Different end-users were chosen to reply to the survey since the apartment building initially chosen to participate in the project did not accept the offer of answering the survey at the time it was distributed. The professional customers are foreseen to be connected to the REWARDHeat solution but for the end-user category no respondents were available as the apartment buildings do not have any residents. Therefore, an approximation was made for end-users. Seven professional customers responded to the survey and five end-users. Five of the professional customers were connected to a DHN as well as three of the end-users. The respondents not connected to a DHN had gas as a source of heating.

13.3.1 General opinion of DHN

The general opinion of respondents is positive and DHC systems are considered to be resource efficient. The view of DHC systems as cost-efficient received the lowest average (Figure 74).

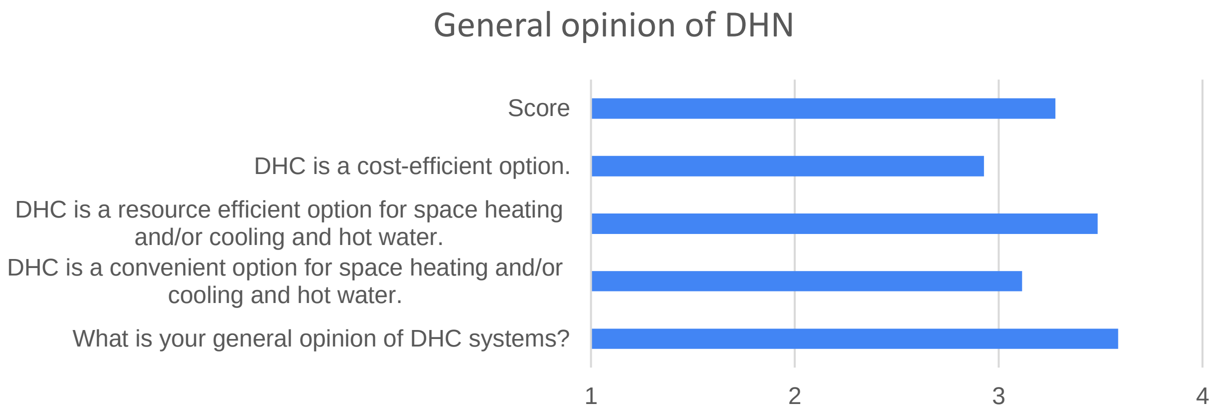


Figure 74 – Mean values of the respondents on their general opinion about DHC (Italian demo site), as well as the resulting score. The respondents answered on a 4-degree Likert-scale were 1= I don't agree, or very negative, and 4= I agree completely, or very positive.

13.3.2 Awareness of technology

Respondents are generally well aware of how a DHN works and no difference is visible between customer groups. The general understanding is that DHN are available here and there in the country. Seven out of 12 respondents have heard about LTDHN and eight out of 12 knows of a DHN that has integrated either excess heat or RES (Figure 75).

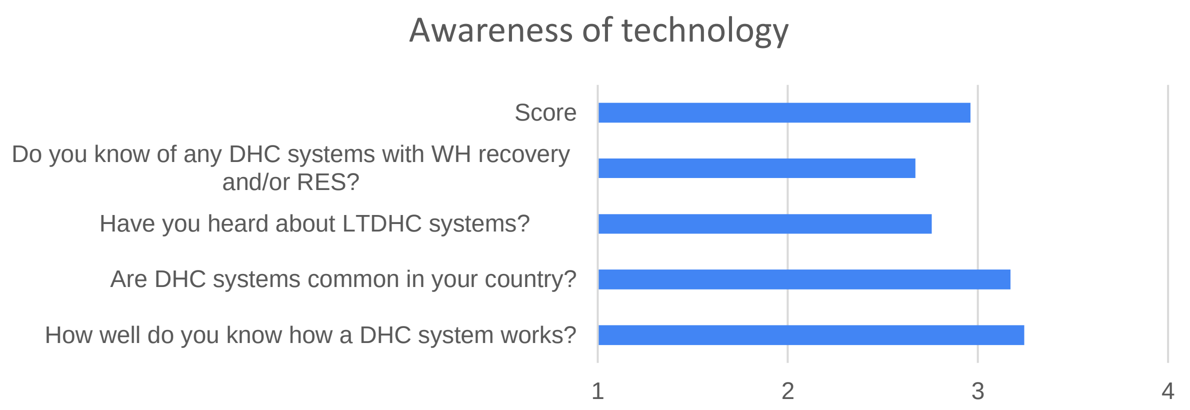


Figure 75 – Mean values on the awareness of the technology, as well as the resulting score (Italian demo site).

13.3.3 Risks and benefits

Energy savings, less pollution and economic savings are identified as the three main benefits of a LTDHN. Identified risks by professional customers are low efficiency and security of supply. End-users identify risks as reduced thermal comfort and low maturity of technology. Integrating RES and WH in a DHN has the main benefit of reduced pollution but also economic and environmental savings. Professional customers identified risks as security of supply and risk of more pollution. End-users perceive a risk of higher cost (Table 14).

Table 14 – Perceived risks and benefits of the REWARDHeat technologies by respondents as well as the resulting score (Italian demo site). Respondents answered in open text fields and could write as many benefits or risks as they wanted. The number displayed in the parenthesis is how many respondents stated the risk/benefit.

	Benefits LTDHN	Risks LTDHN	Benefits RES & WH	Risks RES & WH
Professional customers	Energy savings (2), less pollution (3), economic savings (3)	Low efficiency (1), security of supply (1), normal network management risks (2), no risks (1), don't know (2)	Economic savings (2), less pollution (4), energy savings (1)	Security of supply (1), more pollution (1), no risk (2), don't know (3)
End-users	Energy savings (3), integration of RES (2), don't know (1), less pollution (2), economic savings (1)	Low maturity of technology (1), reduced thermal comfort (2), don't know (1)	Less fossil fuels (1), less GHG emissions (1), economic savings (2), environmental savings (3), energy savings (1), less pollution (1)	Higher costs (1), no risk (2), don't know (1)

13.3.4 Environmental consideration

All respondents are concerned about the impacts of climate change (have answered a three or a four) and all but one professional customer consider climate change in relation to the energy usage for HC. More than half of the respondents think that the effects of climate change are uncertain. All but one professional customer believes that including excess heat and RES in the DHN is beneficial for the environment (Figure 76).

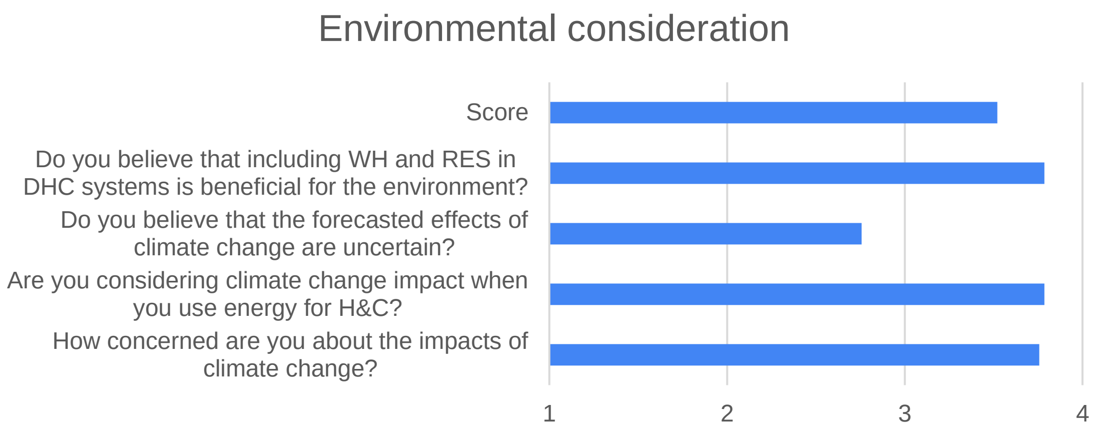


Figure 76 – Mean values on the environmental consideration, as well as the resulting score (Italian demo site)

13.3.5 Cost expectancy

Transitioning from a conventional DHN to a LTDHN is believed to result in lower expenses for the customer according to professional customers, whereas most end-users believe that the energy bill will remain the same. Professional customers think that integrating RE and/or excess heat in a DHN will result in a lower energy bill or same cost as conventional supply sources. The end-user's opinion is divided between if the energy bill will be reduced, remain the same or increase (Figure 77).

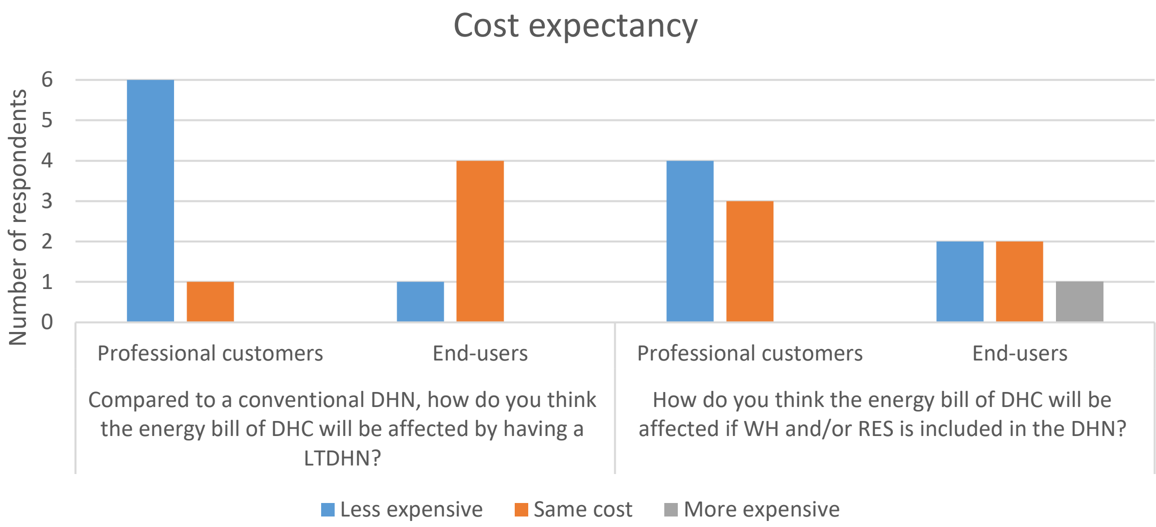


Figure 77 – Cost expectancy of end-users and professional customers (Italian demo site).

13.4 Technical factors

A minor part of the heat demand in Italy is served by district heating networks, mainly in Northern Italy where DH systems have been developing since the 1970s. District cooling is starting to be implemented but at a limited scale and mainly for certain types of buildings. Technical solutions of low and neutral temperature systems are tested at demo sites in small scale networks. The systems need to be competitive and feasible business models need to be developed for being able to extend small scale demo sites to other areas and be replicable.

13.4.1 Level of maturity of the DHC network technology

In Italy a minor part of the heat demand is currently served by district heating networks. There are about 200 DH networks in the entire country, 98% located in Northern Italy. In e.g. the city of Milan alone there are 13 different DH systems, most of them at neighbourhood area size, while three are above 60 km long (trench length). Notwithstanding the number of networks, DH systems cover around 6% of the total national civil heating demand. DH systems have been developing since the 1970s and main networks can be found in Brescia, Turin, Milan, Reggio Emilia, Modena, Verona and Mantua. Although DH is not a recent solution, the main heating systems installed in Italian residential buildings are boilers (diesel, gas, condensing).

In the last years, district cooling networks are starting to be implemented in Italy, but they are still a technology not fully exploited. Normally these systems have been built together with DH networks and are used by some categories of buildings, such as hospitals and universities. Low- and neutral temperature DHC networks is a new technology in the country. At this point it is tested at demo sites in small scale networks.

13.4.2 Availability of technical components, installers and operators

The most important DH operators within Italy include A2A, Iren, Hera, Engie and Acea. Furtherly, a huge number of small networks are managed by municipal utilities or local multi-utilities.

Main network operators and stakeholders created the Italian District Heating Association (AIRU) in 1982, which promotes the national development of this technology. There are main industrial stakeholders within the areas of pipes and technical components, substations and meters. Furtherly, several universities and other research organizations have been involved in the optimization of DH in Italy.
A wide variety of heat sources and technical solutions are used in the DH systems. The most common heat supply is CHP plants, followed by fossil fuels, waste –to – energy plants and gas boilers. DH networks in the Tuscany area, in particular, are based on geothermal supplies, while the most used source for mountain networks is wooden biomass.

Depending on the technique chosen for a low- or neutral temperature DHC, different technical components will be needed. At the REWARDHeat demo site, the project will assess issues regarding the site-specific conditions and increase the knowledge in the area. One technical challenge regarding for example geothermal heat utilization concerns the optimal design of substations, since the systems are not commercially available on a large scale. The specific projects need to develop and design the systems considering the local customer side.

13.4.3 DHC solution replicability

Since low- and neutral temperature DHC networks is a new technology in Italy, DHC solution replicability in general is not assessed. The local prerequisites will be crucial when it comes to selecting the viable technique for a certain site; there are different opportunities of excess heat in different cities and the climate in different areas also diverge. In Milan for example, the high ground water level and the existing geological system with wells is a prerequisite for the chosen technology. In REWARDHeat, one target is to look at the replicability in different future cases and in larger scale.

There are generally big opportunities to lower the return temperature in a DHC network by higher efficiency in the systems. For example, in areas where the building stock needs refurbishment, the potential could be interesting to assess. The systems need to be competitive and feasible business models need to be developed to extend small scale demo sites to other areas and be replicable.

13.4.4 Heat pumps

The Italian legislation recognizes HPs as an important contributor to achieving energy efficiency and climate targets. The statistics of HPs in Italy are provided by the GSE (Gestore dei Servizi Energetici). In hot areas in Italy it is common with a reversible HP that is installed mainly for cooling purposes. In 2018 HPs had a 5% market share in the residential sector, gas boilers are the main competition in Italy. Individual heating solutions are dominating the Italian heat market (~80%).

Actors on the HP market are still, despite measures being taken to increase knowledge and training among installers and other professionals, more likely to turn to conventional solutions than recommend a HP system. End-user knowledge also needs to be increased in order to see market growth. The market segment with the largest potential for HPs are multifamily building with individual systems. The trend toward HPs are already visible in small to medium-sized houses in warmer climate zones.

The key people influencing which heating system is installed in a building depends on the type of intervention. In new building the architects or engineer decides, in building renovations the heating engineer or designer decides and when looking to replace existing heating systems it is either the heating engineer (for centralized solutions) or the installer (for individual solutions).

13.5 Legal

The main Italian regulations in terms of building energy efficiency aims on promoting the improvement of the energy performance of properties and defining the minimum efficiency requirements (Italian Parliament, 2005). In order to promote energy efficiency in both existing and new buildings in Italy several tax measures have been promulgated, providing deduction for certain parts of the cost incurred of the energy improvements. In particular, the 2017´s Budget Law (Italian Parliament, 2016) introduced a tax deduction equal to 65% for costs incurred by the end of the reference year, in order to incentivize buildings energy efficiency initiatives and bring awareness of resource efficiency. It is highlighted that within the set of measures to support recovery from economic crisis following the COVID-19 outbreak, with a recent act – Legislative Decree 34/2020 (Italian Parliament, 2020), the tax deduction for works related to energy refurbishment of existing buildings carried out until the end of year 2021 has been increased to 110%, in order to support the creation of workplaces and businesses in the area, contemporarily achieving energy and climate targets.

13.5.1 Planning and permission

The Italian regulations determines the specific cases in which prearranging for a possible connection to district heating and cooling networks is mandatory. The Ministerial Decree 26/06/15 (Italian Ministry of Economic Development, 2015) establishes that, in general, new buildings and existing buildings subjected to major renovations or energy investments must take into consideration the existence of DHC networks. If the buildings are located at less than 1000 meters from an existing or adopted DHC network, it is mandatory to have a possible connection to the DHC as a subject in technical-economic evaluations. In the assessment the connection to the DHC network must be compared with the other alternatives, in order to optimize the energy performance of the building. For the assessment, the service provider declares the annual cost (including taxes and fixed quotas) of the supply of thermal energy required for standard use of the building.

13.5.2 Heat and cooling market

In Italy the DHC sector is experiencing some barriers when it comes to developing the networks. For example, uncertainty in the regulatory framework contributes to slowing down the investments in DHC. The Italian legislation (Italian Parliament, 2011) that implements the 2009/28/CE has introduced a definition of DHC ("the distribution of thermal energy in the form of steam, hot water or chilled liquids, from a central source of production through a network to multiple buildings or sites, for the use of space or process heating or cooling") but still the legal status of DHC remains unclear. The current legislation does not define if DHC is considered as a public services or private entrepreneurial activities. This aspect would be a key for clarifying which regulatory framework that has to be followed in projects implementation. If DHC networks are considered as public services, governments can assign services to specific operators on an exclusive basis. If not considered as public services DHC networks implementations should follow a free competition scheme with its own regulations. The regulatory gap opens for different interpretations addressed at the local level, causing legal disputes judged by administrative courts case by case.

In the recent years the expansion of DHC projects in Italy have experienced difficulties deriving from lack of standardization and comparability in pricing. The national energy regulatory authority ARERA - Italian Regulatory Authority for Energy, Networks and Environment - is responsible for regulating network tariffs, incentivizing improvements in energy efficiency and supporting dynamic pricing for demand response measures by end consumers (for the DHC, electricity, natural gas and water sectors). Despite the authority's efforts in promoting competition and efficiency as well as ensuring national uniform availability and distribution of services, local authorities can interpret the regulations in different ways (e.g. connection fees, supply rates, network extensions, service quality and heat measurement or metering). These aspects give rise to complications in terms of competitive structure, user's protection and the DHC sector's efficiency and development.

13.5.3 Buildings and indoor climate

Building requirements and energy regulation play a crucial role in the energy distribution of DHC. Over the years, buildings energy performance requirements have been strengthened by the Italian government. The Ministerial Decree 26/06/2015 (DM) (Italian Ministry of Economic Development, 2015) made updates of energy performance calculation methodology, rules for considering the use of RES in buildings, stricter minimum energy performance requirements for buildings, building systems and components, and conversion factors. The DM specifies the requirements of nearly zero-energy buildings and demands that the energy performance of the new building is compared with a reference or target building with the same location, function, size, but with reference insulation level and technical systems efficiencies. Regarding conversions factors of DHC the regulation, in the absence of specific values declared by the supplier and certified by a third party, consider as default values 1.5 as non-renewable (and total) energy factor for district heating, and 0.5 as non-renewable (and total) energy factor for district cooling (Corrado et al., 2017).

Regarding indoor climate conditions, legislative requirements set in the DM are in line with the technical standard UNI EN 10339 (UNI - Ente Italiano di Normazione 1995), which foresees:

- Indoor temperature: 20±2°C for residential and most tertiary areas (24°C for toilets), 18±2°C for industrial buildings, 16±2°C for shopping malls, supermarkets, museums;
- Humidity rate: 65% at 20°C (lower – around 40-50% in winter months, higher – around 70-80% in summer months);
- Ventilation rate: 7-11 l/s/person for residential and most tertiary spaces (hotels, schools, hospitals, cinemas/theatres, conference rooms, etc.).

13.6 Modelling results-based factors

The environmental key factors were assessed as barriers or opportunities based on the results of the TIMES optimization modelling, which are presented and briefly described below.

13.6.1 Specific cost of heat supply

Figure 78 shows the differences between the specific variable, fixed O&M, and capital costs of heat supply in the heating sector of Italy in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be observed that variable and fixed O&M costs are estimated to be lower in the future with developed LTDHC networks and utilization of LTH sources, as compared to the future with conventional DH. Whereas, the capital cost is shown to be slightly greater in case of LTDH development. This indicates that greater heat generation capacity is expected in Italy in the *FutureDH* scenario, as compared to the *ConventionalDH* scenario, but the type of installed plants will lead to significantly reduced variable costs.

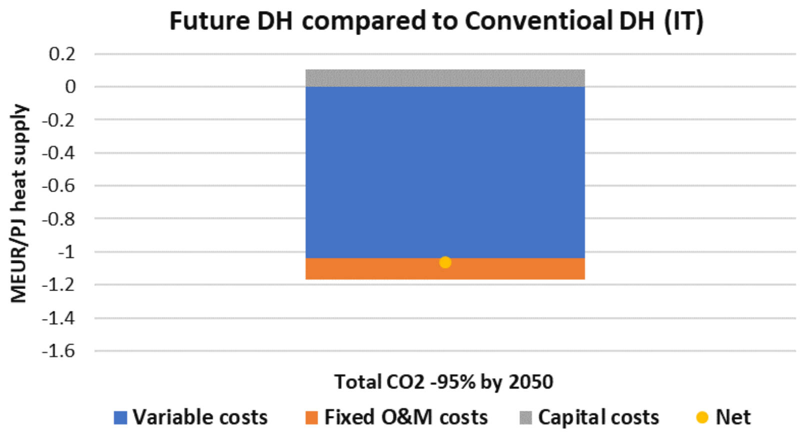


Figure 78 – The differences between the specific undiscounted Variable, Fixed O&M, and Capital (together with their total Net value) costs of heat supply in the heating sector of Italy, averaged over the Years 2020-2050, in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

13.6.2 Specific primary energy use

Figure 79 shows the specific primary energy use, divided into fuel use, electricity use and electricity generation, of heat supply in the heating sector of Italy in year 2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). The modelling results indicate that with the development of LTDH networks and successful utilization of LTH sources the specific net energy use of heat supply will be impacted insignificantly, i.e., reduced by around 50%, as compared to the future with conventional DH networks.

Note: Specific primary energy use values for generated and used electricity were calculated using respective fuel use factors. Values for electricity generation are negative because generated electricity is assumed to be exported (from the heating sector) and substitute electricity generation in the electric power sector.

