Heat Roadmap Europe 4

Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps

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2050 Heat Roadmap Europe
A low-carbon heating and cooling strategy

Heat Roadmap Europe

(Executive summary)

Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps

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Contents

Nomenclature

Scenarios

BL 2015 / BL 2050	Baseline Scenario for 2015 / Baseline Scenario for 2050
CD 2050	Conventionally Decarbonised Scenario
HRE 2050	Heat Roadmap Scenario for 2050

Abbreviations

CHP	Combined heat and power
CO_2	Carbon dioxide
COP	Coefficient of performance
DH	District heating
HRE	Heat Roadmap Europe project series starting in 2012
HRE4	Heat Roadmap Europe 4 (H2020-EE-2015-3-MarketUptake)
PES	Primary energy supply: all energy that is used, before conversion, as input to supply the energy system

Country Codes

EU	European Union
HRE4 Countries	Listed below; the 14 largest EU member states in terms of heat demand, totalling 90% of the EU heat demand.

AT	Austria	HU	Hungary
BE	Belgium	IT	Italy
CZ	Czech Republic	NL	Netherlands
DE	Germany	PL	Poland
ES	Spain	RO	Romania
FI	Finland	SE	Sweden
FR	France	UK	United Kingdom

About Heat Roadmap Europe

Heat Roadmap Europe 4 follows as instalment a series of previous studies that have been carried out since 2012 [1–3], which have resulted in a total of 18 different reports, primarily relating to the long-term changes that are necessary to implement in order to decarbonise the heating and cooling sector in Europe. The acronyms 'HRE' and 'HRE4' are used for brevity and consistency, where '4' distinguishes the new data and methodological improvements produced during this current study, as HRE4 builds on the foundation set by the three previous studies and expands its research scope in terms of both energy sectors and geography.

HRE4 project with a consortium of 24 partners has received funding from the European Union's Horizon 2020 research and innovation programme since 2016 until 2019. It addresses the topic EE-14-2015 "Removing market barriers to the uptake of efficient heating and cooling solutions" of the Energy-efficiency call, by quantifying the effects of increased energy efficiency on both demand and supply side, in terms of energy consumption, environmental impacts and costs.

In order to fulfil Coordination and Support Action Grant objectives and requirements, HRE4 has been executing a strategy of dissemination measures in order to communicate the research findings to the relevant stakeholders, who by position and profession can use the scientific evidence for facilitating the market uptake of efficient and sustainable developments in heating and cooling sectors. Thus, on the one hand HRE is advancing on scientific research which:

- Involves the most detailed spatial mapping of heat demands and renewable heat resources up to date;
- Includes the potential for reducing heat demands through cost-efficient energy efficiency measures in both the heating and the cooling sector;
- Integrates industrial sectors to quantify heat demands;
- Models both long term projections and hour-by-hour energy systems.

On the other hand, it is heavily occupied with measures for coordination and support as:

- Developing user manuals of the research findings and tools, as a way to standardise new knowledge and render it intelligible to non-scientific officials;
- Hosting workshops, strategic panel discussions where policy-makers are invited;
- Participating in events, as conferences, for promotion of project tools and findings;
- Active presence on social media, where the results are communicated to broader audiences;
- Awareness-raising activities in the digital media, such as informative videos and instructional webinars.

Executive Summary

The aim of Heat Roadmap Europe (HRE) is to create the scientific evidence required to effectively support the decarbonisation of the heating and cooling sector in Europe and democratise the debate about the sector. This HRE project is the 4th in a series of analyses that combines local (geographic) data with knowledge on energy savings and detailed all sector hour-by-hour energy system analysis. The project covers 90% of the European heat market by modelling 14 countries and their energy systems individually, allowing for an insight towards the overall European perspective.

Together, heating and cooling represent the largest energy sector today, but by redesigning the energy systems in Europe using only proven and market available technologies, it is possible to combine end-use savings with heat pumps and district heating and cooling using excess heat, efficiency and renewable sources to stay within the 1,5 - 2°C global temperature change threshold. To decarbonise and reduce energy system costs, fossil fuel consumption is replaced with energy efficiency and renewable energy. This has the potential to significantly improve the balance of payments compared to today and create more jobs in Europe when increasing expenditures on local energy efficiency and use of local resources [4]. It also creates a heat supply which more resilient to fuel price fluctuations, as more expenses are tied to investments. The scenario development in HRE makes it evident that by 2050:

- CO_2 emissions can be reduced by 4.340 Mton or 86% compared to 1990 using only known technology in the heating and cooling sector. This is in line with the Paris Agreement and approaches a nearly zero carbon energy system.
- By redesigning the heating and cooling sector the total costs of decarbonisation can be reduced by 6% annually compared to conventional methods of decarbonisation. In all future scenarios less financial resources are spent on fuels and more on investments.
- The use of fossil fuels in HRE can be reduced by almost 10.400 TWh in 2050 compared to the 2015 reference. This also influences the amount of investments needed and balance of payments. HRE would heavily reduce the need for natural gas imports. The amount of natural gas decreases in HRE 2050 by about 87% compared to the 2015 reference, the remainder only being used in industry and flexible combined heat and power. In 2016 54% of the energy consumption was met by imports, 88% of oil was imported and 70% of the consumed natural gas was imported [5]. The imported natural gas had a value of €50-65 billion in 2016.
- Natural gas and inefficient electric heating in buildings can be phased out. Such solutions can be replaced by a combination of refurbishment and end use savings, individual heat pumps and district heating using excess heat and heat from renewable sources. Since renewable energy covers 87% of the total primary energy supply in HRE, and the remaining fossil fuels are primarily in transport,

industry, and flexible combined heat and power, almost all of the heating and cooling demands is covered sustainably.

- The solutions proposed are in line with the Smart Energy System approach enabling a conversion towards 100% renewable energy [6].

Based on the data, knowledge, methodologies, and scenarios developed and made available by the HRE project, it is clear that the European Union should focus on implementing change and enabling markets for existing technologies and infrastructures in order to take advantage of the benefits of energy efficiency in a broader sense and for the heating and cooling sector specifically. Typically, decarbonisation of the energy system is done using only electrification and some degree of refurbishment.

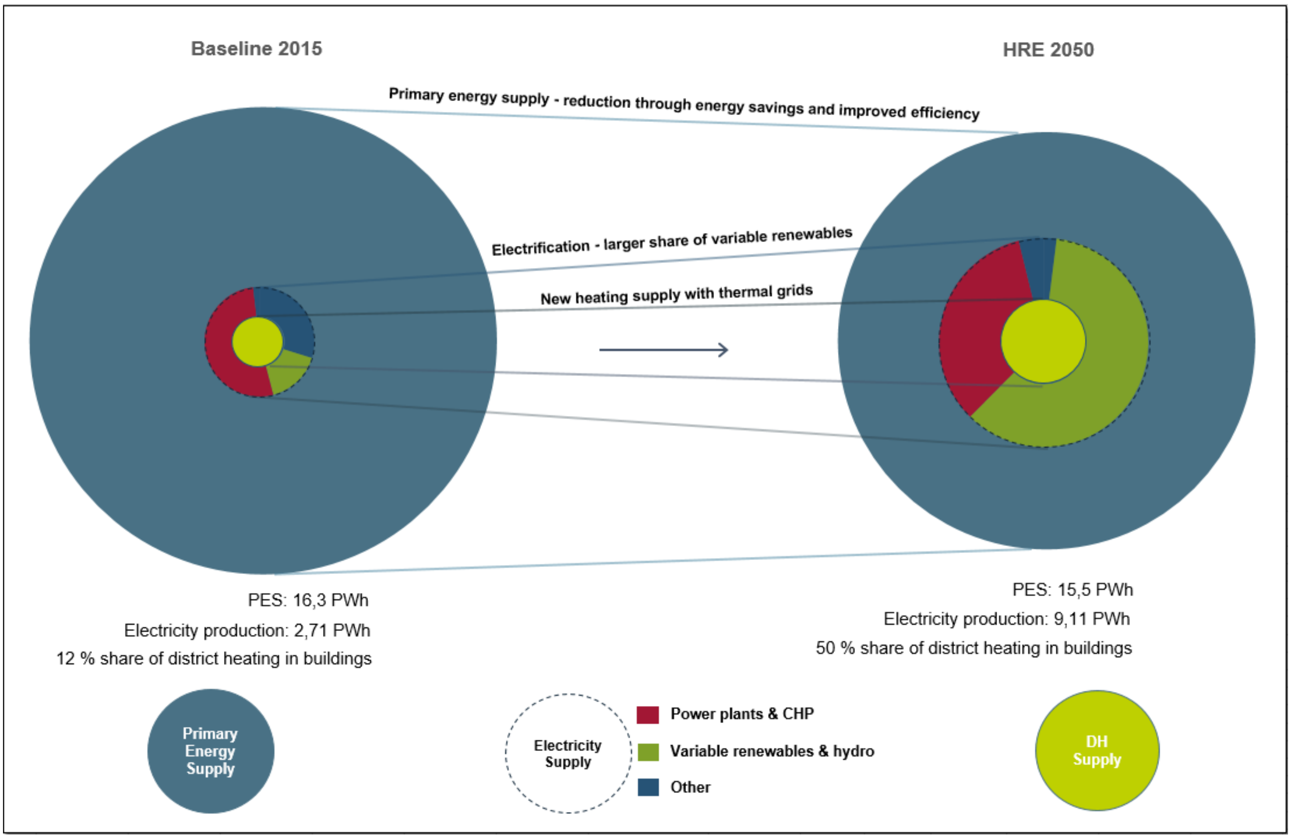

Figure 1. Illustration of the energy system changes implemented in the Heat Roadmap Europe Scenarios towards 2050 with regards to primary energy supply (PES), electrification and new thermal grids.