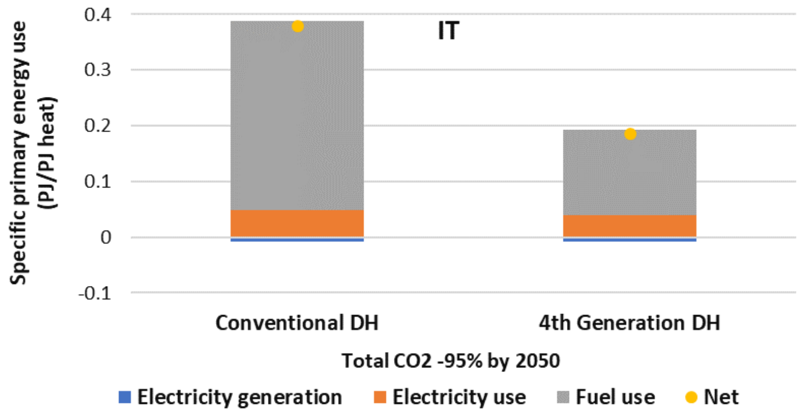


Figure 79 – The specific primary energy use, divided into fuel use, electricity generation and electricity use, of heat supply in the heating sector of Italy in year 2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

13.6.3 Accumulated air pollutant emissions

Figure 80 shows the accumulated NOx, SOx, and PM2.5 emissions from the heating sector of Italy over the period 2020-2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be noticed from the Figure that the replication of REWARDHeat solutions, i.e., development of LTDH networks and utilization of LTH sources, can lead to noticeably lower air pollutant emissions in Italy over the course of the next 30 years.

Note: Negative values in Figure 80 mean that electricity generated in the heating sector substituted emissions in the electric power sector and results in net negative total emissions of an air pollutant.

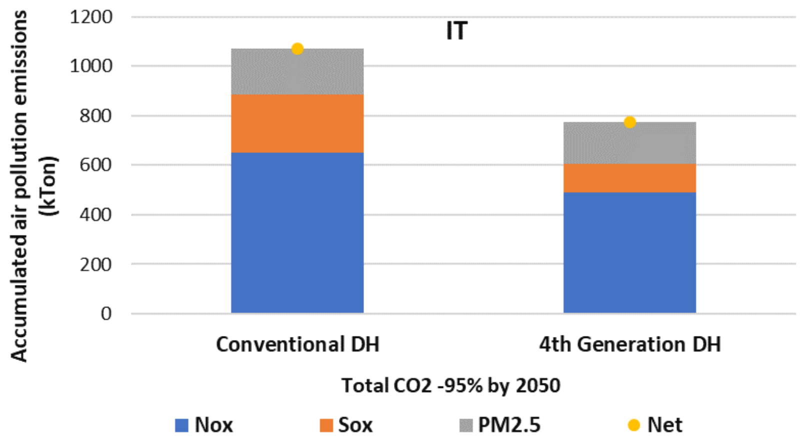


Figure 80 – The accumulated air pollutant emissions (NOx, SOx, PM2.5) attributed to heat supply in the heating sector of Italy over the period 2020-2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

14 Annex: PESTLE Sweden

Sweden is located in northern Europe, between the Baltic Sea and Norway. The population as of 1 January 2019 was approximately 10.2 million (Eurostat, 2019c). The number of heating degree days in Sweden in 2018 was 5122 and 5 cooling degree days (Eurostat, 2019a). The energy consumption for heating in buildings (normal climate) in 2015 was 113 kWh/m^2 (Odyssee-Mure, 2019). The total primary energy supply in 2018 consisted of 20.1% oil, 24.8% biofuels and waste, 3% wind, solar etc, 10.8% hydro, 34.8% nuclear, 2% natural gas and 4.5% coal (International Energy Agency, 2019a). The final energy consumption in 2017 was 376 TWh (Eurostat, 2019b).

Table 15 – Share of renewable energy in total energy, HC, electricity and transport in 2017 (EuroStat, 2019d)

	RES in energy	RES in HC	RES in electricity	RES in transport
Sweden	55%	69%	66%	32%

14.1 Political factors

14.1.1 National energy and climate plan (NECP)

Sweden aims to cut its net greenhouse gas emissions to zero by 2045 and then achieve negative emissions. Carbon neutral or zero-net emissions entails that Sweden will reduce GHG emissions by 85% compared to 1990's level while the last 15% can be achieved by additional measures (for example carbon capture and storage) that should contribute to negative emissions after 2045.

Sweden has no national target for the share of renewable energy in 2030 but the indicated trajectory indicates a 65% share of renewables in the gross energy consumption. The Swedish government has decided not to set specific targets on different renewable energy technology targets but rather leave it to the market to find cost-effective solutions. The target for renewable energy in electricity generation by 2040 is 100% renewable. By 2030 50% energy efficiency should be achieved compared to 2005. The target is measured as energy supplied in relation to gross domestic product (GDP). The overall policy is for policies on energy efficiency should be general and not linked to specific technologies. New buildings in Sweden have specified limits on primary energy consumption, expressed as kWh/m^2, and varies between 80-90 kWh/m^2 depending on type of building.

The Swedish government states that the owners of DHN are the ones to assess whether investment in new infrastructure is necessary and profitable. The district cooling potential is estimated to increase to 2TWh by 2030.

In relation to Article 14 (1) of Directive 2012/27/EU the potential for high-efficiency co-generation and efficient DHC is expected to decline, new connections are not estimated to compensate for energy efficiency measures and conversion to heat pumps (European commission, 2020c).

14.1.2 Political interest in REWARDHeat solutions

Sweden has identified DHN as a key enabler to reaching the goal of becoming carbon-neutral by 2045 (Galindo Fernández et al., 2019). The Swedish building code favours individual solutions such as electricity based heat pumps and due to the low electricity price favouring other heating supply sources (such as heat pumps), only a small expansion of district heating is foreseen in the coming years (EuroHeat & Power, 2017).

An estimation is that only 5-7% of the energy demand in Sweden by 2030 will be from new buildings and 10-15% by 2050 (Sköldberg and Rydén, 2014). The newly constructed buildings have requirements on energy efficiency and amount of energy delivered to the building measured in kWh/m^2. The pace of renovating buildings in Sweden is currently at approximate 1.2% and the common understanding is that the number must increase to meet energy efficiency targets. More energy efficient buildings with a lower heating demand can be an opportunity for LTDHN.

14.1.3 Financial support for REWARDHeat solutions

Today there is no specific funding available for investments in DHN.

Sweden has had a market-based support system for renewable electricity production since 2003, the electricity certificate system. Each MWh of produced renewable energy qualifies for one certificate. The certificates are sold on an open market to electricity consumers who must fulfil a quota of certified electricity. Since 2012 Sweden and Norway have a shared electricity certificate market. Wind, solar, geothermal, some hydro and certain biofuels are included in the system. The electricity certificate system has been extended to 2030 (International Energy Agency, 2020).

Since 2009 solar PV systems connected to the grid have been eligible for support in the *Investment Aid for solar PV* connected to the grid. The financial aid has varied over the years and as of 2013 a maximum of 35% of the investment cost can be covered. The support is also for hybrid PVT systems (International Energy Agency, 2020), if the electricity produced amounts to at least half of the installations total annual production. The maximum amount per installation if SEK1,2 million. These subsidies are expected to end at the end of 2020. All renewable energy is exempt from both CO_2 and energy tax obligations (Vågerö, 2019). CO_2 taxation on fuels was introduced in 1991 and has been one of the main drivers for transitioning the energy system. The CO_2 tax is coordinated with the EU-ETS systems and industrial installations in a way such that industries in the EU-ETS do not pay the CO_2 tax. Heat only boiler covered in the ETS still must pay 80% of the CO_2 tax (Galindo Fernández et al., 2019). The CO_2 tax in 2019 was at 114 € per tonne CO_2 (The Government of Sweden, 2019). Property owners can receive a tax deduction of 30% of the labour cost for renovation, conversion and extensions to the building (European commission, 2020c).

14.2 Economic factors

14.2.1 Heating and cooling demand

The final HC demand in Sweden in 2015 was 178 TWh, approximately 48% of total energy demand (Fleiter et al., 2017). As can be seen in Figure 81, space heating is the largest demand and the main part of the residential and tertiary demand. Closely followed by process heating for the industrial sector. Cooling is less than 5% of the total demand (Paardekooper et al., 2018d).

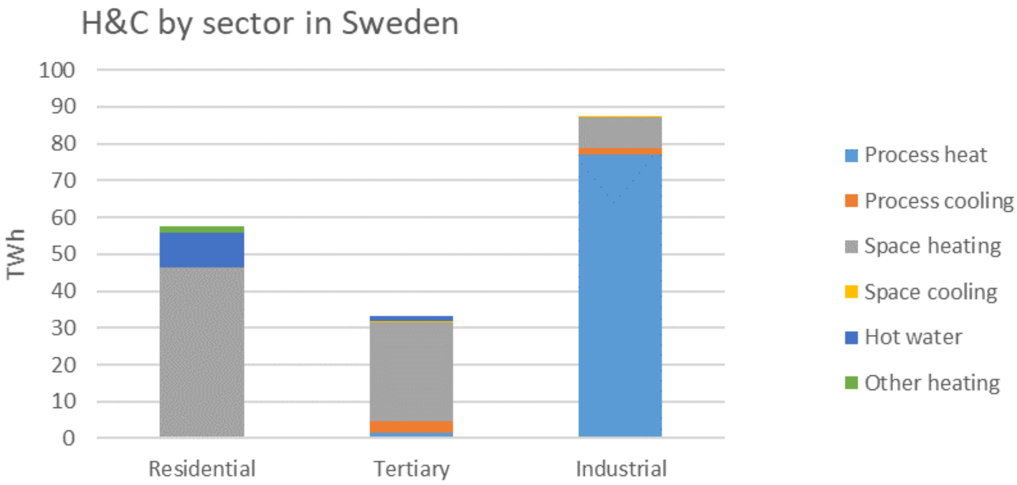


Figure 81 – HC by sector in Sweden (Fleiter et al., 2017).

In the Heat Roadmap for Sweden estimations based on the current policy the total demand for HC is expected to increase by 1% to 2050. Space heating will be reduced by 16%. Process heating and hot water will grow by 10% in demand. Cooling is expected to be the fastest growing demand to 2050 but the total cooling demand will still be less than 17% of the total HC demand. Space cooling is expected to almost double in demand mainly driven by the service sector. Process cooling is expected to increase by 47% to 2050 (Paardekooper et al., 2018d).

14.2.2 Heating and cooling supply

The HC supply in Sweden is mainly supplied by biomass (31%) and district heating (27%). Biomass is mainly used to produce process heating for the industrial sector, shown in Figure 82 and Figure 83. District heating is mainly used for space heating and supplies the largest demand of hot water, mainly to the residential and tertiary sector (Fleiter et al., 2017).

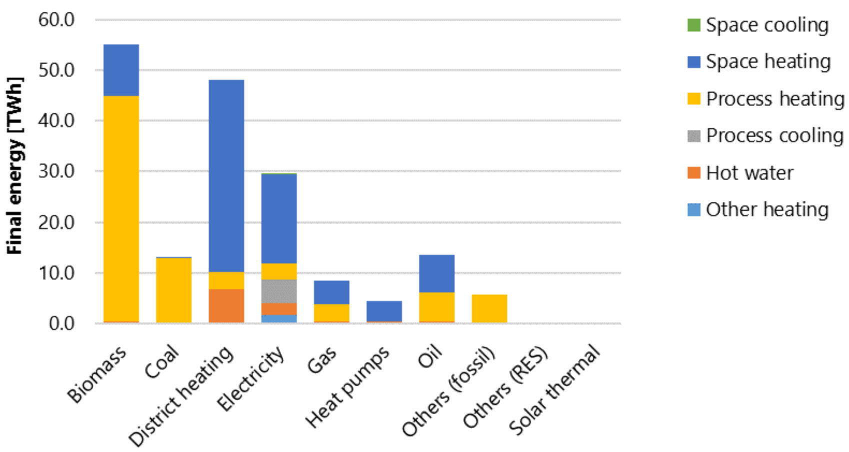


Figure 82 – Energy carrier for the final HC demand for all sectors in Sweden [TWh] (Fleiter et al., 2017).

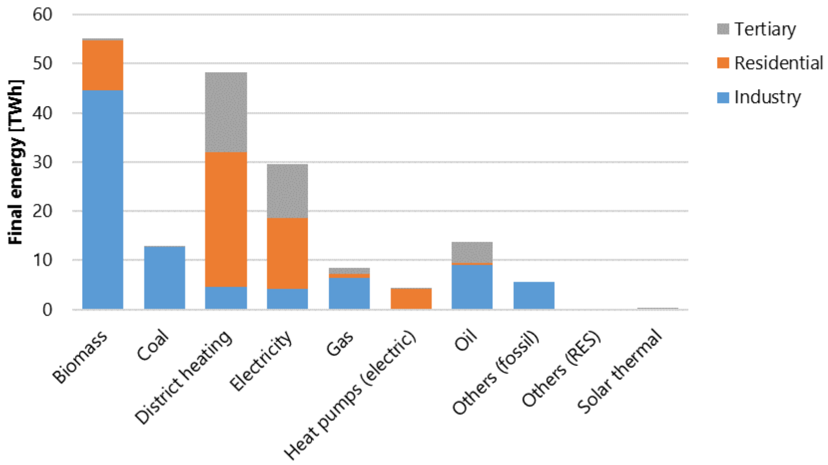


Figure 83 – Energy carrier split by sectoral demand in Sweden [TWh] (Fleiter et al., 2017).

14.2.3 District heating

District heating networks In Sweden were developed by municipalities from the 1950's to the 1990's. Previous (1998-2002 and 2006-2010) subsidies for transitioning away from oil and direct electricity for heating lead to increasing amount of connection to the DH network (Galindo Fernández et al., 2019). Municipalities had almost 100% of the ownership in 1990. Following the national electricity market deregulation in 1996 many DHN were sold to mainly three companies (Vattenfall, Fortum and EON) and in 2004 municipality portion of ownership had decreased to 60%. The business set-up consists of both business-to-business contracts and contracts with private customers (Werner, 2017).

In 2014 about 500 DHN were listed in Sweden and the technology is very common in Sweden. 42% of the heat in 2015 was produced in CHP plants (Werner, 2017). Fossil fuels are approximately 5% of the district heating supply (Energiföretagen, 2019). Industrial waste heat accounted for 8.2% (4.2 TWh) of the district heating supply in 2018 and waste heat is recovered from more than 85 industries.

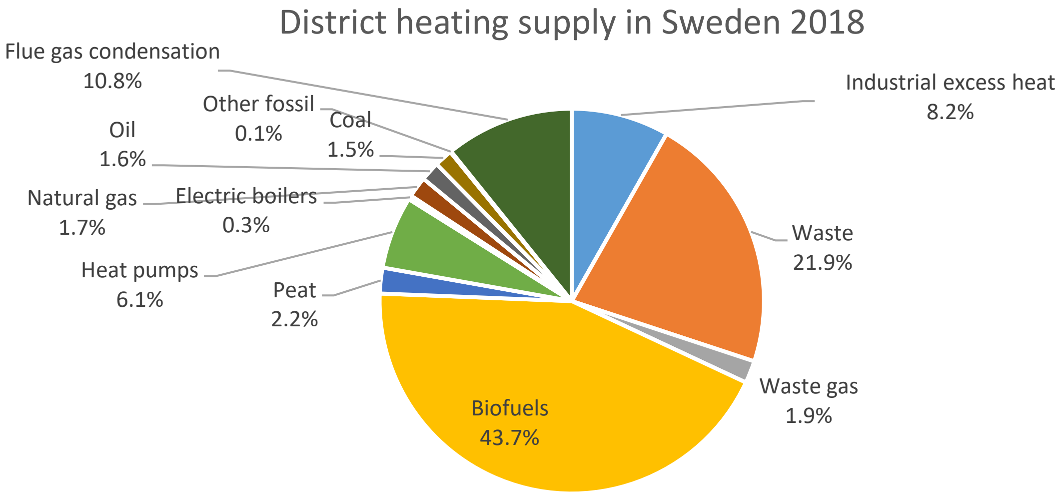


Figure 84 – District heating supply in Sweden 2018 (Energiföretagen, 2019).

40 urban areas in Sweden had a district cooling system in 2014 (Werner, 2017). Low- and neutral temperature DHN exists in Sweden but to a very limited extent.

The Swedish Energy Authority is the responsible authority for district heating. Since 2008 the Energy Agency has an independent unit called The Swedish District Heating Board. The role of the Swedish District Heating Board is to ensure the District Heating Act (2008:263) is complied with. This includes to mediate between district heating companies and customers about terms and conditions and between district heating companies and other companies who want to access the DHN. The district heating industry has a voluntary initiative called The Price Dialogue with the aim to increase transparency and to strengthen the position of the customer with regards to pricing of district heating. The Price Dialogue covers 75% of all delivered district heating in Sweden and was launched in 2013 (Prisdialogen, 2020).

There is only one example of geothermal energy being utilized in the district heat system, a plant from 1985 located in Lund (Gehlin and Andersson, 2019). Some examples of solar thermal plant supplying energy to the district heating system exists in Sweden. 22 such installations were installed between 2000 and 2010. The installations are all small-scale production units (Dalenbäck et al., 2013).

14.2.4 Potential for waste heat and renewable energy sources

The practical utilization potential for annual available urban waste heat from four studied categories identified a potential of 40 PJ in Sweden (Persson and Averfalk, 2018). The potential per category was identified at data centres (13.3 PJ), metro stations (0.9 PJ), service sector buildings (5.4 PJ) and wastewater plants (20.3 PJ). The industrial waste heat recovery in the country has been estimated at 7 TWh/year (Papapetrou et al., 2018a). Another study found the industrial waste heat potential to be 29 TWh (Persson, 2015).

In the Heat Roadmap for Sweden the geothermal potential to be a part of the DHN was estimated at zero (Paardekooper et al., 2018d). The potential for deep geothermal is scarce in Sweden. Shallow geothermal systems using ground sourced heat pump for space heating and domestic hot water, is common and it is estimated that Sweden has over 300 000 installations, mainly for single-house buildings (Gehlin and Andersson, 2019). In the Heat Roadmap for Sweden, solar thermal is estimated to produce 2% of the DH demand in 2050, however the technical potential would not be fully utilized at this percentage (Paardekooper et al., 2018d). The installed solar PV capacity in Sweden in 2017 was 244 MW and produced 0.23 TWh (EurObserv'ER consortium, 2018).

14.3 Social factors

In Sweden responses were collected by distributing the survey via email to selected respondents. The professional customers are foreseen to be connected to the REWARDHeat solution, as well as one of the private customers. For the remaining end-users it was not possible to reach customers in connection to the demo site and hence an approximation was made. Two professional customers responded to the survey and five end-users. The professional customers, and one private customer, were connected to DH today. One had a ground-sourced heat pump and the remaining did not know.

14.3.1 General opinion of DHN

The general opinion of respondents is positive, especially that DH is a convenient option. The view of DHC systems as cost-efficient received the lowest average (Figure 85).

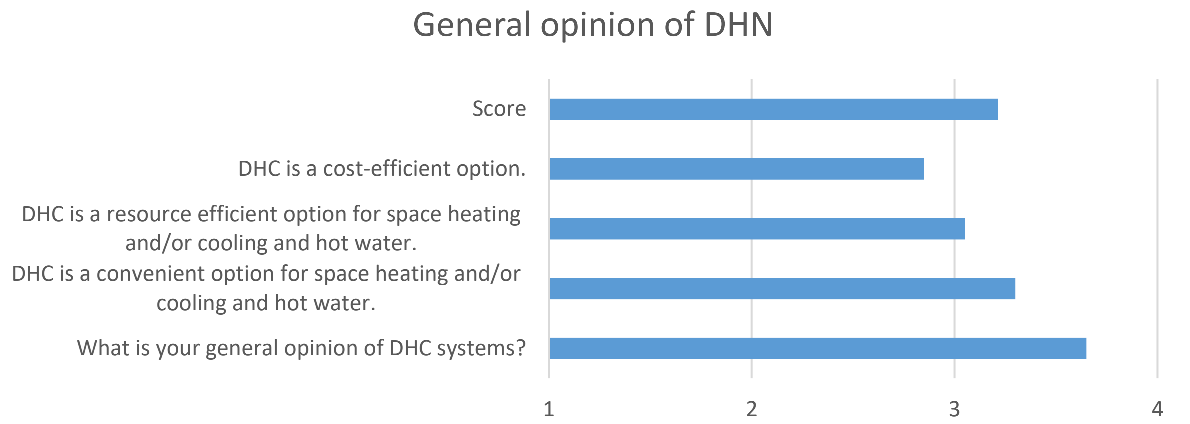


Figure 85 – Mean values of the respondents on their general opinion about DHC (Swedish demo site), as well as the resulting score. The respondents answered on a 4-degree Likert-scale were 1= I don't agree, or very negative, and 4= I agree completely, or very positive.

14.3.2 Awareness of technology

Respondents to a large extent think that DHN are common in the country and most perceive that the understand well how such a system works. The awareness of LTDH as well as DH with WH and RE is generally lower (Figure 86).

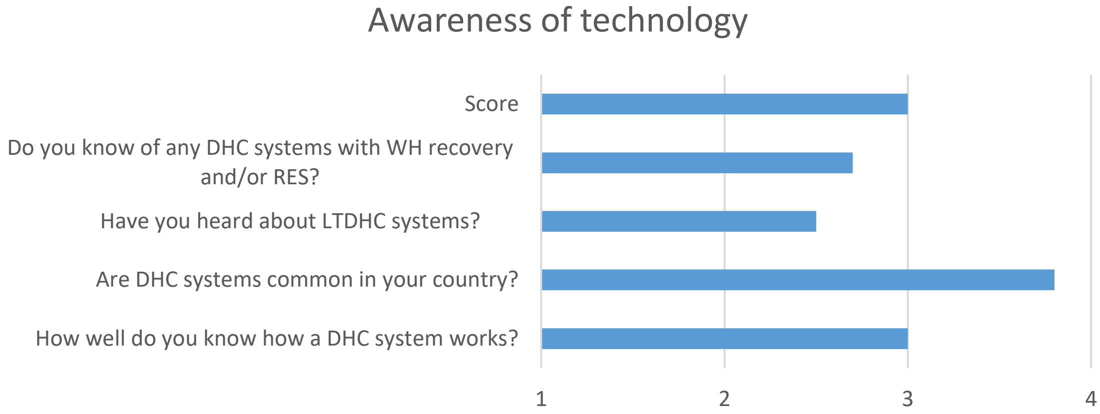


Figure 86 – Mean values on the awareness of the technology, as well as the resulting score (Swedish demo site).

14.3.3 Risks and benefits

Better for the environment, lower losses and better use of resources are the three main perceived benefits of having a LTDHN. Professional customers see no risk whereas most end-users don't know. One identifies a risk of not being supplied with enough heat and one thinks the risk of developing bacteria. Integrating RE and WH into a DHN is seen as efficient, both from an energy and a resource perspective. Most respondents don't see a risk (Table 16).

Table 16 – Perceived risks and benefits of the REWARDHeat technologies by respondents as well as the resulting score (Swedish demo site). Respondents answered in open text fields and could write as many benefits or risks as they wanted. The number displayed in the parenthesis is how many respondents stated the risk/benefit.

	Benefits LTDHN	Risks LTDHN	Benefits RES & WH	Risks RES & WH
Professional c ustomers	Less heat loss (1), utilization of LTHS (1)	No risk (2)	Necessary (1), all benefits (1)	No risk (2)
End-users	Lower losses (1), environmental (2), better use of resources (2), don't know (1)	Don't know (3), not enough heat (1), bacteria (1)	Environmental (2), energy efficient (2), resource efficient (1)	Energy might still be wasted (1), variability (1), don't know (1), no risk (2)

14.3.4 Environmental consideration

All respondents are concerned about the impacts of climate change (have answered a three or a four). All but one private customer believed that the effects of climate change are uncertain. All respondents believe that including waste heat and RES in the DHN is beneficial for the environment (Figure 87).

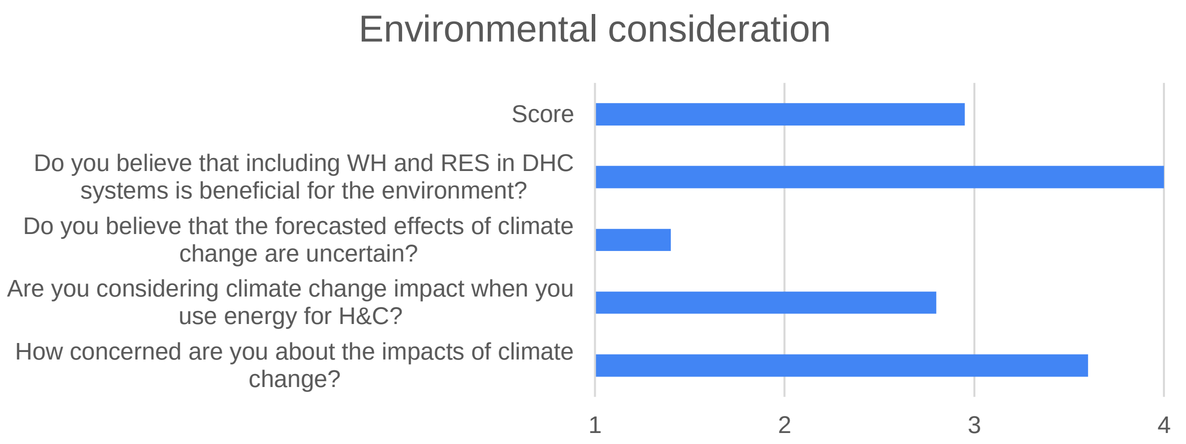


Figure 87 – Mean values on the environmental consideration, as well as the resulting score (Swedish demo site)

14.3.5 Cost expectancy

Transitioning from a conventional DHN to a LTDHN is expected to result in a lower cost for customers or the same cost as today. Integrating RE and WH into the DH supply is believed to result in a lower energy bill (Figure 88).

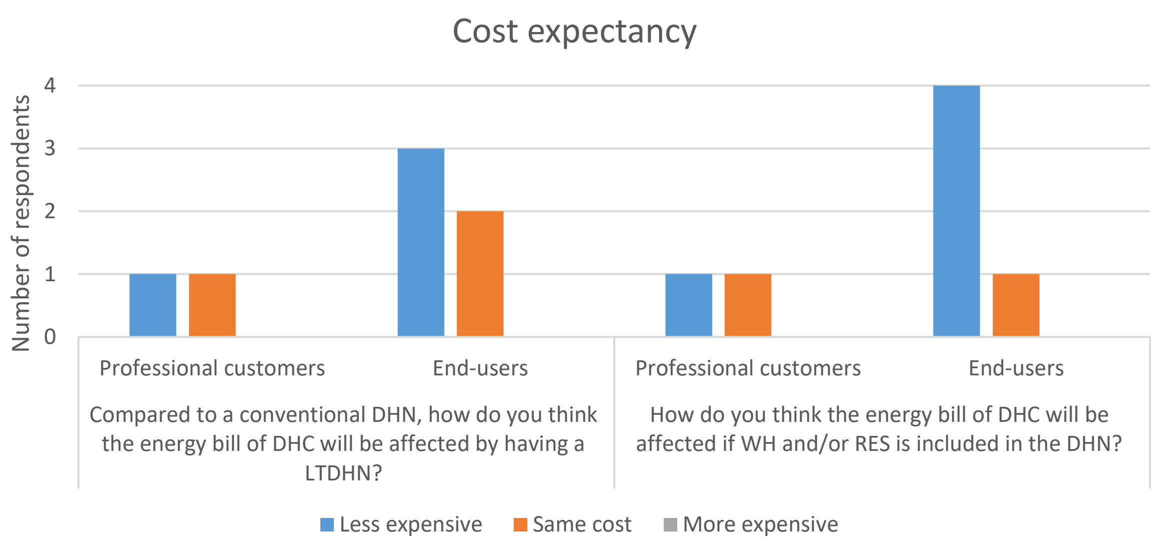


Figure 88 – Cost expectancy of end-users and professional customers (Swedish demo site)

14.4 Technical factors

Technical prerequisites that impact the DHC development in Sweden concern e.g. that conventional DH is a mature and widely used heat solution with rather similar production and distribution concepts within the country. Furtherly, DC is a growing solution that meets an increasing demand. The DH sector phases challenges such as increasing competition and a need to decrease return temperature levels, within which there is good potential for low-temperature systems and improved DH water cooling at customer side.

14.4.1 Level of maturity of the DHC network technology

DH is a mature technology applied in growing scale since the 1950s in Sweden. The use has increased almost linearly from the 1970s to the 2010s, but with a tendency to level-off in the last couple of years (Energiföretagen, 2020a). About half of all heating supply is by DH, mainly to multi-household buildings, business facilities and a smaller number of single households (Energimyndigheten, 2019). DH suppliers have during the last 5-10 years experienced market changes, with increasing competition from other heat solutions and a threatened business (Energiforsk, 2016). This correlates well with the stagnation of DH increase. Being a large sector, DH has needs as well as skills to evaluate and invest in low-temperature technology for retaining its market position.

The DH production has been gradually expanded with e.g. a steady increase of renewably operated facilities since the 1990s (Energiföretagen, 2020b). The technical experiences of the high-temperature systems and needs to develop more cost-efficient supply systems are a good basis for developing low-temperature systems, and research work within this field is ongoing (Högskolan Halmstad, 2020). The supplied amount of DC is only a fraction compared to DH, but continuously growing since the 1990s, meeting an increased demand from office and business facilities (Energimyndigheten, 2019).

14.4.2 Availability of technical components, installers and operators

The components and skills needed for construction and operation of DHC networks are generally well available as these types of facilities are continuously taken into operation.

Among the technical concerns of the Swedish DH sector is that some main professions such as operation technician and operation manager are judged as deficit professions (Energiföretagen, 2020a). It is hence continuously important with educational efforts to maintain or improve this availability. It is also notable that components as well as installers involved in DH or DC facilities and commissioning are at an international market, so dominical as international actors are both involved in these kinds of projects. All services must thus not be met domestically, but the deficit professions should be acknowledged.

The experiences of excess heat for Swedish DH systems are significant; approximately 10 % of the energy applied in Sweden's large DH production is excess heat. The use of heat pumps for DH is also substantial, contributing with approximately the same amount of energy to the DH systems. Heat pumps are also applied as local heat source for approximately 1.2 million single-households (approximately 60 percent of all single-households in Sweden) (Energimyndigheten, 2019). Numerous important actors and disciplines needed for low-temperature systems through excess heat and/or heat pumps should thus be available.

14.4.3 DHC solution replicability

DHC solutions in Sweden have overall been rather replicated already with many similar DH concepts in cities concerning production facilities, distribution and deliverance. DH is supplied almost exclusively by high-temperature systems, however with some variations in temperatures: Average supply/return temperature is 86°C/47°C, but they can in cases be at 110°C and 60-70°C respectively (Åberg et al., 2017). The predominant share of the energy used for DH production in Sweden is fuels, and 62% is biofuels (Energimyndigheten, 2019). The many similar DH concepts based on this should overall enhance the potential to replicate current systems updates.

A common strive for Swedish DH suppliers, and a reason for assessing new low-temperature systems, is to decrease the return line temperatures (Åberg et al., 2017). The return line temperatures are often high enough to utilize for space heating in new building areas, although domestic hot water generally should need energy boosting (e.g. by heat pumps) (Lindahl et al., 2018). DH is often applied in high residential density areas. In such areas where further expansion is planned, return line utilization for low-temperature DH should have a significant replication potential. Furtherly, improved cooling at customer side of the DH water should be prioritized. An estimation from 2014 was that 75% of all DH customers have faults in substations and secondary systems, which today is compensated for by increasing the supply temperatures (Gadd, 2014).

14.4.4 Heat pumps

In Swedish legislation technology neutrality is strived for and therefor there is no special attention given to HPs as such. The technology is however widespread in Sweden. HPs and direct electricity for heating are grouped together in statistics under electricity for heating, which is not considered beneficial for HPs. Using electricity for heating is generally not encouraged under the common energy agreement (Energiöverenskommelsen). Attempts are being made in the official statistics to separate HPs from other electrical heating sources.

Looking at all buildings HPs are supplying approximately 22% of used energy for heating. HPs are supplying heat to all building segments with the largest technical improvement area being towards industry where the solutions are less standardised. From a market share perspective, the largest increase could be made from multifamily houses that are supplied with district heating.

Actors on the market are generally knowledgeable about HPs and able to both recommend the solution and install the system, however, there is always room for improvement. In new buildings the project developer, an individual or a construction company, decides on heating solution. In renovation projects the individual owner decides for small family houses and for multifamily houses, that are often owned by a housing cooperative, the decision is taken by the board which normally consists of residents in the housing cooperative.

The gas grid in Sweden is only very limited and the competing heating solutions are rather district heating, biofueled boilers or direct electric heating. The price difference between the alternatives is relatively small and no imbalance in energy price ratio is experienced on the Swedish market. Oil boilers are basically non-existing and not a competition for new buildings or renovation.

14.5 Legal

For Sweden, legal prerequisites that impact DHC systems include the legislated municipal planning of land use, the “natural monopoly” that DH traditionally has had in parts of Sweden, time and cost driving permission procedures and conversion factors for the energy performance requirements of the building regulations.

14.5.1 Planning and permission

Spatial planning in Sweden is regulated through the Planning and Building Act (Plan- och bygglagen, PBL). It regulates how the municipalities are obliged to plan the land-use, water and building works, by *overview plans* ("översiktsplaner") covering the whole municipal area and guiding the decisions on how areas of the municipality shall be used (Boverket, 2020). It also regulates that the municipalities can make legally binding *Detail plans* ("detaljplaner") over defined parts of the area. This is used e.g. for new exploitation of areas for facilitating the handling of multiple building permissions.

The possibility to oblige certain energy solutions (e.g. DHC) through this planning is uncertain and largely untried. Generally, municipalities do not set binding requirements to use certain energy solutions in the plans (personal communication with Tor Fossum at the environmental department in the city of Malmö, 2 December 2019). How municipalities interpret and use their possibilities can be of importance for DHC opportunities (IVL Swedish Environmental Research Institute, 2020). In indirect senses, possibilities to affect the opportunities for DHC by the plans are clearer, since customer density, business and household mix can be defined in ways that benefit or disbenefit DHC.

Furtherly, DHC facilities are subject to permission trial according to PBL and the Swedish Environmental Code (Miljöbalken). The procedures can be long and costly, especially for larger facilities, e.g. high-temperature DH plants that require a large area. Low-temperature systems based on e.g. excess heat should often require less interference with current built environment, which could make permission procedures less complicated and costly.

14.5.2 Heat and cooling market

The Swedish energy market is regulated by several acts and decrees, some aimed towards a specific energy carrier, such as the district heating law (Fjärrvärmelagen). The purpose of this law is primarily to strengthen the position of the DH customers. It regulates e.g. obligations for transparency of the DH price setting, the right for two-month notice before contract term changes and rights to negotiate on terms at certain circumstances (Energimarknadsinspektionen, 2020).. Although the purpose is not to promote the DH sector, increased transparency can be beneficial also through increased focus on DH production and its environmental qualities (e.g., 70 % of the energy supplied for DH production is by bio fuels or residual heat) (Energimyndigheten, 2019).

DH has in Sweden constituted a "natural monopoly" during long time in the many areas with grid connection. For many urban DH customers, there are practically no other heat alternatives but to use the already connected DH system, meaning that the DH could have a "lock-in effect" (Energimarknadsinspektionen, 2016). Replacements to local boilers or heat pump solutions in heat stations are always possible, but the decisions are often complex. A replacement is an uncertain investment having to be agreed within e.g. a housing cooperative or housing company and could not be made by individual rental tenants in multi-family buildings. This contributes to DH as a strong long-term competitor although being challenged by other heat solutions. In new area exploitations, competition from other heat solutions can be challenging, but DHC have benefits through existing DH grids often being nearby. In exploitation cases, DHC has now a flexibility to offer by either extension of current high-temperature lines or attaching low-temperature systems with excess heat from return lines and/or local heat sources.

14.5.3 Buildings and indoor climate

Requirements on heat systems, thermal performance and indoor quality are set by the Swedish Building regulations (Boverkets byggregler, BBR). BBR prescribes that buildings and their installations shall be formed so that air and water quality as well as light, humidity, temperature and hygiene conditions become satisfying, and cater for these needs through a number of limit values (insulation levels, ventilation rates, hot water circulation temperatures etc.), inspection obligations and other undertakings. The regulations challenge the low-temperature DHC sector to find efficient solutions that could lower the supply temperatures but still manage the requirements (e.g. apartment level hot water preparation), and work within this field is ongoing (Högskolan Halmstad, 2020).

BBR defines the required building energy performance. This is based on a recalculation of the delivered energy amounts to a primary energy factor ("primärenergital") through conversion factors for the energy carriers used. Decisions on these generic conversion factors have a very significant role in the opportunities for DH systems compared to electrical heat systems, since they impact system choices in many exploitation projects. With respect to reaching required levels and e.g. environmental certifications for buildings, the factors should give a balanced indicator taking the whole energy supply system into account and not favour any solutions unjustifiably. Previous energy performance requirements took only delivered energy into account (not primary energy). Thus, the incorporated conversion factors (with higher factor for electricity than DH) is a step in the right direction for DHC.

14.6 Modelling results-based factors

The environmental key factors were assessed as barriers or opportunities based on the results of the TIMES optimization modelling, which are presented and briefly described below.

14.6.1 Specific cost of heat supply

Figure 89 shows the differences between the specific variable, fixed O&M, and capital costs of heat supply in the heating sector of Sweden in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be observed that all three types of costs are estimated to be significantly lower in the future with developed LTDHC networks and utilization of LTH sources, as compared to the future with conventional DH.

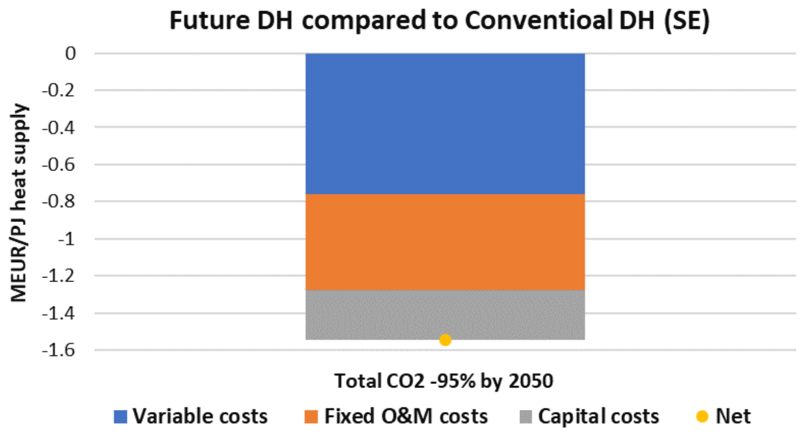


Figure 89 – The differences between the specific undiscounted Variable, Fixed O&M, and Capital (together with their total Net value) costs of heat supply in the heating sector of Sweden, averaged over the Years 2020-2050, in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

14.6.2 Specific primary energy use

Figure 90 shows the specific primary energy use, divided into fuel use, electricity use and electricity generation, of heat supply in the heating sector of Sweden in year 2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). The modelling results indicate that with the development of LTDH networks and successful utilization of LTH sources the specific net energy use of heat supply will be impacted drastically, i.e., reduced by more than 70%, as compared to the future with conventional DH networks.

Note: Specific primary energy use values for generated and used electricity were calculated using respective fuel use factors. Values for electricity generation are negative because generated electricity is assumed to be exported (from the heating sector) and substitute electricity generation in the electric power sector.

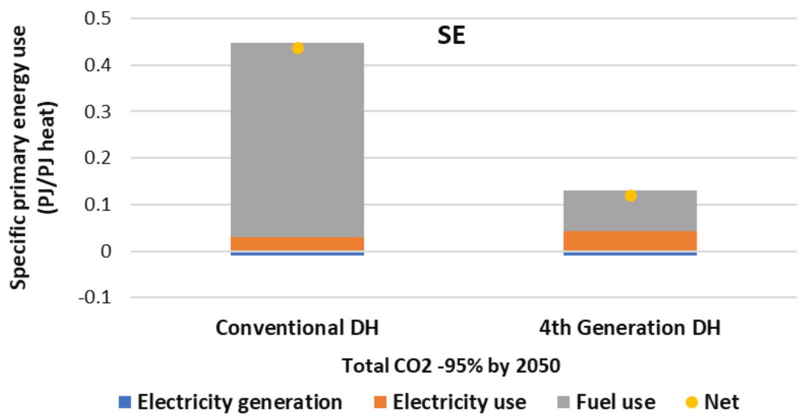


Figure 90 – The specific primary energy use, divided into fuel use, electricity generation and electricity use, of heat supply in the heating sector of Sweden in year 2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

14.6.3 Accumulated air pollutant emissions

Figure 91 shows the accumulated NOx, SOx, and PM2.5 emissions from the heating sector of Sweden over the period 2020-2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be noticed from the Figure that the replication of REWARDHeat solutions, i.e., development of LTDH networks and utilization of LTH sources, can lead to substantially lower air pollutant emissions in Sweden over the course of the next 30 years.

Note: Negative values in Figure 91 mean that electricity generated in the heating sector substituted emissions in the electric power sector and results in net negative total emissions of an air pollutant.

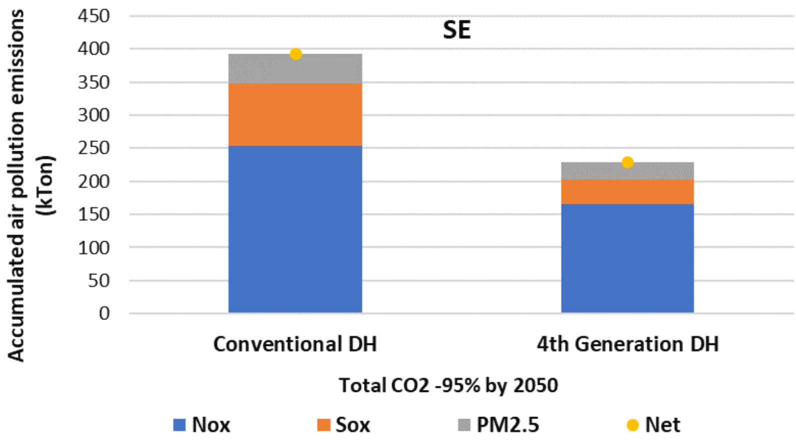


Figure 91 – The accumulated air pollutant emissions (NOx, SOx, PM2.5) attributed to heat supply in the heating sector of Sweden over the period 2020-2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

REWARDHeat

15 Annex: PESTLE The Netherlands

Netherlands, in the north-west of Europe, has a coastline towards the North Sea. The population as of 1 January 2019 was approximately 17.3 million (Eurostat, 2019c). The number of heating degree days in Netherlands in 2018 was 2526 and 31 cooling degree days (Eurostat, 2019a). The energy consumption for heating in buildings (normal climate) in 2015 was 90 kWh/m^2 (Odyssee-Mure, 2019). The total primary energy supply in Netherlands in 2018 consisted of 36.1% oil, 6% biofuels and waste, 1.9% wind, solar etc, 1.3% nuclear, 43.4% natural gas and 11.5% coal (International Energy Agency, 2019a). The final energy consumption in 2017 was 523 TWh (Eurostat, 2019b).

Table 17 – Share of renewable energy in total energy, HC, electricity and transport in 2017 (EuroStat, 2019d)

	RES in energy	RES in HC	RES in electricity	RES in transport
Netherlands	7%	6%	14%	6%

15.1 Political factors

15.1.1 National energy and climate plan (NECP)

The overall target for the Netherlands by 2030 is a 49% reduction of GHG emissions compared to 1990 levels. The long-term objective to 2050 is to reduce GHG-emissions by 95%. By 2030 the share of renewable energy is targeted at 27%, where offshore wind, increased measures towards making the heat generation more sustainable and energy savings is expected. Electricity generation in 2050 must be supplied 100% by renewable sources.

Energy savings by 2030 based on primary energy consumption should be 1950 PJ (excluding use for non-energy purposes). Corresponds to a final energy consumption of 1837 PJ by 2030.

Energy infrastructure will be required in the built-up environment to reduce the amount of natural gas supplied. Suitable infrastructure to encourage depends on the district and no specific assessment of DHC infrastructure is required.

Article 14 (1) 2012/27/EU required an assessment of the potential for CHP and efficient DHCN. The assessment shows a decline in heat and electricity co-production in recent years due to an unfavourable price ratio between natural gas and electricity. The use of centralised CHPs for district heating is expected to decrease further. Natural gas is the most common form of heating for buildings in the Netherlands and the gas infrastructure is extensive. Some growth is still expected in heat supplied via heat networks by 2030, both in the major heat grids but also through smaller projects (European commission, 2020c).

15.1.2 Political interest in REWARDHeat solutions

As district heating is not prevalent in the Netherlands, there is little understanding amongst policymakers of the technical aspects and associated benefits of low-temperature heat networks. Despite the potential lack of knowledge, Dutch politicians in general are in favour of the use of waste heat and of low temperature techniques.

District heating systems are mentioned in the *Climate Act* as the most suitable heating solution for densely populated areas with older houses, for other areas all electric solutions are considered more suitable and it is also recognised that the gas network will remain in place beyond 2030. District heating is expected to expand some to 2030 and to be supplied with an increasing share of renewable heat source, waste heat and power-to-heat. New buildings will not be connected to the natural gas grid according to the Gas Act from 2018, and existing buildings need to enable fossil-free heating which has led to a tendency to meet the heating needs of new builds with low-temperature heat networks. Therefore, the majority of new builds in the Netherlands in the coming years are suitable for low/neutral temperature DHC networks. Heating grids and renovations are mentioned as two means to achieving an emission free building stock by 2050 (Government of the Netherlands, 2019). The Dutch National Climate Agreement stipulates that the integration of waste heat and renewable heat in district heating and cooling networks is an alternative to natural gas and can potentially cover 25-50% (2 to 4 million houses) of the heat demand in buildings. The production of renewable heat will be subsidized, and the use of waste heat will be promoted.

Sustainable heating is described in policies to decarbonize the building stock and transition away from natural gas. In the framework conditions for sustainable heating in the *Climate Agreement*, lowering the supply temperature in heating networks to enable low temperature heating sources to be integrated is to be considered. However, priority is given to improving the building with improve insulation and heat delivery systems. The government will also examine under what conditions waste heat could be considered as sustainable through regulation (Government of the Netherlands, 2019).

In 2003, the Dutch Parliament decided to introduce a Heat Act, which was adopted in 2009 and entered into force in 2014, following heated discussion and criticism, especially around its price regulation. The Act protects small-scale consumers by regulating the price they pay for heat, setting a reasonable maximum price. The Act also regulates the security of heat supply. Further details of the Heat Act still have to be worked out by the Ministry of Economic Affairs and the energy regulator. The most important elements of the regulations have been in place since January 2014.

15.1.3 Financial support for REWARDHeat solutions

Tax credits are available for RES-HC infrastructure in the framework of the Energieinvesteringsaftrek (Energy Investment Allowance). The Energy Investment Allowance is a government tax scheme which provides support for investments in energy saving equipment and sustainable energy. DHC networks, waste heat, thermal storage and RES heat are covered under this scheme. The construction of heat networks and cold networks is stimulated by including the piping between source and end user in the Energy Investment Allowance.

Stimuleringsregeling Aardgasvrije Huurwoningen (SAH) is a subsidy for housing companies for connection to heat networks. The subsidy of € 200 million is active since early March 2020, for owners of rental houses, e.g. housing corporations. Maximum subsidy is € 5.000 per building. Investments in green projects can receive a lower interest rate by banks as the Dutch government gives tax benefit to consumers with savings in a green fund (Anciaux, 2019).

The Dutch government strongly supports the development of geothermal energy, as part of efforts to ensure Dutch companies are competitive. As part of the Geothermal Heat Action Plan, the government wants Dutch geothermal heat plants to generate 11 petajoules (PJ) by 2020. This plan will also reduce risks associated with geothermal investments, develop software for exploration and provide grants for fixed geothermal heat pumps.

The main support instrument for renewable energy production is since 2011 a feed-in premium *SDE+* that covers the difference between market price and cost of production for both thermal and electrical energy production. All categories of renewables compete for a yearly budget where low-cost technologies are prioritized. The budget has grown from 1.5 billion in 2011 to 12 billion in 2018 (International Energy Agency, 2020).

For small installations of renewable electricity connected to the grid energy taxes only apply to the net electricity consumption and is mainly a support mechanism for solar PV (Salderingregeling) (Netherlands Enterprise Agency, 2020). The Investeringssubsidie Duurzame Energie (ISDE) provides subsidies to private sector and small businesses investing in solar thermal collectors and heat pumps.

For companies investing in renewable energy or energy efficiency measures a tax benefit can be applied for in the *Energy Investment Allowance* if the investment is higher than €450 and can cover about half of the investment costs. The budget for *Energy Investment Allowance* in 2019 was €147 million (Netherlands Enterprise Agency, 2020). National Energy saving Fund (NEF) can assist with advantageous loans for energy saving measures for private owners.

DEI (Demonstratie Energie- en klimaatinnovatie) is a subsidy available for investments in pilot projects to test and improve new technologies in a situation that is close to real world initiatives. Topics can include; energy innovation, energy efficiency, renewable energy (including storage in the electricity infrastructure, like hydrogen), local infrastructure, carbon capture utilization and storage.

15.2 Economic factors

15.2.1 Heating and cooling demand

The final HC demand was 284 TWh, approximately 50% of the total energy demand (Paardekooper et al., 2018c). The main demand is for space heating to the residential and tertiary sector and process heating to the industrial sector, as seen in Figure 92 (Fleiter et al., 2017).

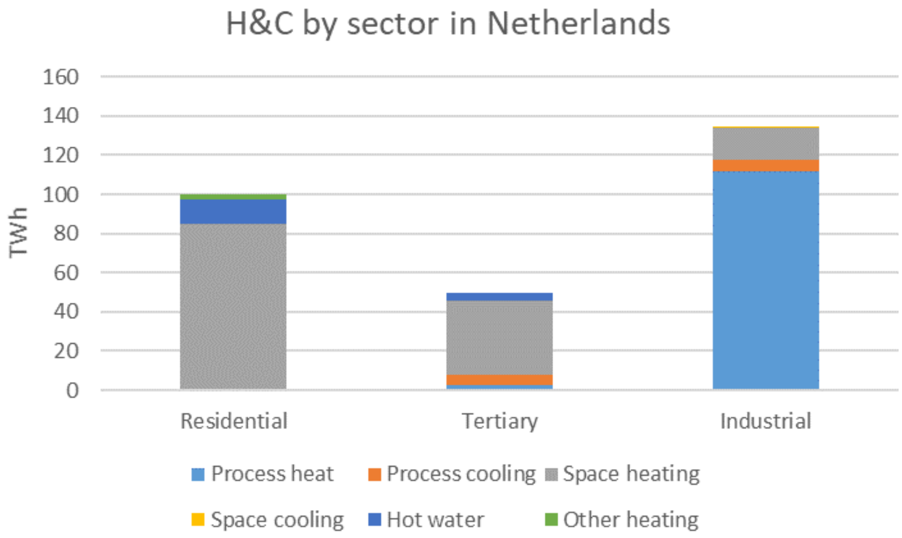


Figure 92 – HC by sector in Netherlands (Fleiter et al., 2017).

In the Heat Roadmap for Netherlands it was estimated that the current policies, which mainly focus on space heating, will lead to an increase in the total energy demand for HC by 4% to 2050. Space heating is expected to decrease by 16%, process heating and hot water increase by 21%, space cooling is expected to double and process cooling to increase by 20%. Cooling is the fastest growing demand but is still expected to represent less than 14% of the total HC demand in 2050 (Paardekooper et al., 2018c)

15.2.2 Heating and cooling supply

The HC demand in Netherlands is mainly supplied by gas (62%) to all three sectors, as seen in Figure 93 and Figure 94. The main part is used for space heating in the residential sector (Fleiter et al., 2017). The dominance of gas due to is large reserves of domestic natural gas (EuroHeat & Power, 2017). District heating supplies 6.5% of the HC demand and most is used in the industrial sector (Fleiter et al., 2017).

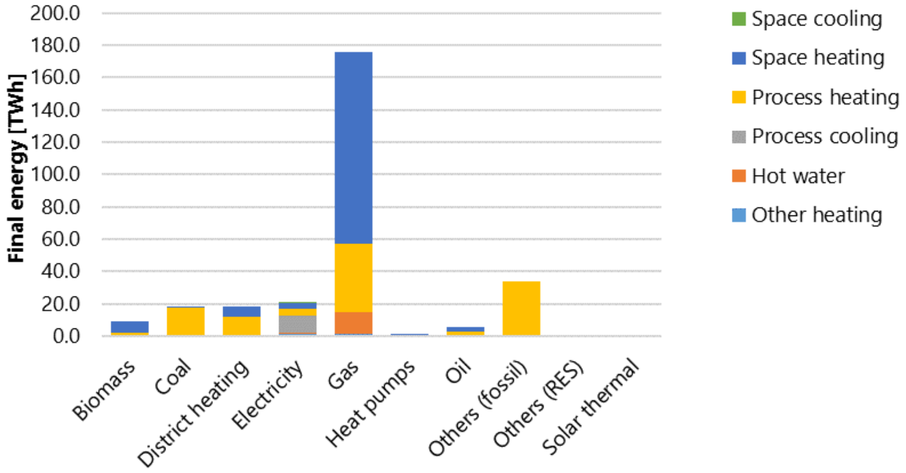


Figure 93 – Energy carrier for the final HC demand for all sectors in Netherlands [TWh] (Fleiter et al., 2017).

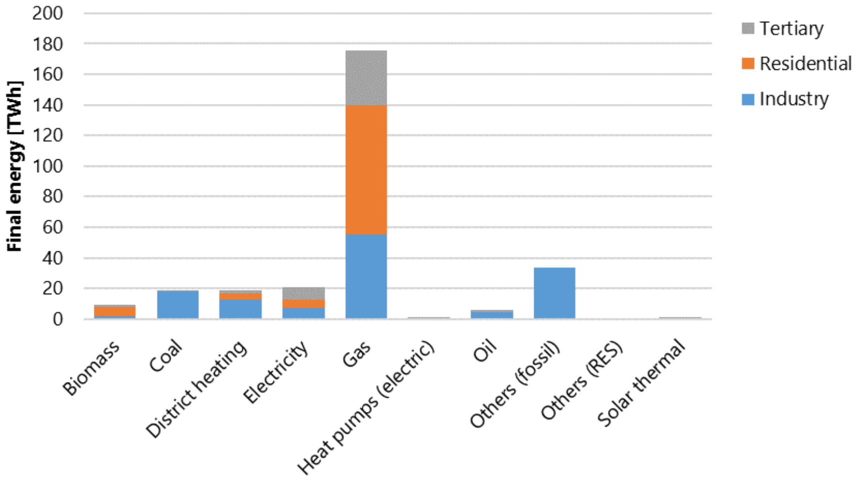


Figure 94 – Energy carrier split by sectoral demand in Netherlands [TWh] (Fleiter et al., 2017).

15.2.3 District heating

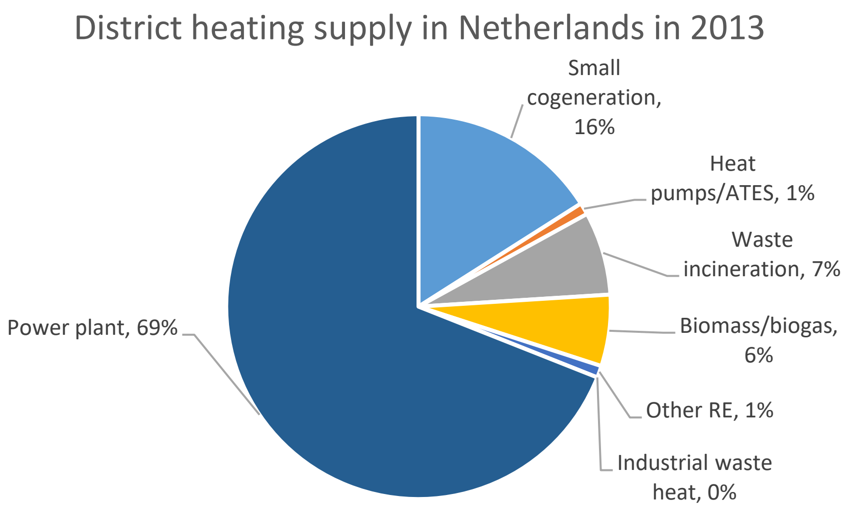


Figure 95 – District heating supply in Netherlands in 2013. The fuel used in power plant and in cogeneration is mainly natural gas, with a small share of coal and biomass (Niessink and Rösler, 2015).

Overall, the district cooling market in the Netherlands is not well developed albeit some examples of district cooling are existing. The low temperature district heating networks in the country are small scale. Recent developments show a tendency towards lower system temperatures for district heating projects in the Netherlands (EuroHeat & Power, 2017).

Warmtenetwerk is a heat network foundation acting as the networking platform for the heat sector. Members are companies, that initiate events, work groups or excursions. RvO (Rijsdienst voor Ondernemend) – Netherlands Enterprise Agency is a government agency which operates under the auspices of the Ministry of Economic Affairs and Climate Policy. Responsible for, among other things, operational execution of subsidy schemes, like SDE+ and ISDE. Warmte Koude Zuid-Holland - Organizer of the low temperature heat networks knowledge group, shares knowledge about low temperature heat networks with experts and project developers. AEDES - The Association of Housing Corporations is the national sector organisation promoting the interests of almost every social housing organisation in the Netherlands.

The Association of Energy Companies in the Netherlands (Energie-Nederlands) represents the electricity producers, electricity and gas traders and electricity, gas and heat retail companies (EuroHeat & Power, 2017).

In most Dutch DHC networks, the owner of the energy plant also owns and operates the heat network. For small-scale customers around 50% of connected customers are connected via a DHN owned by a homeowner association or housing cooperative, which is mainly neighbourhood level DHNs. The larger DHNs are owned by companies such as Eneco (to 55% owned by municipalities), Vattenfall Nederland B.V (owned by the Swedish state, former Nuon) and Ennatuurlijk (private sector).

Profitability of DHNs is low in the Netherlands due to the high infrastructure cost and highly competitive gas network. The internal rate of return is low. In a 2009 study carried out by the research organisation CE Delft, the profitability figures cited by heat suppliers vary considerably, depending on the grid concerned: from -11% to 23% for large scale grids and from -258% to 7% for small scale grids. Heat suppliers in a position to do so often opt for a portfolio strategy, using profitable heat grids to compensate for loss-making ones. The heat tariffs charged by the major energy companies are based mainly on the NMDA tariff recommendations drawn up by EnergieNederland, the country's energy trade association. The tariffs charged by the other suppliers (housing corporations, owner associations, etc.) are often computed by heat cost allocation agencies, based on the actual costs of heat supply.

As of 2014 there were eight geothermal energy plants supplying heat the to DHNs in the Netherlands (Dumas and Bartosik, 2014).

15.2.4 Potential for waste heat and renewable energy sources

The practical utilization potential for annual available urban waste heat from four studied categories identified a potential of 27 PJ in Netherlands (Persson and Averfalk, 2018). The potential per category was defined as data centres (8.3 PJ), metro stations (0.6 PJ), service sector buildings (2.4 PJ) and wastewater plants (15.3 PJ). The industrial waste heat recovery in the country has been estimated at 12 (Papapetrou et al., 2018a) - 47.5 TWh/year (Persson, 2013).

At the end of 2018 18 deep geothermal energy were in operation with a total capacity of 221 MW_{th} and almost 55000 ground source heat pumps (Provoost et al., 2019). In the Heat Roadmap for Netherlands geothermal energy has the potential to represent about 6% of the district heating supply (Paardekooper et al., 2018c). In a study from 2014 the potential was assessed as a percentage of the population that can be reached by geothermal district heating and found that it is possible for almost 30% of the population in Netherlands, temperatures at 60-100°C at 1000 meters depth (Dumas and Bartosik, 2014).

Installed capacity of solar thermal in 2017 454 MW_{th} and the installed solar PV capacity in was 2903 MW and produced 2.2 TWh (EurObserv'ER consortium, 2018). The Heat Roadmap for Netherlands estimated the solar thermal energy in the district heating supply at 1% (Paardekooper et al., 2018c). The solar PV power potential for the Netherlands, visualised in Figure 96, show a higher potential along the coastline (SOLARGIS, 2020).

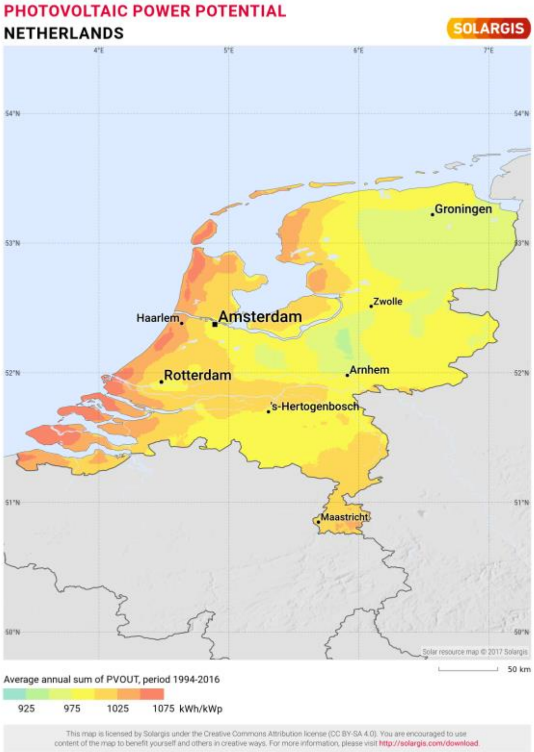


Figure 96 – Solar PV power potential for Netherlands (SOLARGIS, 2020).

15.3 Social factors

Responses for the Netherlands were collected via distributing the survey online to customers connected to, or foreseen to be connected to, the demo site. Nine end-users, all in apartment buildings, and three professional customers, mix of apartment building, separate house and commercial buildings, replied to the survey. All but one professional customer was connected to a DHN and received space heating, space cooling and hot water. The only customer not connected used gas for heating and electricity for cooling.

15.3.1 General opinion of DHN

The general opinion of DHN is neutral, neither positive nor negative. The most negative aspect is on DHN as a cost-efficient solution and the most positive aspect is that DHN is a convenient solution (Figure 97).

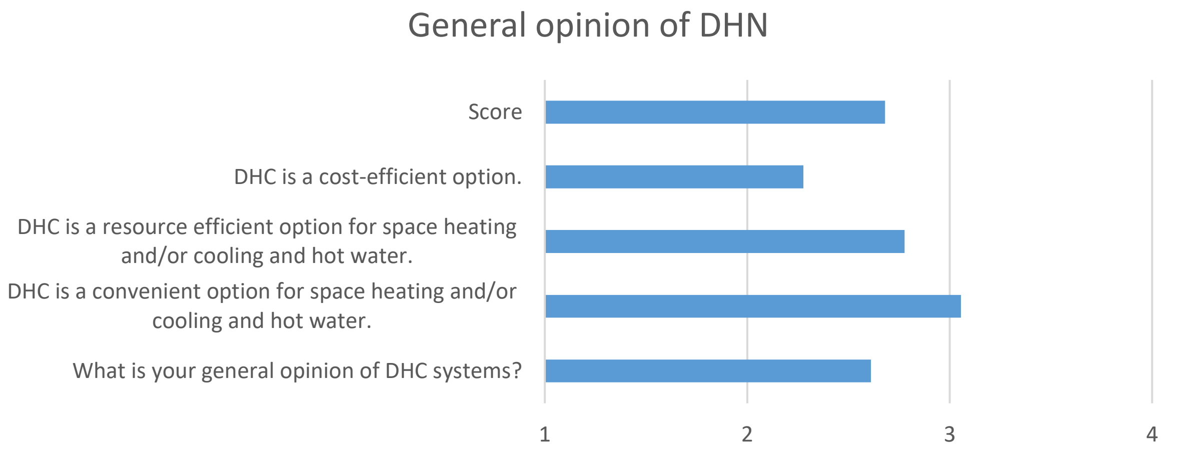


Figure 97 – Mean values of the respondents on their general opinion about DHC (Dutch demo site), as well as the resulting score. The respondents answered on a 4-degree Likert-scale were 1= I don't agree, or very negative, and 4= I agree completely, or very positive.

15.3.2 Awareness of technology

Respondents are generally well aware of how a DHN works with professional customers knowing very well and end-users well to very well. The general understanding is that DHN are available here and there in the country. Eight out of 12 respondents have heard about LTDHN and half of the respondents knew of a DHN with both excess heat and renewables (Figure 98).

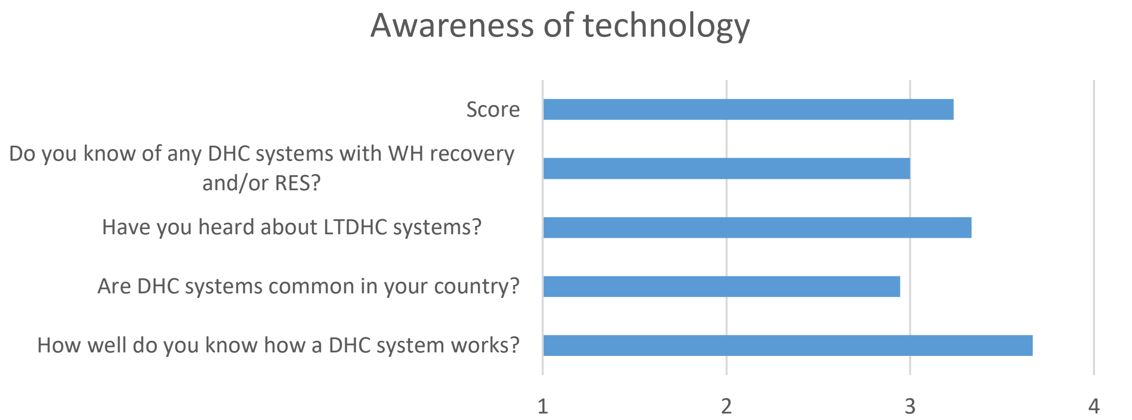


Figure 98 – Mean values on the awareness of the technology, as well as the resulting score (Dutch demo site).

15.3.3 Risks and benefits

Increased comfort, energy savings and environmental were identified as the three main benefits of LTDHN. Some end-users saw no benefits or did not know of any benefits. Looking at risks of LTDHN, the risk of increased costs is identified by both professional customers and end-users. Professional customers see a risk in that the house and hot water won't be warm enough as well as new technology being risky. 4 end-users did not feel knowledgeable enough to respond and one saw a risk in DHN being a monopoly and a risk of not having back-up in case of system failure. The main benefit of integrating RES & WH into the system is seen as mainly energy savings and environmental. Reduced costs and less usage of fossil fuels is also seen as a benefit. The main foreseen risk by customers with integrating RES & WH is security of supply. Four respondents did not know what potential risks could be (Table 18).

Table 18 – Perceived risks and benefits of the REWARDHeat technologies by respondents as well as the resulting score (Dutch demo site). Respondents answered in open text fields and could write as many benefits or risks as they wanted. The number displayed in the parenthesis is how many respondents stated the risk/benefit.

	Benefits LTDHN	Risks LTDHN	Benefits RES & WH	Risks RES & WH
Professional customers	Energy savings (2), environmental (1), utilize new energy sources (1), comfort (1)	Not warm enough (2), new technology (1), higher costs (1)	Energy savings (3)	Security of supply/No back-up (2), don't know
End-users	Energy savings (1), environmental (2), comfort (3), no fossil fuels (2), no benefits (2), don't know (1)	No back-up (1), monopoly (1), higher cost (1), no risk (1), don't know (4)	Energy savings (4), reduced cost (1), environmental (2), less fossil fuels (1)	Security of supply (1), system failure (1), no risk (1), don't know (3)

15.3.4 Environmental consideration

All, but one respondent, are concerned about the impacts of climate change. 42% of respondents consider climate change as they use energy for HC and 58% respondents believe the effects of climate change to be uncertain. All, but one end-user, believe that including WH & RES in the DHC system is beneficial for the environment (Figure 99).

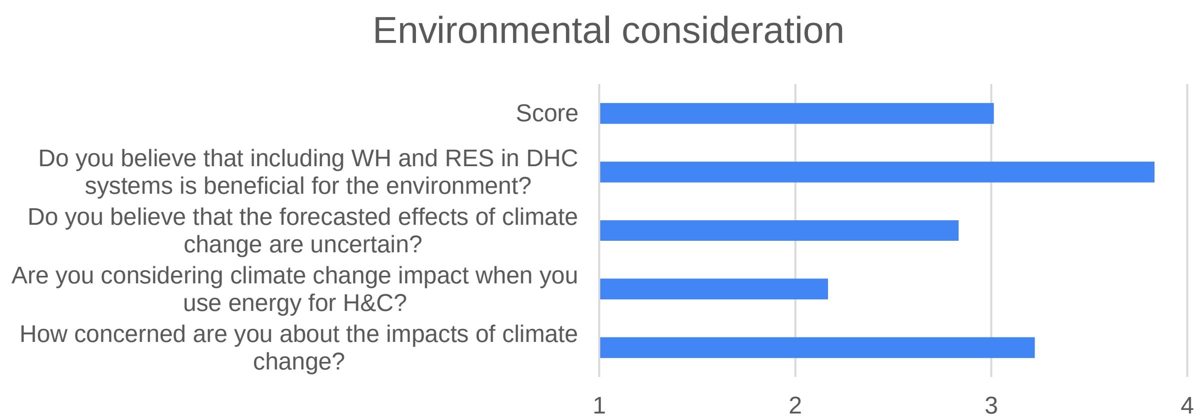


Figure 99 – Mean values on the environmental consideration, as well as the resulting score (Dutch demo site).

15.3.5 Cost expectancy

50% of respondents believe that a LTDHN would result in higher prices compared to conventional DHN. Some end-users are expecting the price to be lowered and some think the cost will be the same. 56% of end-users think that the energy bill will be more expensive by including WH & RES into the DHN. The opinion of the professional customers is divided (Figure 100).

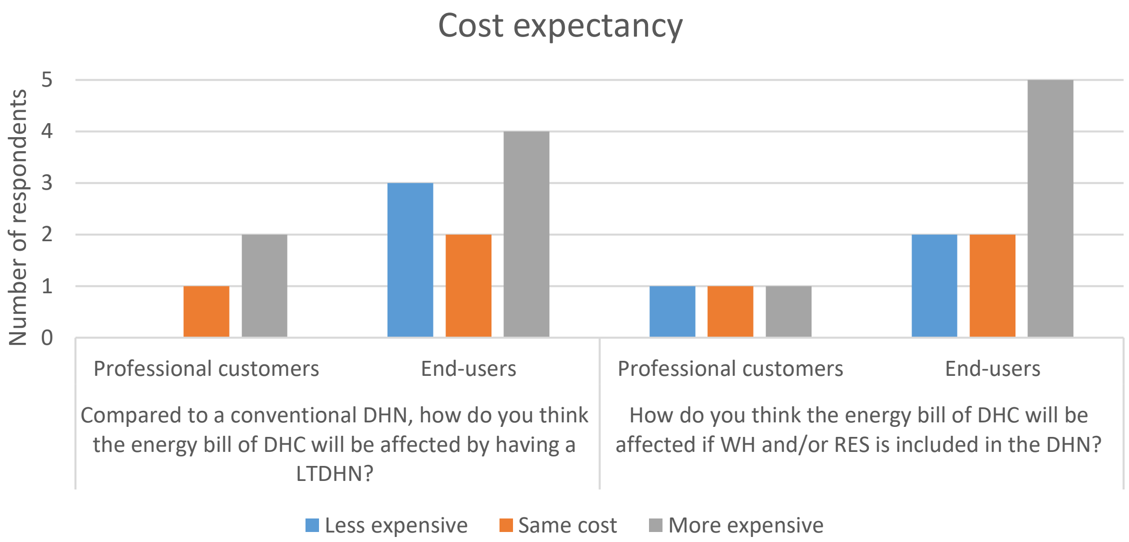


Figure 100 – Cost expectancy of end-users and professional customers (Dutch demo site)

15.4 Technical factors

Traditionally it is more common with individual heating systems for buildings in the Netherlands, and the share of conventional district heating is about 6 %. Diverse pilot projects are looking into technical possibilities to utilize waste heat sources (e.g. low and neutral temperature solutions). In Netherlands, a driver for the development of DH technical solutions is a subsidy program that enables companies to research how to retrofit buildings and how to combinate it with suitable local heating solutions.

15.4.1 Level of maturity of the DHC network technology

In the Netherlands it is more common with individual building heating systems than to be connected to a DH system. Most houses have an individual gas heated boiler and cooling is mostly achieved via air conditioning. Cooling networks are mostly used by tertiary buildings like offices and malls. New buildings are not anymore allowed to use natural gas, so these buildings are mainly using geothermal energy (ATES/BTES) or air-heat pumps. It can be stated that generally DHC is not the first thing in mind for most real estate developers.

There are several further ongoing pilot studies looking into different types of excess heat sources (e.g. data centres, harbours and steel industries) and how to develop heat systems. A developing research area over the last years has been heat utilization from aquathermia e.g. sewage, drinking water, open water and rivers, and in most cities, there have been initiated projects on how to utilize heat from the sources in the local perspective.

15.4.2 Availability of technical components, installers and operators

The components and skills needed for construction and operation of DHC networks are generally well available as these types of facilities are continuously taken into operation.

Although, there is a lack of knowledge on DHC networks from consumer to installer, from local government to developer. The installer is often not connected to a project from an early stage and therefore they seldom see the big picture. The real estate developer finds it easier to look for the individual solution, and usually applies air heat pumps or BTES for households. DC networks are, as aforementioned, not the main cooling solution but the technology used is available on the market from several providers and has been used in the Netherlands for more than ten years. Some system examples are from Maastricht, where absorption cooling machines are used to 'make' cold from residual heat, and Heerlen, where there is a combined heat and cold network.

In 2018 a Green Deal was signed on heat pumps, part of which is education. It was there estimated that the Netherlands needs 6000 technicians. The 6000 new heat pump technicians, who can also be trained installation technicians, will become skilled in advising on sustainable heating technology and in installing and maintaining (hybrid) heat pumps among other things.

15.4.3 DHC solution replicability

The concept of low temperature DHC systems can be applicable in several situations depending on local prerequisites. E.g. the specific technical features of the REWARDHeat demo site of the mines in Heerlen may not be exactly applicable at other sites in the country but can be interesting in mining areas in other countries. Thanks to innovation, the network can now also be separated from the underground mine galleries, by placing prefab tanks or pits in the underground, where there are no mines.

A potential barrier for the low and neutral DHC development is lack of knowledge at end user side about how low temperature HC networks are functioning and if the systems provide enough and comfortable indoor temperatures. Generally, current price conditions create difficulties for DH to be competitive with other main heat solutions. All cities in the Netherlands will in the upcoming months establish heat transition road maps, and regional energy strategies will also be presented. In these documents the focus is often on energy sources such as wind and solar. When DH is described it is mainly related to traditional high temperature DH.

There are though possibilities for more cases of low and neutral temperature DH systems. In the Netherlands there are subsidy programs (the Energy Jump (Energiesprong), TKI Urban Energy) constituting a driver for the development of DH technical solutions. This enables companies to research on how to retrofit buildings and combining it with the heating solution. Several housing associations are interested in the concept and are in the initial stage.

Overview of building stock in the Netherlands:

- ~20% before 1945 (not suitable for low temp)
- ~35% 1965-1984 (mainly not suitable for low temp).

- ~35% 1984-2005 (partly suitable for low temp)
- ~10% 2005 or later (suitable for low temp)

15.4.4 Heat pumps

Under the Dutch 'Bouwbesluit' (Building directive) it is no longer required to connect new building to the gas grid which has resulted in new buildings either connecting to a DHN or implement individual heating solutions with HPs as the default. HPs are included in the energy statistics under the National Statistics Bureau.

HPs have an annual market share of about 10% and a total share of about 2.5% (compared to district heating that has about 5% market share). The largest potential for uptake is with new buildings.

Installers, architects and planners generally don't have sufficient knowledge about HP technology which is a barrier for market uptake. Typically, the required physical space for HPs and hot water storage are excluded in the planning stage. Depending on the building's ownership, purpose and exploitation model different stakeholders would be deciding on the heating system for the building.

15.5 Legal

The important legal aspects impacting district heating are set out in the Dutch Heat Act, introduced in 2014 and amended in 2019 (Authority for consumers and markets, 2020). The Act protects small-scale consumers by regulating the price they pay for heat, setting a reasonable maximum price. Buildings and indoor quality are regulated through energy efficiency norms. New buildings require an Energy Performance Standard, with a complicated counting system that does not favour district heating. The right to heat your home, currently interpreted as a right to a gas connection, will soon be replaced by a technology-neutral right to heat. Large-scale heat grids will be regulated in a similar way to electricity and gas grids.

15.5.1 Planning and permission

To supply heat the network operator needs a supply licence from the energy regulator (provided that the heat is supplied to more than 10 customers at the same time and that the network delivers more than 10,000 GJ per year). The permit to supply heat costs €500. The municipalities provide concessions or licences for networks and have the responsibility to lead the local transition of the heat supply using the environment plan. The environment plan, which also acts as a local energy and heat plan, must be approved by the municipal council. The municipalities are responsible for the regional coordination of energy and heat plans. The consistency of these plans is an important condition for network operators to make sound investments. For DHC network construction projects the application for a digital permit is made at a 'one-stop-shop', and the municipality or province may take it into consideration (Authority for consumers and markets, 2020).

15.5.2 Heat and cooling market

The Heat Act protects small-scale consumers by regulating the price they pay for heat, setting a reasonable maximum price. Heat consumers can claim compensation from their supplier in case of a severe heat supply failure.

The Heat Act ensures that, at the request of a producer the operator of the heat grid needs to enter negotiations concerning access to the network. A producer can request the network owner to provide information of available transport capacity on the heat grid, the applicable tariffs, technical characteristics (such as pressure or flow rate) and the transportation profile. The law does not contain provisions on third-party supplier access, and therefore heat consumers are still unable to choose between multiple suppliers.

The current right of the general public and businesses for heat to buildings is currently interpreted as a right to a gas connection. This regulation will be replaced by a technology-neutral right to heat. Through this, the government will guarantee the presence, quality and affordability of the required energy infrastructure. Large-scale DH grids will be regulated in a similar way to electricity and gas grids.

The current tax legislation favours DH plants largely (more than 50%) using residual heat. Residual heat refers to heat that is released as a by-product of waste incineration, electricity generation or industrial processes that would otherwise be emitted into the open air or via cooling water into surface water (Ministry of Economic Affairs, 2017). The arrangement does not as such apply to renewable heat production plants whose purpose is only to generate heat. As a result, in practice a heat grid may in some cases be worse off with RES. The Dutch government will examine if DH will face a disadvantage due to increase in energy tax when switching from gas-fired boilers to the use of RES.

Under the revised Heat Act, the Netherlands Authority for Consumers and Markets (ACM) will set multiple tariffs that are associated with the supply of heat. Tariff regulation will be based on average actual costs rather than gas. The new tariffs take effect in 2020.

15.5.3 Buildings and indoor climate

The Energy Performance Standards (EPN), established in 1995, were replaced in July 2012 by the Energy Performance Standard for Buildings (EPG) (van Eck, 2016), which replaced both the existing residential and non-residential standards. The main requirement for the energy performance of new buildings is the energy performance coefficient (in Dutch the “energieprestatiecoefficient'), setting minimum requirements for new buildings and being mandatory to calculate for all new buildings and for large renovations in houses and offices. This indicator is based on the estimated total primary energy consumption of a building, adjusted to the useful floor area and the renewable energy produced by the building.

Since the oil crisis in the 1970s, The Netherlands has applied minimum requirements for the thermal quality of the building envelope. These are separately specified for roofs, floors, facades etc. for new buildings and at major renovations (van Eck, 2016). From 2020 all new buildings are to be almost energy neutral. Requirements set for what constitutes almost energy neutral includes a maximum heat demand requirement in kWh/m^2/year, maximum use of fossil fuels and minimum use of renewable resources and varies per property type. For existing buildings an energy label is obligatory. There are furtherly several rules regarding the quality and efficiency of heat systems and installations. Building owners are responsible for the quality of tap water. They must ensure that the health of people in contact with this water is not at risk due to legionella. High risk businesses must engage a certified company to conduct a risk analysis and draw up a legionella management plan for the water supply system.

A 2017 study carried out by the Dutch National Institute for Public Health and the Environment (RIVM) found that there is less national regulation in the Netherlands to improve the quality of the indoor environment, compared to other European countries (National Institute for Public Health and the Environment, 2017). It is concluded that there is little or no insight into how high the concentrations of substances in the indoor environment are.

15.6 Environmental factors

The environmental key factors were assessed as barriers or opportunities based on the results of the TIMES optimization modelling, which are presented and briefly described below.

15.6.1 Specific cost of heat supply

Figure 101 shows the differences between the specific variable, fixed O&M, and capital costs of heat supply in the heating sector of the Netherlands in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be observed that all three types of costs are estimated to be lower in the future with developed LTDHC networks and utilization of LTH sources, as compared to the future with conventional DH.

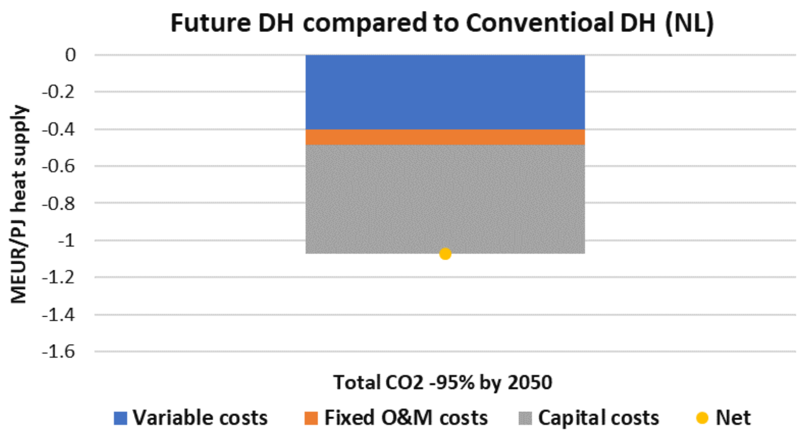


Figure 101 – The differences between the specific undiscounted Variable, Fixed O&M, and Capital (together with their total Net value) costs of heat supply in the heating sector of the Netherlands, averaged over the Years 2020-2050, in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

15.6.2 Specific primary energy use

Figure 102 shows the specific primary energy use, divided into fuel use, electricity use and electricity generation, of heat supply in the heating sector of the Netherlands in year 2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). The modelling results indicate that with the development of LTDH networks and successful utilization of LTH sources the specific energy use of heat supply will get reduced, as compared to the future with conventional DH networks.

Note: Specific primary energy use values for generated and used electricity were calculated using respective fuel use factors. Values for electricity generation are negative because generated electricity is assumed to be exported (from the heating sector) and substitute electricity generation in the electric power sector.

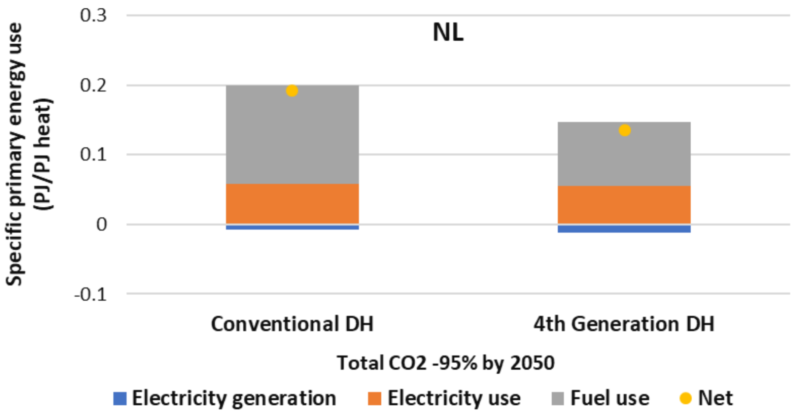


Figure 102 – The specific primary energy use, divided into fuel use, electricity generation and electricity use, of heat supply in the heating sector of the Netherlands in year 2050 in the FutureDH and ConventionalDH scenarios (with 95% CO2 reduction by 2050).

15.6.3 Accumulated air pollutant emissions

Figure 103 shows the accumulated NOx, SOx, and PM2.5 emissions from the heating sector of the Netherlands over the period 2020-2050 in the modelled *FutureDH* scenario (scenario with LTDH networks and LTH available for utilization) and in the *ConventionalDH* scenario (scenario with conventional DH). It can be noticed from the Figure that the replication of REWARDHeat solutions, i.e., development of LTDH networks and utilization of LTH sources, can lead to substantially lower air pollutant emissions in the country over the course of the next 30 years.

Note: Negative values in Figure 103 mean that electricity generated in the heating sector substituted emissions in the electric power sector and results in net negative total emissions of an air pollutant.

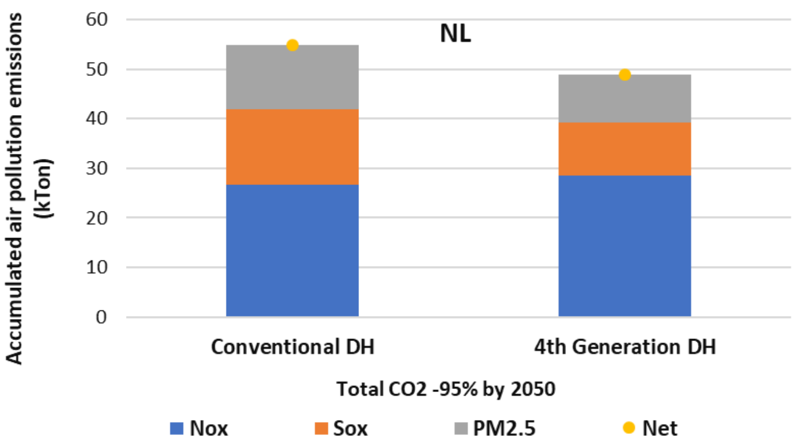


Figure 103 – The accumulated air pollutant emissions (NOx, SOx, PM2.5) attributed to heat supply in the heating sector of the Netherlands over the period 2020-2050 in the FutureDH and ConventionalDH scenarios (with 95% CO_2 reduction by 2050).

16 Annex: Key factors

Table 19 presents the identified for the PESTLE analysis key factors and lists them (within each of the 6 aspects) in accordance with the prioritization concluded by the workshop participants.

Table 19 – Key factors for the PESTLE analysis and the priority according to workshop participants.

PESTLE	Priority	Key factor	Short description
Political	1	National targets	Targets on energy efficiency, GHG emissions, renewables
	2	State-based financial support	For DHC, LTDHC, renewables such as solar thermal, geothermal
	3	Predictability	Predictability of state-based support and regulations
	4	Competition	Other heating and cooling sources are promoted in policies
	5	Supportive structure with associations and organizations	Networks surrounding the DHC business
Economic	1	Price of DHC	The price of district heating and cooling
	2	HC Supply	The supply today and in the future
	3	Profitability of DHC	Ownership structure and potential requirements on profitability
	4	Potential for renewable heat and waste heat	Relates to supply of Solar thermal+geothermal, urban+industrial waste heat
	5	HC demand	The demand today and in the future.
		Specific cost of heat supply	The cost of delivered energy per unit of energy used (modelling results)
Social	1	Customers' Cost expectancy	Expected cost of implementing REWARDHeat technologies, Anticipated effect on energy bill by having a LTDHC, Anticipated effect on energy bill by including LTH and/or RES in DHC supply
	2	Customers' opinion about DHC	General opinion towards DHC, DHC as a convenient option, DHC as a resource efficient option,

	3	Customers' awareness about DHC	Knowledge of DHC, Believes DHC to be common in the country, Knowledge about LTDHC, Knowledge about LTH and/or RES integration in DHC
	4	Customers' environmental consideration	Climate change consideration in general, Climate change consideration in relation to HC,
	5	Customers' perceived benefits and risks of REWARDHeat solution	Perceived risks and benefits of LTDHC, Perceived risks and benefits of integrating LTH and/or RES in DHC
Technical	1	Building stock suitability	Building stock is (or will be) suitable for LTDHC
	2	Technical maturity/establishment	DHC is common in the country, DHC has been around for a long time (established technology)
	3	Replicability/standardization	Possible to replicate and standardize DHC technical solution within the country (with respect to thermal energy demand, natural resources availability, other heat or cooling solutions within the country etc.)
	4	Availability of technical components	Technical components are available, Suppliers of components are available
	5	Availability of installers and operators	DHC system installers (subcontractors etc) are available, DHC system operators are available, Installers and operators have knowledge and experience of technology
Legal	1	DHC market legislation	Impact of the HC market legislation/regulations on DHC opportunities
	2	Buildings/construction	Impact of the building legislation/regulations on DHC opportunities
	3	Permissions	Legal/regulatory permission procedures necessary for building or extending DHC systems and grids

	4	Planning (spatial/land-use exploitation)	The impact of land-use regulation on DHC establishment
	5	Indoor thermal climate	Impact of indoor climate legislation/regulations on DHC opportunities
Environmental	1	Specific primary energy use	Energy use per unit of generated heat (modelling results)
	2	Accumulated air pollutant emissions	Air pollutant emissions associated with heat generation (modelling results)

17 Annex: TIMES model

17.1 Model

In the study, the well-established TIMES (The Integrated MARKAL-EFOM System) energy system model is used for the analysis (Etsap, M. Gargiulo, 2009).

A TIMES model can be used to optimize energy systems over a mid- to long-term horizon. The model is driven by exogenously given demands for energy services and based on a perfect-foresight, linear programming bottom-up approach, where the objective function is minimization of the total system cost. The studied energy system is represented by different processes that are connected by flows of commodities. Each process (such as an energy conversion technology) is described, e.g., by its input and output commodities, efficiency, availability, lifetime and costs, whereas each commodity (such as a fuel) is described by its availability, extraction or import cost and environmental impacts.

For this study, a TIMES models representing the heat sectors of the studied countries was developed, hereafter referred to as the TIMES_Heat model. The TIMES_Heat model represents the heat sectors in the countries, including both the heat generation in DH systems and in individual heating units in buildings. The electricity system as well as international markets for fuels are treated exogenously.

The objective function of the TIMES_Heat model is to minimize the cost of meeting the heating demands (residential and service sectors) of each of the countries under any constraints put on the system, such as emission constraints and limited energy resources constraints. The system cost, which is minimized, is the net cost of supplying heat in the sense that it includes revenues for electricity sale (at exogenously assumed prices) from electricity production in CHP plants. The shares of centralized DH and individual heating in buildings are endogenously decided by the model.

The TIMES_Heat model covers the time period between 2015 and 2052. The modelled time period is divided into 9 model years (with shorter lengths in the beginning, i.e., one year: 2015, three years: 2016–2018, four years, 2019–2022; and longer lengths starting from 2023 (five years)). Each model year is divided into eight time slices, representing day and night in four different seasons. The seasons are winter, spring, summer and fall. For each model scenario (set of model input assumptions), the model generates an "optimal" future energy system development and calculates the associated system costs. A discount rate of 5% was used in the model.

The heating sector of each modelled country is represented in an aggregated way, including existing individual heat boilers/devices in buildings, existing DH systems and DH distribution networks. Heat demands in the case countries are defined for each time slice. Energy efficiency measures in buildings are handled exogenously and projections for future heat demands (including implementation of efficiency measures) are provided as input to the model.

The base year (2015) model representations of individual heat boilers/devices and DH systems in the case countries are based on the current fuel mix in the heating sectors and existing generation units in the respective DH systems. Under the modelled period, current generation capacities will gradually be phased out and replaced by new technologies as a result of the model optimization. Technologies are described by parameters such as fuel input, capacities, efficiencies, lifetimes, availabilities, heat to electricity ratios (only for CHP plants) and operation and maintenance (O&M) costs. A selection of technology data used in the model is presented in 17.12 Energy technology data.

17.2 Modelled scenarios

In the analysis, three DH technology development scenarios, combined with three climate policy scenarios (resulting in nine different scenarios), were designed and applied to assess the span of outcomes regarding the potential developments of the heating sectors of the investigated countries.

The three chosen DH technology development scenarios are: “ConventionalDH”, “TransitionDH” and “FutureDH”. The “ConventionalDH” scenario limits the future development of the heating sectors to only include conventional DH production if deemed cost-effective. The “TranistionDH” scenario assumes availability of conventional DH networks and allows for the utilization of LTH sources in such networks. In the “FutureDH” scenario, investments in both LTDH networks and in LTH sources are allowed. The assumptions for temperature levels in DH network in the three DH scenarios are presented in Table 20.

Table 20 – The DH network temperature levels in each of the technology development scenarios.

Scenario	ConventionalDH	TransitionDH	FutureDH
Supply temperature (°C)	80	80	55
Return temperature (°C)	40	40	25

The three chosen climate policy scenarios are: “Ambitious”, “WEO-SD” and “WEO-NP”. The “Ambitious” scenario assumes a rigid climate policy, with zero CO2 emissions in the heat and power systems of the demo countries by 2030. The “WEO-SD” and “WEO-NP” scenarios are in line with the Sustainable Development Scenario and the New Policies Scenario, respectively, of the International Energy Agency (IEA)’s World Energy Outlook (WEO) 2017 report (IEA, 2017). In the model, the WEO-SD scenario represents a scenario in which both the fossil CO_2 (corresponding to fossil fuel use in the heating sector) and the total CO_2 (when effects on electricity generation outside the modelled heating systems are taken into account) emissions are linearly decreased by 95% by 2050, as compared to 2015. In contrast, the WEO-NP scenario sets both the fossil CO_2 and the total CO_2 to decrease linearly by 60% by 2050, as compared to 2015. The WEO-NP scenario aims to provide a sense of where today's policy ambitions seem to take the energy sector (see Figure 104).

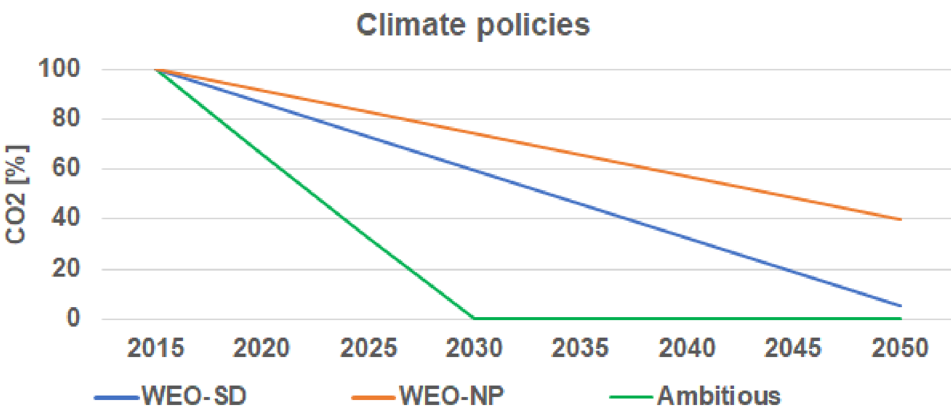


Figure 104 – Upper bounds for CO_2 emissions in the model scenarios. Constraints apply both to fossil fuel CO_2 emissions within the heating sector of the countries and to system-wide CO_2 emissions when effects on electricity generation outside the modelled system are considered.

In the model, the three climate policy scenarios influenced four main types of model inputs: (1) the applied CO_2 reduction levels for the countries (Section 17.10), (2) fuel and electricity prices (Section 17.9), (3) CO_2 emissions and primary energy factors for electricity (Section 17.10), and (4) the level of energy efficiency of the building stock and, thus, the end-use demand for heating (section 17.4). Table 21 presents an overview of the nine main scenarios.

Table 21 – Composition of the nine main scenarios.

Scenario	Climate policy	DH type	LTH sources included	CO_2 emission level	Fossil fuel prices (excl. CO_2 cost)	Electricity prices (incl. CO_2 cost)	End-use heat demand)
ConventionalDH	Ambitious	Conv DH	No	zero by 2030	Low	High	Low (HRE2050)
	WEO-SD	Conv DH	No	-95% by 2050 compared to 2015	Low	High	Low (HRE2050)
	WEO-NP	Conv DH	No	-60% by 2050 compared to 2015	High	Low	BL2050
TransitionDH	Ambitious	Conv DH	Yes	zero by 2030	Low	High	Low (HRE2050)
	WEO-SD	Conv DH	Yes	-95% by 2050	Low	High	Low

				compared to 2015			(HRE2050)
	WEO-NP	Conv DH	Yes	-60% by 2050 compared to 2015	High	Low	BL2050
FutureDH	Ambitious	LTDH	Yes	zero by 2030	Low	High	Low (HRE2050)
	WEO-SD	LTDH	Yes	-95% by 2050 compared to 2015	Low	High	Low (HRE2050)
	WEO-NP	LTDH	Yes	-60% by 2050 compared to 2015	High	Low	BL2050
Abbreviations: Conventional district heating (Conv. DH), Low-temperature district heating (LTDH), World Energy Outlook- Sustainable Development (WEO-SD), World Energy Outlook-New Policies (WEO-NP), Heat Roadmap Europe (HRE 2050) scenario, Baseline (BL 2050) scenario of Heat Roadmap Europe.							

17.3 Cases for sensitivity analysis

In addition to the nine main scenarios, supplementary model runs (about 55 per country) were carried out to assess the robustness of the model outcomes with regards to parameter values for which future levels are uncertain but are of relevance for the present study. Specifically, the impact of the following changes to the base assumptions of the main scenarios on the share of Large-scale heat pumps utilizing LTH sources was studied:

1. Various CO_2 emissions reduction levels by 2050

The climate policy scenarios (Ambitious, WEO-SD and WEO-NP) applied different CO_2 reduction levels (zero by 2030, -95% and -60% by 2050, respectively). To specifically test the influence of the CO_2 reduction level, the level in the model was varied between 0% and 100% (in all the countries).

2. 50% less geothermal energy potential in the DH supply

According to "The State of Renewable Energies in Europe" report, (Observ'ER, 2018), there is considerable amount of geothermal energy potential for DH use in different EU countries. In this study, the values from the Observ'ER report were assumed for the case countries in the base assumptions. Due to uncertainty in the total potential, alternative model runs decreasing geothermal energy by 50% compared to the base assumptions were carried out.

3. 50% less solar potential in the DH supply

In this study, the values identified in PESTLE analysis were assumed for the case countries in the base assumptions (see Table 25). Due to uncertainty in the total solar potential, alternative model runs decreasing solar energy by 50% compared to the base assumptions were carried out in all the case countries.

4. 50% less industrial EH availability

In the base assumptions, industrial EH potential are based on the values reported in (Papapetrou et al., 2018b); however, the prospects of using this source face barriers and uncertainty in the long-term. Thus, alternative model runs were carried out to test the impact of 50% less access to industrial EH in all the countries.

5. 50% Higher cost of DH infrastructure development.

Most of the case study countries (except for DK and SE) currently have low shares of DH in the heat sector. A significant amount of DH growth in the countries might involve barriers and costs not fully captured by the model. To test the sensitivity of the model to this assumption, the DH infrastructure costs are in the alternative model runs were increased by 50% compared to the base assumptions.

Except for these parameters, the sensitivity cases applied the same conditions as in the WEO-SD scenario.

17.4 Case study countries

A brief description of the current heat supply system of the studied countries (DE, DK, FR, HR, IT, NL and SE) as well as assumed projections of future heat demand developments are given in Table 22.

The 2015 levels for total heat demand (excluding heat demand in industry) are based on (Mathiesen et al., 2019) and future levels are based on national projections from the Heat Roadmap Europe project for the "HRE 2050" scenario and the "baseline" (BL 2050) scenario (Paardekooper et al., 2018e).

Table 22 – Current heat supply system and future heat demand projections in the case study countries.

		Units	DE	DK	FR	HR	IT	NL	SE
Total heat demand (2015)[a] (Mathiesen et al., 2019)		PJ	3 071	202	1 865	104	1 627	518	317
Total heat demand decrease from 2015 to 2050 level[b] (Paardekooper et al., 2018e)		%	36-42	17-23	29-39	13-24	13-24	18-32	17-23
DH market share (Paardekooper et al., 2018e)		%	9	48	4	7	3	4	50
Fuel/ electricity use in individual boilers/HPs in buildings (Paardekooper et al., 2018e)	Coal	%	1.1	0	0.5	0	0	0	0
	Natural gas	%	47.3	30.8	43.8	30.1	62.9	86.5	6
	Oil	%	30.8	13.5	19.8	7.5	7.2	1.0	10
	HP	%	1.1	1.9	1	0	2.1	1.0	10
	Thermal Solar	%	1.1.	1.9	0.5	3.2	1.0	0	0
	Electricity	%	7.7	17.3	17.7	8.6	10.3	6.3	50
	Biomass	%	11.0	34.6	16.7	50.5	16.5	5.2	24
DH production capacity	Heat [c]	GW	44	15	4.8	1.8	9.3	8.1	23
	Electricity [c]	GW	15	4.9	1.5	0.45	2.8	3.3	3.5

DH production plants [c]	Fuel use in CHPs	-	Natural gas and waste [c]	–	Natural gas and minor shares of wood and waste [e]	Natural gas and minor shares of wood and fuel oil	Natural gas, waste, coal and minor shares of wood and biogas	Natural gas and minor share of wood	Wood, waste, Natural gas, coal, fuel oil, peat and minor shares of bio oil and heavy fuel oil
	HPs/ fuel use in heat-only boilers	-	Natural gas, industrial waste heat and minor share of heavy fuel oil, wood, coal, and solar.	-	Natural gas, wood waste, coal and minor shares of heavy fuel oil and diesel	Natural gas	Natural gas, wood and minor shares of geothermal heating, ambient temperature HP and industrial waste heat	Natural gas and wood	Diesel, heavy fuel oil, wood, ambient temperature HP, waste bio oil, electric boiler, industrial waste heat, peat and natural gas

Abbreviations: DH (district heating), CHP (combined heat and power), HP (heat pump)

[a] Including both individual and DH for residential and service sector

[b] According to scenarios of the Heat Roadmap Europe project: "baseline" (BL 2050) scenario and the "HRE 2050" scenario, respectively (Paardekooper et al., 2018e). For the ambitious and WEO-SD scenarios, the "HRE 2050" scenario, while for the WEO-NP scenario the baseline scenario ("BL 2050") is used.

[c] DE (AGFW, 2016), DK and SE based on assumptions made in the SHIFT model ((Salvucci et al., 2019)), FR (Fedene, 2018), HR (MOE, 2015), IT (AIRU, 2018), NL

Total heat demand including both individual and DH is an exogenous input to the model (the share between individual heating and DH is endogenously decided in the model). Residential and service sector heat demand is covered. The total heat demand level for 2015 and for 2050 for each country is presented in Figure 105. The heat demand is in line with the scenarios of the Heat Roadmap Europe project: "baseline" (BL 2050) scenario and the "HRE 2050" scenario (Paardekooper et al., 2018e). For the ambitious and WEO-SD scenarios, the "HRE 2050" scenario, while for the WEO-NP scenario the baseline scenario ("BL 2050") is used.

The seasonal distribution of the heat demand over the year is presented in Figure 106. The distributions are based on data from the national EnergyPlan models (AAU, 2020).

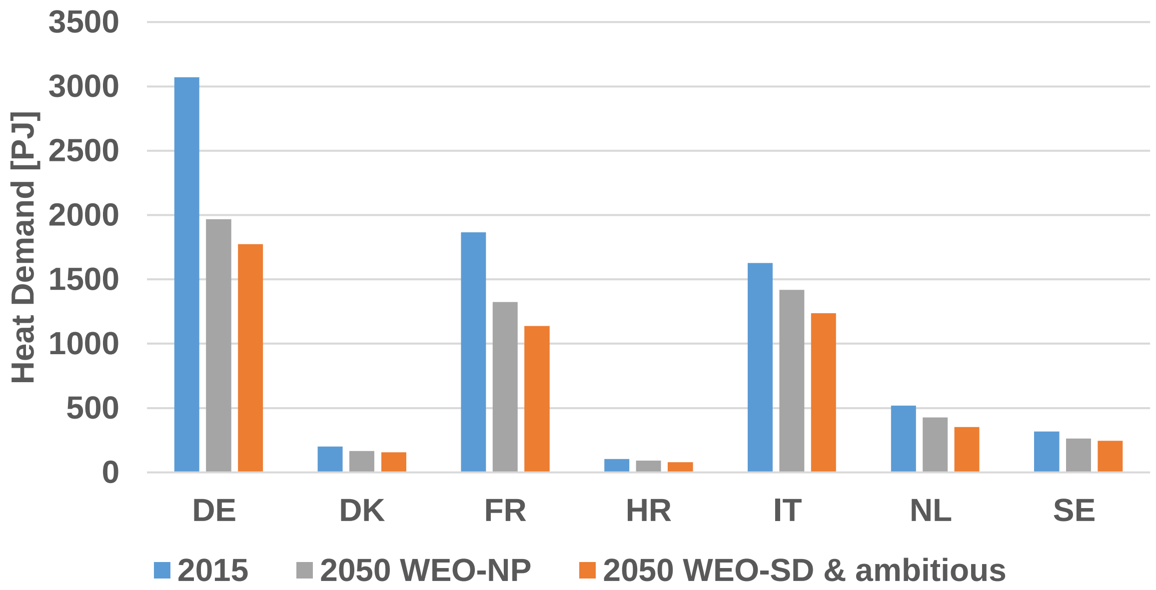


Figure 105 – Total demand in model base year (2015) and in 2050 for three climate policy scenarios.

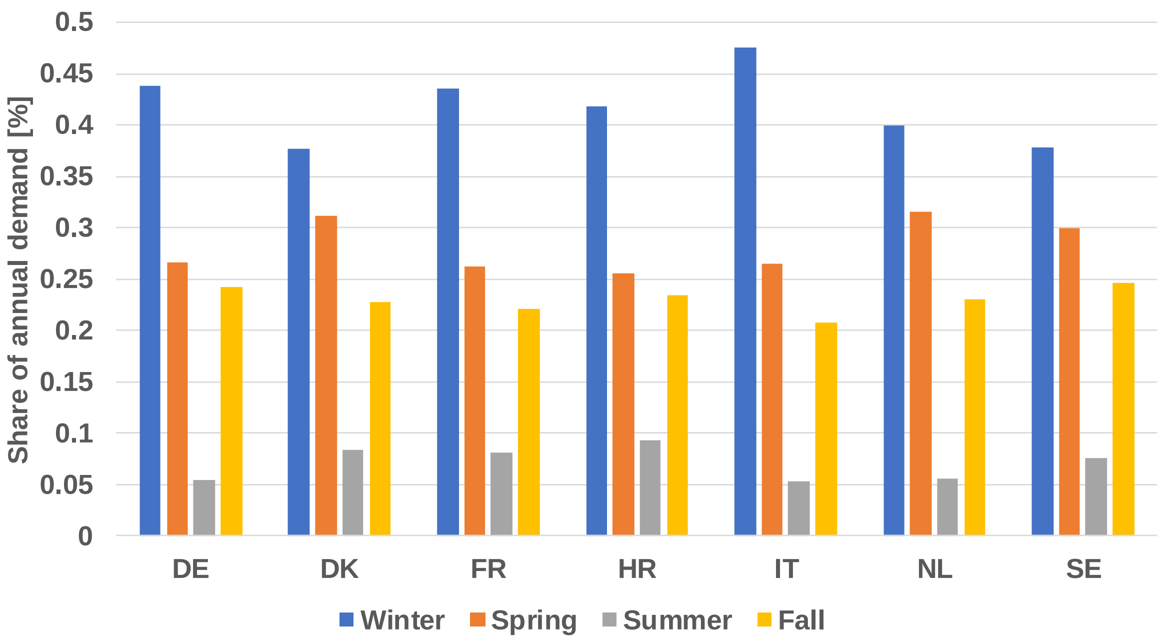


Figure 106 – Seasonal distribution of heat demand for the studied countries.

17.5 Excess heat

17.5.1 Excess heat sources in the case study countries

In this study, the impact of heat recovery from low-temperature LTHS sources for use in DH systems is assessed for the case study countries (DE, DK, FR, HR, IT, NL and SE). A common property of low-temperature heat sources is that a HP is required to upgrade the heat before it can be utilized in DH systems. Heat recovery from four different types of LTHS sources is in focus: metro stations, data centers, sewage systems and service sector buildings. The heat sources and corresponding temperature levels are data centers (25–35 °C), metro stations: (5–35 °C), service sector buildings (30–40 °C), sewage systems (8– 15 °C). NACE (Nomenclature of Economic Activities) Class Codes (2015, 2018) were used to identify the LTHS sources and their associated temperature levels and temporality (Persson, 2018).

17.5.2 Excess heat potentials

In addition to the LTHS, heat recovery from industrial processes (conventional EH: 80–90 °C) and from ambient heat sources are also included in the assessment. In the model, available EH potentials from the different sources in the studied countries are included as they are presented in Table 23. Base year (2015) potentials for LTHS are based on (Persson, 2018). By 2050, it is assumed that the EH of data centers will triple in all the studied countries, whereas service sector buildings' EH will increase by 320% in DE, by 200% in DK, HR, IT, NL and SE and by 330% in FR (Paardekooper et al., 2018e) compared to current levels. For the other heat sources, it is assumed EH potentials will remain unchanged by 2050.

Table 23 – Excess heat potentials in the case countries (PJ/year).

	DE 2015/2050	DK 2015/2050	FR 2015/2050	HR 2015/2050	IT 2015/2050	NL 2015/2050	SE 2015/2050
Industrial EH [(a)]	77 / 77	5.1 / 5.1	43 / 43	4.2 / 4.2	41.7 / 41.7	13 / 13	5.9 / 5.9
Data centres EH [(b)]	39 / 127.2	2.5 / 7.8	30.6 / 108.6	1 / 3.9	13.6 / 70.2	5.5 / 26.1	8.9 / 31.2
Service sector buildings EH [(b)]	17.7 / 57.3	1.3 / 2.6	33.4 / 109.9	1.7 / 3.4	45.9 / 91.8	1.6 / 3.2	3.6 / 7.2
Metro stations EH [(b)]	4.8 / 4.8	0.1 / 0.1	7.4 / 7.9	0 / 0	3.8 / 4.5	0.4 / 0.4	0.6 / 0.6
Sewage systems EH [(b)]	80.8 / 132.6	9.7 / 10.1	57 / 63.7	2.7 / 2.8	26.6 / 56.7	10.2 / 18.8	13.5 / 14.9

(a) Data based on (Papapetrou et al., 2018b).

(b) Data for 2015 based on (Persson, 2018).

The temporal distribution of the LTHS sources over the year is based on (Lund and Hansen, 2019) (see Figure 107). While about half of the EH from cooling service sector buildings and ventilation of metro stations is available during the summer, EH from data centers and sewage systems does not significantly vary over the year. In the model, the temporal distribution of the LTHS sources are represented in each time slice of a year.

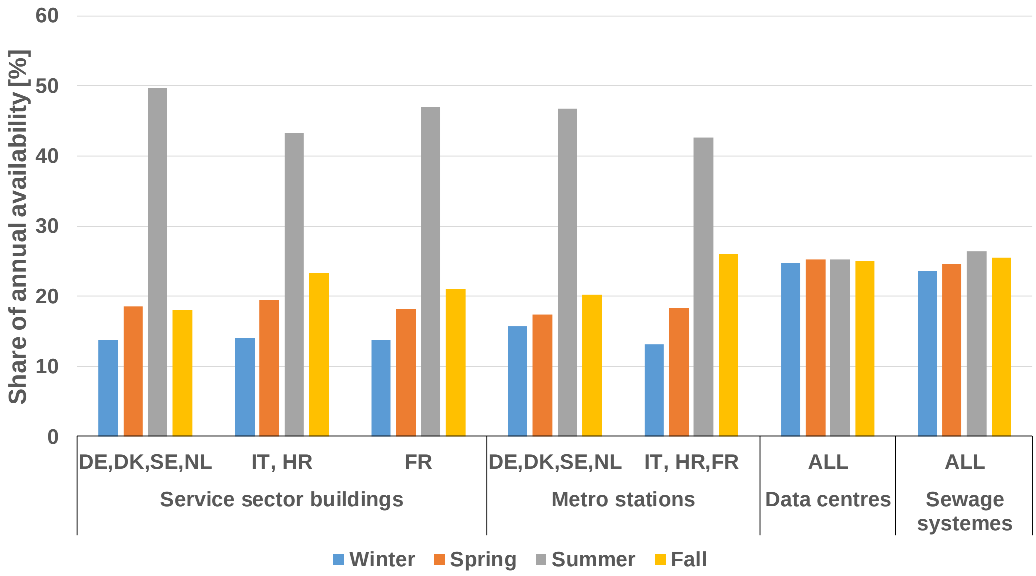


Figure 107 – Seasonal distribution of available heat from the different LTHS sources.

17.5.3 Large-scale HPs

For LTH sources, i.e. LTHS sources and ambient heat, HPs are required for the heat to be usable in DH. Since HPs use electricity, investments in and utilization of HPs affect both the local energy and electricity systems of the studied countries. The assumptions for coefficient of performance (COP) of HP technologies in the Conventional DH and the Future DH scenarios in the model are presented in Table 24. The increase in the COP from 2020 to 2050 is due to the assumed cycle efficiency improvements of HP technology. The higher COP levels in the Future DH is also due to reduced DH supply temperatures.

In addition to the COP values, specific investment cost, fixed and variable O&M costs and lifetime of HP technologies are also included in the model (see Section 17.12). Cost of extracting LTHS sources are treated as sunk cost since it is associated with LTHS use in all applications (not limited to DH production). This makes future comparisons between LTHS use in DH production and in other applications (e.g. electricity generation) straighter (not within the scope of this study).

Table 24 – COP for large compressor heat pumps in Conventional DH and Future DH based on different heat sources.

Low-temperature heat source	COP Seasonal average (yearly average)		
	Conventional DH 2015	Conventional DH 2050	Future DH 2050
Service sector buildings [(a)]	3.46 - 4.70 (4.05)	5.05 - 7.93 (6.39)	9.90 - 15.6 (12.5)
Data centres [(a)]	3.68 - 4.02 (3.85)	5.31 - 6.02 (5.66)	10.4 - 11.8 (11.1)
Metro stations [(a)]	3.59 - 5.76 (4.60)	4.73 - 8.90 (6.62)	9.27 - 17.5 (13.0)
Sewage systems [(a)]	3.51 - 3.85 (3.68)	4.63 - 5.20 (4.91)	9.09 - 10.2 (9.64)
Ambient temperature [(b)]	4.00 - 6.19 (5.10)	5.27 - 8.92 (7.06)	6.19 - 9.59 (7.91)

(a) Data in 2015 and 2050 for Conventional DH is based on (Lund and Hansen, 2019) while in 2050 for Future DH are calculated based on (Rämä et al., 2020).

(b) Data in 2015 is based on (OPSD, 2019) while in 2050 for Future DH are calculated based on (Rämä et al., 2020).

17.6 Renewable heat sources

For each heat source and studied country the availability of renewable heat sources for district heating is included in the model (see Table 25). The potential of geothermal is assessed in relation to if the source is in close proximity to existing district heating networks.

Table 25 – Renewable heat sources and municipal waste potential in the case countries.

	Unit	DE	DK	FR	HR	IT	NL	SE
Municipal waste[(a)]	PJ	101.9 / 131.7	36.5 / 32.6	61.8 / 113.5	0.1 / 0.1	24.1 / 42.8	38.2 / 67.9	39.9 / 39.9
Woodchips [(a)]	PJ	884.1 / 344.3	27.7 / 19.5	477.7 / 189.9	37 / 16.2	205.7 / 134	10.1 / 7.5	270.4 / 108
Biogas [(a)]	PJ	104 / 105.6	43.7 / 43.3	259.8 / 258.4	3.3 / 3.3	118.2 / 115.6	49.3 / 48.8	17.6 / 17.5
Straw [(a)]	PJ	214.8 / 381.7	29.4 / 23.7	246 / 476.4	40.1 / 48.8	66.2 / 210.7	6.3 / 26.1	28.9 / 32
Solar thermal [(b)]	GW	23.7 / 57.2	1.91 / 4.62	3.84 / 9.26	0.28 / 0.68	5.02 / 12.1	0.8 / 1.94	15.4 / 15.4
Geothermal [(b)]	GW	0.78 / 2.68	0.07 / 0.26	1.15 / 4.07	0.05 / 0.16	0.36 / 1.28	0.32 / 1.13	0.10 / 0.35

The values are given as "value in 2015"/"value in 2050".

(a) Values are based on (Ruiz et al., 2015)

(b) Values based on (Observ'ER, 2018)

17.7 Future DH (LTDH)

Lowered DH distribution temperature (LTDH) increases the efficiency of flue gas condensation in the heat-only boilers and CHP plants compared to the assumed values for the Conventional DH (see technology data in Section 17.12). Changes in thermal unit operation parameters compared to conventional DH are presented in Table 26.

Table 26 – Changes in thermal unit operation parameters in Future DH compared to conventional DH, adapted from (Rämä et al., 2020).

Technology	Parameter	Change [%]
Biomass / waste, CHP	Electricity efficiency (MW_{elc} / MW_{fuel})	0
	Heat efficiency (MW_{DH} / MW_{fuel})	+10
Biomass / waste, heat-only boiler	Heat efficiency (MW_{DH} / MW_{fuel})	+8
Natural gas, CHP	Electricity efficiency (MW_{elc} / MW_{fuel})	0
	Heat efficiency (MW_{DH} / MW_{fuel})	+25
Natural gas, heat-only boiler	Heat efficiency (MW_{DH} / MW_{fuel})	+10

Large heat pumps significantly benefit from lower distribution temperatures. The COP is estimated to improve 5% when supply temperature is lowered by 5°C, because a lower temperature level upgrade is required (Rämä et al., 2020). Thus, in the model it is assumed that lowered DH distribution temperature (LTDH) increases COP of large-scale heat pumps utilizing LTHS and ambient temperature heat sources as they were presented in Section 17.5.3.

District heating connected solar heat collectors also benefit significantly from lower distribution temperatures. The yield (collected heat) increases quickly when the temperature of the return and supply water lowered (Rämä et al., 2020). In the model we assumed twice higher yield of the solar collectors relative to the Conventional in all the case counties.

Distribution losses can be decreased by increasing heat density (delivered MWh per length of grid), investment in new pipelines, and lowering the distribution temperatures. We assume that in the Conventional DH scenario the DH distribution losses will improve only slightly (i.e. 7%) from their current levels in all countries. For Future DH scenario, we assume 13 % lower distribution losses for each country from 2020.

Lower DH supply and return temperature can increase the investment cost of DH network due to increased pipe sizes. In this study we assume the investment cost of DH network in the Future DH scenario increase by 5% compared to the assumed values in the Conventional DH scenario (see Section 17.8).

17.8 District heating network and infrastructure

Heat demand vary in different parts of the studied countries and this has implications for the potential development of DH infrastructure. Since investment cost of DH infrastructure (including DH transmission and distribution network) depends on heat demand density (i.e., greater heat demand densities give lower DH network investment costs), in the model, each country has been divided into five zones. The division of heat density zones are based on (Persson et al., 2019) while the estimation of corresponding investment cost of DH network expansion is based on PETA 4.3 (PETA4.3, 2018).

The model zones and the corresponding heat demands for the model base year (2015) are presented in Table 27. Figure 108 presents the shares of heat demand for different heat density levels.

Table 27 – Heat demand in the seven country zones for model base year (2015) (Persson et al., 2019).

Model zone	Heat demand density	DE	DK	FR	HR	IT	NL	SE
	[PJ/km2]	[PJ/year]	[PJ/year]	[PJ/year]	[PJ/year]	[PJ/year]	[PJ/year]	[PJ/year]
A	> 300	737	52	261	2	488	26	127
B	120 - 300	983	44	485	17	553	238	57
C	50 - 120	921	50	578	31	309	202	57
D	20 - 50	307	34	317	33	146	31	41
E	< 20	123	20	224	21	130	21	35

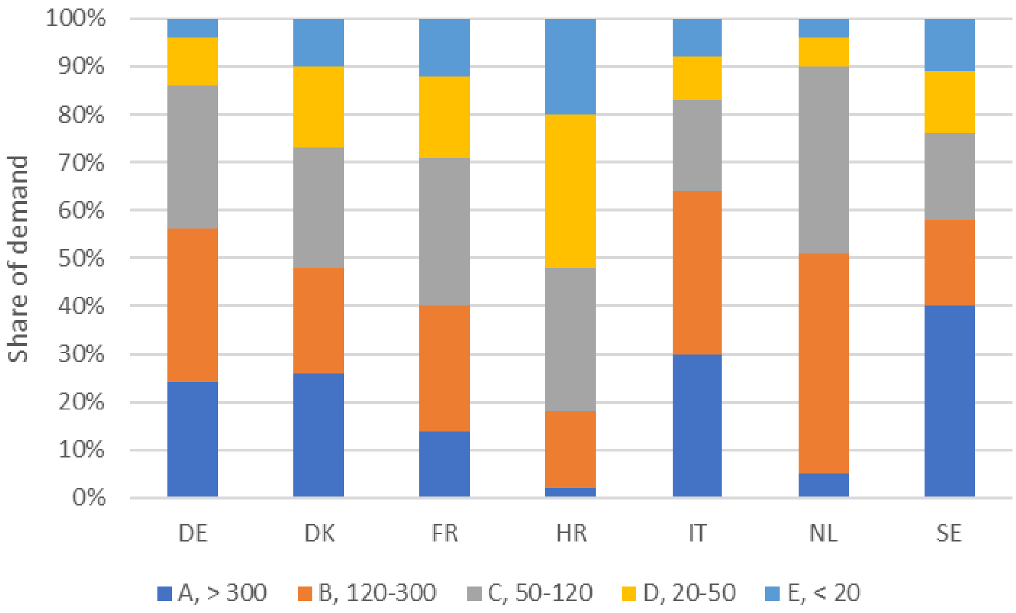


Figure 108 – Share of heat demand for different heat density levels (PJ/km2) and corresponding model zones A-E.

Figure 109 presents the DH network investment costs used in the model. Since the heat demand densities in the model zones D and E are very low, a DH network expansion in these zones is assumed not to be feasible and no costs are given. The cost increases stepwise with increasing build-up of DH. For each zone three cost levels are given. The heat demands in each zone (Table 27) is divided in three parts which each is linked to one of the three DH infrastructure cost levels (Figure 109).

Costs in PETA 4.3 (PETA4.3, 2018) include distribution pipes for DH. Costs for service pipes to buildings or costs for substations are not included. Building-related DH costs, such as DH heat exchangers, are represented in other parts of the model (see 17.12: Energy technology data). However, due to cost uncertainties of large build-up of DH in countries which currently only have small DH shares, a sensitivity analysis linked to DH infrastructure cost is also carried out (see Section 17.14).

In PETA 4.3, DH distribution cost data are provided based on annualized investment cost (calculated by assuming 3% interest rate and a 30-year investment lifetime) per unit of heat. Here, these numbers have been recalculated to total upfront investment costs (through equations 1 and 2) below) before included in the model.

Investment cost = annuity present value factor * annualized investment cost [EUR/(GJ/year)] (1)

Annuity present value factor $= \frac{1-(1+r)^{-n}}{r}$ (2)

Where: r rate per period (3%), n number of periods (30 years)

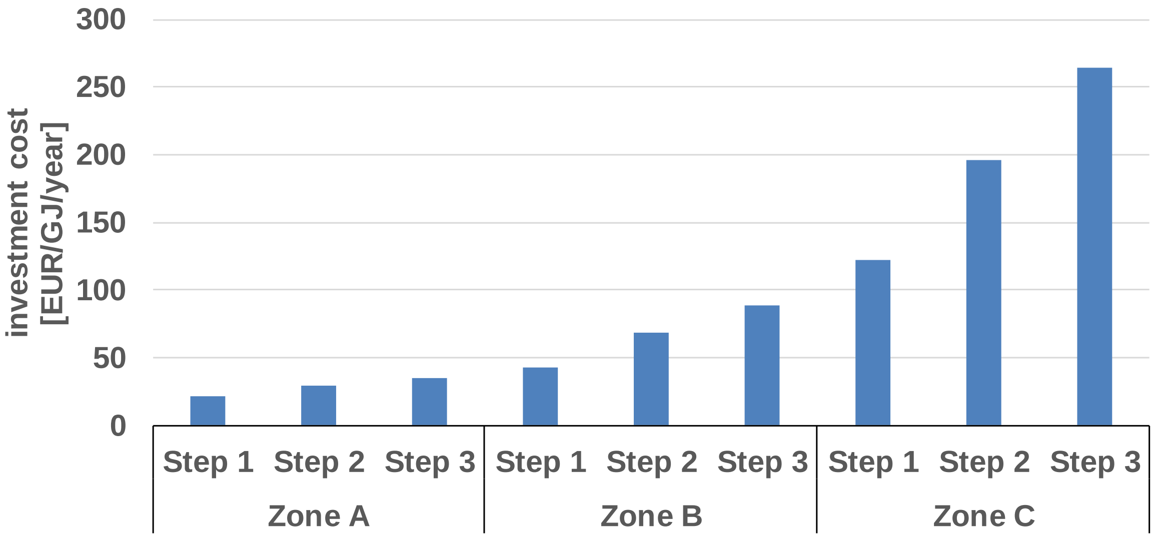


Figure 109 – DH network investment cost in different country zones. Each heat density zone has three cost levels (steps) which is linked to specific potentials.

17.9 Fuel and electricity prices

Fuel and electricity prices and costs assumed in the study are presented in Table 28. Fossil fuel prices are based on the Sustainable Development Scenario and New Policies Scenario of the International Energy Agency (IEA)'s WEO report [(IEA, 2017), (DEA, 2018)]. Biomass price assumptions are based on Danish Energy Agency's report for energy prices for industrial and central power plants (DEA, 2018) consistent with the WEO scenarios.

Electricity prices are calculated based on the assumption that the variable cost of the marginal technology (i.e., the sum of fuel cost, CO2 charge and variable operation and maintenance cost) determines the electricity price. Since the price setting technology depends on the climate ambition, these are scenario dependent. The calculations are based on a selection of various coal and natural gas thermal power plant technologies. The variable cost of the marginal technology is assumed to set the electricity price for each time period and time slice.

Table 28 – Summary of input data for the WEO-SD/ Ambitious and WEO_NP scenarios (kEUR/PJ).

	WEO-SD/ Ambitious	WEO-NP
	2020/ 2030/ 2040	2020/ 2030/ 2040
Energy prices - International markets		
Natural gas	5.7/ 7/ 7.4	4.8/ 6.5/ 7.8
Fuel oil – light	11.8/ 14/ 12.2	12/ 14.6/ 16.8
Fuel oil – heavy	7/ 9.5/ 7.5	7.3/ 9.9/ 12.1
Bio oil		
Diesel		

Coal	2.4/ 2.4/ 2.3	2.7/ 2.8/ 2.9
Liquid petrol gas		
Bio-pellets	10.2/ 14/ 17.8	9/ 9.4/ 9.6
Electricity[(a)] – Spring/fall	22.9/ 23.8/ 28.5	16.6/ 16.1/ 19.3
Electricity[(a)] – Summer	16.5/ 23.8/ 28.5	13/ 16.1/ 19.3
Electricity[(a)] – Winter	24.4/ 37.1/ 43.3	17.6/ 18.8/ 23
Energy costs - Local markets (limited potential)		
Wood chips	6.8	6.8
Straw	5.8	5.8
Peat		
Municipal solid waste	0	0
Excess heat[(c)]	0	0

a) CO2 charges used for calculating electricity prices are based on the 2017 WEO report (IEA, 2017). In WEO-SD/ Ambitious, the CO_2 charges in 2020/ 2030/ 2040 are 0.04/ 0.09/ 0.14 kEUR/tonne whereas, in WEO-NP, they are 0.021/ 0.025/ 0.042 kEUR/tonne. Electricity prices in the table are for the DH sector. Electricity prices for households are assumed to be 30–50% (depending on the climate scenario and season) higher than the electricity prices (EC, 2016).

b) Excluding the technical costs of bringing the heat to the DH system.

17.10 CO2 emissions and primary energy

17.10.1 Emission factors

The model calculates CO_2 emissions and primary energy use associated with heating buildings. Table 29 presents the CO_2 emission factors and primary energy factors used for fuels and electricity.

Due to interactions between DH and electricity systems, the choice of heat production technology influences emissions and primary energy factors associated with the marginal electricity production in current and future-built power plants over the short and long term, respectively.

Marginal electricity is assumed to be based on a mix of coal, natural gas and renewables. Coal-based production is assumed to be the marginal technology in the short term. However, in almost all European countries, governments strongly support investments in renewable energy sources such as wind and solar in the power system. In order to integrate these intermittent renewable energy sources, investments in flexible power plants (e.g., gas turbines) or other flexibility measures are needed to provide services and to cover demand. Thus, we assume wind, solar, combined cycle gas turbines (CCGT) and gas turbines will gradually develop to be the long-term marginal built power generation by 2050. As is reflected in Table 29 the extent and rate at which renewables are introduced differ between the WEO-SD and WEO-NP scenarios, with a faster and larger influence in the former case.

Table 29 – CO_2 emission and primary-energy factors. Based on (Jenny Gode et al., 2011) and the authors' assumptions.

Fuel/ Electricity	Primary energy factor	CO_2 emission factor [kt/PJ]
Coal	1.15	96
Heavy and light oil	1.11	82
Liquid petrol gas	1.11	60
Natural gas	1.09	60
Bio-pellets	1.11	0
Wood chip	1.06	0
Straw	1.05	0
Municipal waste	0.05	35/ 17.5 [a]
Solar	0.22	0
Excess heat	0	0
Electricity – WEO-SD [b]	2.9/ 2.7/ 1.5/ 1.0/ 0.4	224/ 196/ 78/ 50/ 30
Electricity – WEO-NP [b]	2.9/ 2.7/ 1.8/ 1.4/ 1.3	224/ 196/ 99/ 76/ 71

a) Values refer to model years 2015 and 2050. Reduction based on the assumption of lowered fossil content in the waste.

b) Values refer to model years 2015, 2020, 2030, 2040 and 2050. Values in the table are annual averages, while in the model seasonal differences can exist.

17.10.2 CO2 constraints

The CO_2 emission constraints in the model reflect different levels of climate policy ambitions for CO_2 emissions reduction in the countries. The CO_2 emissions are constrained such that the allowed amount of emissions from the heat sector linearly decreases between 2015 and 2050 (for each country individually), reaching a reduction of 95% and 60% by 2050, in the WEO-SD and WEO-NP scenarios, respectively.

In the scenarios, two categories of CO_2 emissions were constrained simultaneously: 1) "fossil CO_2", that is, the direct CO_2 emissions from combustion of fossil fuels within the heating sector of each country (both DH and individual heating), and 2) "total CO_2", that is, system-wide CO_2 emissions including both "fossil CO_2" and indirect emissions due to use and production of electricity. While the use of electricity increases emissions, the production of electricity (in CHP plants) reduces emissions outside the modelled system. The applied CO_2 constraints imply that each country needs to limit both fuel and net electricity use (production minus consumption) at the same time.

17.11 Air pollutant calculations

For air pollutant calculations the TIMES model is soft-linked with the GAINS model (IIASA, 2018). Three air pollutants; 1) Nitrogen Oxides (NOx), 2) Sulfur Oxides (SOx) and 3) particles less than 2.5 µm (PM2.5) were estimated for all heat production technologies which supply buildings' heat demand in different scenarios for each case country.

The principle was based on multiplying the technologies' heat output (PJ) by an emission factor unique to each substance, technology and fuel (ktonne/PJ). A suitable source for these emission factors is the GAINS model which was developed by the IIASA research institute in Austria and is used by many countries in the EU and also globally. The GAINS model can be described as a cost model for measures against emissions to air which contains a large amount of data on European emission sources, including emission amounts, energy values and emission factors. However, the GAINS model's categorization of fuels and technology is different from the TIMES model, and in order for the calculation of air pollutants to be possible, the categories from both models must be matched. The categorization in both TIMES and GAINS is based on a combination of technology and fuel, which together form a category. The models are differently accurate both for technology and fuel, and it may vary which of the models has the most accurate categorization. It is thus common with a "several-to-one" relationship in both directions, even relationships with several against several occur. This means that the energy values are not completely comparable between the models, but this matching is necessary for the calculation to be carried out.

After the category matching, data were extracted from the GAINS model, which contains several future scenarios in Europe on the development of fuels and technologies. The scenario in GAINS used in this study is called NO_CLE_EU_post2014_CLE, where CLE stands for "current legislation". The scenario data is the same as in the scenario called REF_post2014_CLE_v.Dec.2018 from Clean Air Outlook 2017. The scenario includes the legislation already in place in 2014 (the 'pre-2014' legislation) and also the new legislation adopted after 2014 (the 'post- 2014 'legislation), see (Amann et al., 2018). The scenario contains emission and energy data for the years 2015, 2020, 2025 and 2030. For only the year 2030, another scenario has also been used called (MFR, maximum feasible reduction), which means with full implementation of the technical emission control measures.

Emission factors are also present in the GAINS model; however, they are not based on specific years and are different depending on the degree of abatement installed. In order to get the right emission factors per year, country and combination of technology and fuel, data were extracted for total emissions per substance and total energy for each combination, where all different emission factors were calculated by dividing the emission by energy values for each category. However, this method gives large gaps in cases, where in the scenarios calculated by the TIMES model in this study, heat is produced in technologies which does not produce, or is not assumed to be produced in the GAINS' future scenario. In these cases, emission factors have been estimated based on the existing technologies in the GAINS model that are most similar. This can be another year in the same country, the same year but a different country, or the same year and country but from a different technology with the same fuel.

The data in the GAINS scenarios extends until 2030, for the years 2035-2050, the 2030 data has been assumed. The emission factor for EH use is set to zero.

For air pollutants related to the electricity use in the heat sector (i.e. in electric boilers and small and large-scale HPs), we applied the concept of marginal electricity production in current and future-built power plants over the short and long term (see Section 17.11 for the marginal electricity assumptions). Moreover, we assume that electricity generation in CHP plants replaces marginal electricity generation in the power sector, resulting in less air pollutant from electricity used in the heat sector. The emission factors (NOx, SO2 and PM2.5) of the power generation technologies were extracted from Danish emission factors. Finally, the air pollutant related to the electricity use was calculated by multiplying the net of electricity use (electricity purchased from the grid minus electricity produced in CHPs and sold to the grid) by the NOx, SO2 and PM2.5 emission factors of the built marginal electricity (see Table 30).

Table 30 – Air pollutant factors related to marginal electricity generation technologies, adapted based on Danish emission factors (tonne/PJ electricity)

Scenario	NOx	SO2	PM2.5
WEO-SD	109/ 113/ 83/ 41/ 25	37/ 28/ 0.2/ 0.1/ 0.06	2/ 1/ 0.03/ 0.01/ 0.01
WEO-NP	109/ 113/ 116/ 83/ 66	37/ 28/ 0.3/ 0.2/ 0.1	2/ 1/ 0.04/ 0.03/ 0.03

Values refer to model years 2015, 2020, 2030, 2040 and 2050 separated by "/".

17.12 Energy technology data

From 2020, various investment options for DH supply technologies, and different individual heat production technologies in the cities are included in the model. In Table 31 and Table 32, examples of included technologies and a selection of the technology data are presented.

Table 31 – Investment options for Conventional DH supply based on Danish Technology Data for Energy Plants (DEA, 2019).

Technology		**Electricity Efficiency (Total)**	**Specific investment cost**	**Fixed O&M cost**	**Variable O&M cost**	**Lifetime**
		2020 / 2050	**2020 / 2050**	**2020 / 2050**	**2020 / 2050**	
Combined heat and power plants			**k€/MW$_{el.}$**	**k€/MW**	**k€/TJ**	**years**
Coal Power Plant		0.46 / 0.54 (1.07 / 1.06)	1930 / 1780	31 / 29	0.82 / 0.76	25
Gas Turbine Single Cycle		0.41 / 0.45 (0.84 / 0.90)	600 / 520	20 / 18	1.3 / 1.1	25
Gas Turbine Combined Cycle		0.58 / 0.63 (0.92 /0.92)	900 / 800	30 / 26	1.3 / 1.1	25
Gas engines		0.46 / 0.50 (0.97 / 0.98)	1000 / 850	10 / 8.5	1.5 / 1.4	25
Waste-to-energy		0.22 / 0.24 (0.96 / 0.97)	8000 / 6500	54 / 37	1.6 / 1.6	25
Biomass Steam Turbine	Wood chips	0.28 / 0.28 (1.05–1.06)	3500 /3000	100 / 86	1.1 / 1.1	25
	Straw	0.29 / 0.29 (0.94–0.93)	3500 / 3000	129 / 105	0.53 / 0.53	25
	Bio pellets	0.31 / 0.31 (0.91–0.92)	2400 / 2000	66 / 56	0.44 / 0.44	25
Heat-only boilers		**Heat efficiency/ coefficient of performance**	**k€/MW$_{heat}$**	**k€/MW**	**k€/TJ**	**years**

Electric boiler		0.98 / 0.99	70 / 60	1.1 / 0.92	0.22 / 0.28	20
Large-scale heat pumps utilizing LTHS or ambient temperature air		See Table 24	700/533	2	0.6 / 0.4	25
Biomass boiler	Straw	1.0 / 1.0	910 / 760	53 / 43	0.17 / 0.17	25
	Wood chips	1.1 / 1.1	700 / 590	33 / 29	0.28 / 0.28	25
	Bio pellets	1.0 / 1.0	740 / 670	34 / 29	0.14 / 0.14	25
Geothermal heat (high temperature)		0.93 / 0.94	1400 / 1200	28-20	0 / 0	25-30
Solar heating with diurnal storage [(a)]		-	367 / 283	0.07-0.06	0.05-0.1	30
Waste-to-energy		1.05–1.06	1800–1550	85–69	2.1–2.4	25
Industrial excess heat		0.9	200 [(b)]	0	0	20

(a) The availability factor for solar heating varies between seasons and between countries and is based on EnergyPLAN models used in (Lund and Hansen, 2019): DE: 0.05–0.27; DK: 0.03–0.27; FR: 0.07–0.27; HR: 0.07–0.3, IT: 0.09–0.3; NL: 0.04 –0.25; SE: 0.02 –0.28.

(b) Investment cost represents the cost of constructing a DH transmission pipeline between industry and DH system assuming an average distance of 10 km from source to DH network, based on (Axelsson et al., 2018).

Table 32 – Investment options for individual heat devices in buildings based on Danish Technology Data for Heating Plants (DEA, 2019).

Technology		Efficiency	Specific investment cost	Variable O&M cost	Life-time
		2020 / 2050	**2020 / 2050**	**2020 / 2050**	
			k€/MW$_{heat}$	**k€/TJ**	**years**
Natural gas boiler		0.98 / 0.99	113 / 94	0 / 0	25
Oil boiler		0.85 / 0.91	123 / 103	4.9 / 4.1	20
Biomass boiler (Bio pellets)		0.82 / 0.92	236 / 198	5.4 / 4.5	20
Electric boiler		0.97 / 0.97	101 / 85	0 / 0	30
Heat pump	Air-to-water	2.7–4.2 / 3.0–4.7 [(a)]	375 / 285	0.14 / 0.11	20
	Brine-to-water	2.9–4.1 / 3.2–4.5 [(a)]	662 / 505	0 / 0	20
Heat pump-gas absorption	Air-to-water	0.94–1.5 / 1.2–1.8 [(a)]	409 / 175	0 / 0	20
	Brine-to-water	1.0–1.4 / 1.3–1.7 [(a)]	750 / 314	0 / 0	20
Solar collector [(b)]		-	614 / 479	52 / 65	20
DH heat exchanger		0.97 / 0.97	62 / 52	0 / 0	25

(a) Coefficient of performance (COP) for heat pumps with seasonal variation.

(b) The availability factor for solar heating varies between seasons and between countries and is based on EnergyPLAN models used in (Lund and Hansen, 2019): DE: 0.05–0.27; DK: 0.03–0.27; FR: 0.07–0.27; HR: 0.07–0.3, IT: 0.09–0.3; NL: 0.04 –0.25; SE: 0.02 –0.28.

17.13 Description of the LTHS sources

NACE Class Codes are used to identify the LTHS sources and their associated temperature levels and temporality (2015, 2018). The NACE code for the studied LTHS sources are summarized in Table 33.

Table 33 – Descriptions of the modelled LTH sources.

Source	Section Code/ Name	Division Code/ Name	Group Code/ Name	Class Code/ Name
Data centres	J/ Information and communication	63/information service activities	63.1/Data process, hosting and related activities; web portals	63.11/ Data process, hosting and related activities
Metro stations	H/Transportation and storage	49/ Land transport and transport via pipelines	49.3/ Other passenger land transport	49.31/ Urban and suburban passenger land transport
Service sector buildings	292 Class Codes under 16 Section Codes within Division Codes: 33, 36, 37, 38, 39, 45, 46, 47, 52, 53, 55, 56, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82, 84, 85, 86, 87, 88, 90, 91, 92, 93, 94, 95, 96 and 99.			
Sewage systems	E/ Water supply; Sewerage, Waste management and remediation activities	37/ Sewerage	37.0/ Sewerage	37.00/ Sewerage

17.14 Sensitivity analyses

The modelling results on the impact of the sensitivity cases on the utilization levels of large-scale HPs based on LTH sources are presented below.

- Various CO2 emissions reduction levels by 2050

With increases in CO_2 emission reduction levels, the cost-efficient utilization of HPs increases. However, at very high reduction levels, the trend is in many cases the opposite (Figure 110). The reasons are that renewables such as bio-CHP and solar compete with HPs and that the electricity use of the HPs is limited by CO_2 emissions in the electricity sector. Lower CO_2 emission factors for electricity (see Section 17.10.1) could improve the performance of HPs at very high reduction levels as well. This was shown in our Ambitious scenario where CO_2 emission factors for electricity is zero from 2030 (see Figure 104).

- 50% less geothermal energy potential in the DH supply

If the geothermal energy potential decreased by half, the share of large-scale HPs in both the TransitionDH and the FutureDH scenario remained unchanged in DE (Figure 110).

- 50% less solar potential in the DH supply

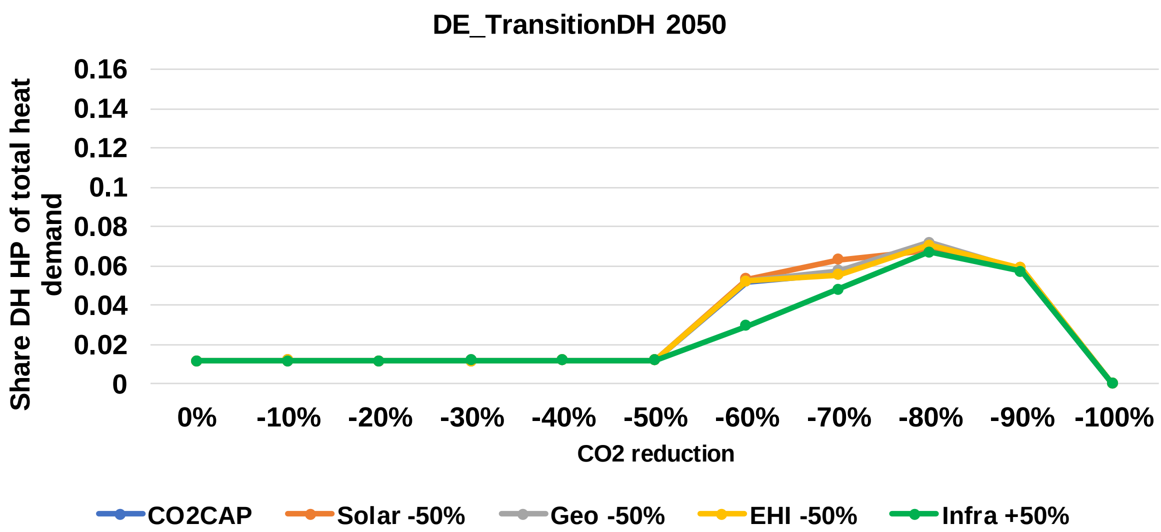
If the solar potential decreased by half, the share of large-scale HPs increased in the FutureDH scenario for CO_2 emission reduction levels below 70% while it remained unchanged in the TransitionDH scenario in Germany.

- 50% less industrial excess heat availability

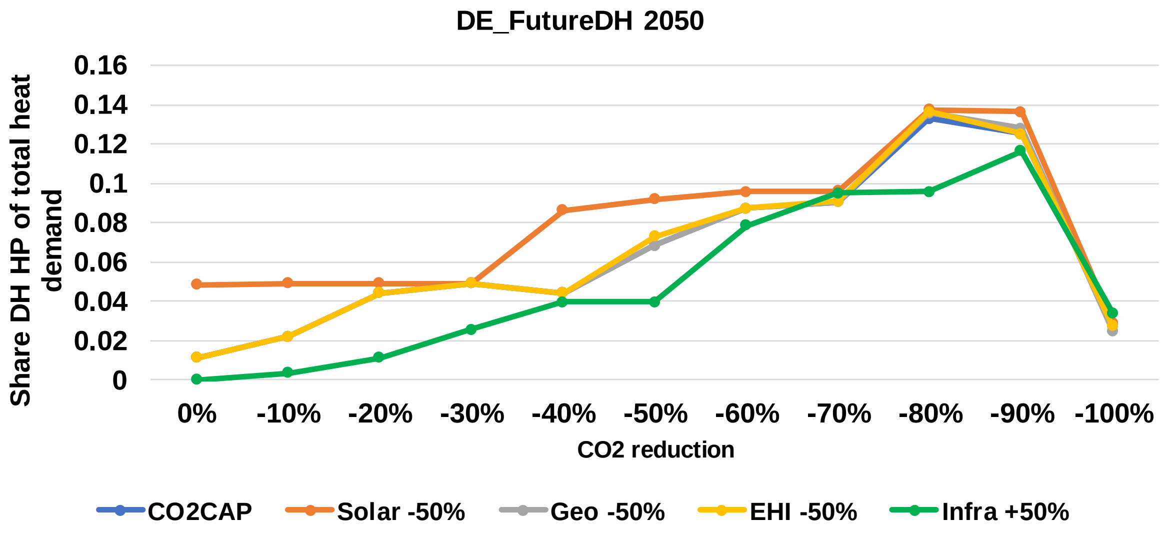
If industrial excess heat reduced by half in Germany, in both the TransitionDH and FutureDH, the share of large-scale HPs remained unchanged in Germany.

- 50% Higher cost of DH infrastructure development

In both the TransitionDH and FutureDH scenarios, the share of large-scale HPs utilizing LTH sources decreased for all CO_2 emission reduction levels (Figure 110). However, the share reduction is scenario and case dependent. The reason is that LTH sources use is highly dependent on DH costs, which in turn depends on heat densities and the corresponding heat demands in each zone of the countries. As presented in Annex 17.8, Figure 108, in some of the case countries (e.g., SE and IT) the heat densities and heat demand in the country-zones were much higher than in the other case countries (e.g., HR and NL).



(a)



(b)

Figure 110 (a,b) – Shares of the LTH sources (upgraded by HP (heat pumps) in DH systems) in the total heat demand, as a function of CO_2 reduction level, as a result of LTH sources use and LTDH in Germany in 2050. Abbreviations: CO2CAP (CO_2 reduction level), Geo (Geothermal heat), EHI (Industrial EH), Infra (District heating infrastructure/ network cost)

17.15 Modelling discussion

It is not within the scope of the work to assess the probability of whether certain developments or policies will occur; thus, none of the scenarios and pathways presented are to be considered more likely than the others. They are instead constructed to present a span of relevant and plausible results in terms of DH networks development and LTH and RE sources use together with the consequent system effects. Nevertheless, given the reality of climate change as well as EU policies and targets, scenarios with stringent CO2 reductions represent desirable pathways from a normative perspective.

The results of the model show that biomass heat-only boilers play an important role in DH production. In our CO_2 emission calculations, biomass is carbon neutral. Biomass is a renewable source of energy, but it is also a limited resource. Under climate stringent policies, when all sectors of energy systems need to reduce their CO_2 emissions, use of biomass for heating purposes could potentially limit its use in the transport and power sectors. This in turn, with a wide system perspective, could indirectly affect net global CO_2 emissions. Such potential consequences are not accounted for in the present study. Further, in this study, a local market for unrefined biomass is assumed, resulting in just including the cost of biomass extraction (while refined bio-pellets are assumed to be traded on international markets). However, in the future and under climate-stringent policies, competition between different sectors for biomass use could also lead to an international market for unrefined biomass and, thus, a stronger likelihood of higher costs. This could in turn improve the competitiveness of LTH sources compared to biomass in DH systems.

All excess heat (low-temperature and industrial) sources are assumed to be carbon neutral in our calculations, since there are no direct emissions associated with their utilization. This might to some degree underestimate total CO_2 emissions because it does not account for any increase in emissions from the industrial processes and urban sources that might occur if the price of the EH is sufficiently high to decrease the profitability of energy-efficiency measures.

Since LTH sources are not continuously available for DH during an entire year and their availability mismatches with buildings' heating demand (i.e. heat from metro stations and service sector cooling are more available during summer when DH demand is limited), thermal heat storage could improve the competitiveness of LTH sources compared to other heat sources by making them equally available over the year. However, there are additional investment costs associated with thermal storage that more likely even out benefits from low-cost excess heat sources. This has not been analyzed in-depth by the present analysis.

Fuel and electricity prices and technology costs are assumed to be equal in all the case countries. This might to some degree change profitably of DH production or individual heat boilers in buildings in some case countries. Instead, in this study we could show and compare how the heat sector would evolve over time in the different case countries while meeting heat demands and equal CO_2 emission constraints in less complex way.

The quantitative dynamic optimization modelling approach applied in the study is a powerful method for framing and addressing complex and data-intensive energy system investigations. Unlike statistics models, the modelling performed here assesses both the mid-term and the long-term system impact utilization of RE and LTH sources and LTDH in the heating systems of the case countries. This is advantageous since energy systems are dynamic by nature and the response to any intervention in the system can differ over time.

Since the model bases its decisions on direct energy technology-related costs, indirect costs or other barriers hindering a certain development might not be reflected in the results. For instance, the significant build-up of DH capacity seen in some scenarios for countries that currently only have very small DH capacity (e.g. Italy and France) will certainly be challenging. However, this does not change or diminish the model results, which do suggest that such development is advantageous from the applied techno-economic perspective.