In the HRE scenarios, reductions in the primary energy supply are created by combining several energy efficiency components in the form of further end-use savings, district heating and cooling grids and use of excess heat (for urban areas). This is combined with electrification using heat pumps (at an individual building scale in rural areas, and in the form of large-scale heat pumps in district heating and cooling grids). Like in other decarbonisation scenarios, further electrification of the energy system happens in the form of electric vehicles and the production of green gasses using hydrogen and carbon sources. The combination of electrification, thermal grids and energy savings has benefits across the energy system and for the integration of renewable energy capacities (Figure 1).

On the country level, action and implementation plans should include and develop adjustment efforts in order to consider approaches to 1) energy savings, 2) thermal infrastructure expansion, 3) strategic location and availability of excess heat utilisation and heat production units, and 4) individual heat pumps outside urban areas. These are the main technologies that contribute to the efficiency, decarbonisation, and affordability of the heating and cooling sector.

End use savings in delivered energy are vital to efficiency, decarbonisation and affordability. This is particularly true for space heating in existing buildings, where higher renovation rates and depths are needed. With the current policies and targets, a 25% reduction in total delivered energy can be reached in 2050, also considering an increased amount of buildings. This represents an annual refurbishment rate between 0,7% and 1,0% towards 2050, and implies that all policies are fully implemented. In HRE it is recommended to increase the target to at least 30% savings for space heating in buildings. This requires a higher refurbishment rate of 1,5% to 2%, and deeper renovations when they occur [7]. In order to achieve both the current ambitions for savings and the levels recommended in HRE, a very strong focus should be put on implementation on country and/or regional level regarding the effectiveness of policies and implementation strategies, in order to ensure the EU and country level energy savings goals are met.

The **expansion of thermal grids** is crucial to redesign the energy system and enable better integration of renewable energy and excess heat sources. District heating can cost-effectively provide at least half of the heating demand in 2050 in the 14 HRE countries, expanded from about 12% of the heating market today in the 14 countries or 90% of the EU heat markets covered here. While there are differences from country to country going beyond half towards 70% of the heat market in the 14 countries as a whole can provide additional energy efficiency and strategic benefits. This requires thermal grids to be recognised as an important infrastructure in the Energy Union as well as targeted EU level and country level policies that enable city or regional development of and financing of district heating infrastructure.

Excess heat recovery from industry and heat from power production is key to an efficient and resilient heating and cooling sector, and has the potential to support local industries, economies, and employment. These sources could cover at least 25% of the district heat production considering their location. This requires a concerted change in planning practices to ensure that they are within geographic range and fairly distributed among different potential district heating areas and cities. This is the case for local industries, waste-to-energy facilities, future bio-, green gas or electro fuel production sites, and potentially also data centres, sewage treatment facilities and other types of non-conventional excess heat. Further sources of excess heat, for example that which requires heat pumps to be upgraded, should be investigated. These lower temperature sources are not included in the analysed scenarios, which means that the analysed of both industrial excess heat and large-scale heat pumps are likely to be on the conservative compared to the real potential.

Future **production and storage units** for district heating should be more varied and versatile to integrate low-carbon sources and enable flexibility. Production facilities include biomass boilers, various renewables, different types of excess heat, and the use of combined heat and power (CHP) and large-scale heat pumps. Overall CHP covers 25-35% of the heat generation, but operates only in response to the needs of the electricity markets. This means the heat is created as an unavoidable by-product of flexible electricity production, and its use contributes purely contributes to the overall energy system efficiency. Large heat pumps 20-30% using mainly renewable energy and the remainder from excess heating (25%) and other renewable sources such as geothermal and solar thermal heating (5%). Renewable sources such as deep geothermal energy and solar thermal heating can only be exploited to their full potential in the energy system if district heating is present, and are a valuable resource for district heating systems that do not have obvious sources of industrial excess heat. The capacity of boilers can cover the peak demands over the year, however boilers should not produce more than 10% of the district heating demand corresponding to times with peak demands or low production from other sources.

The most important thermal energy storage to consider should cover on average 2-8 hours in larger cities and 6-48 hours in smaller cities. These types of short-term storages are crucial to balance the electricity grid as well as to handle fluctuating local low value heat sources. Seasonal storages may be relevant to locally increase the coverage of excess heat otherwise it is wasted in the summer period from e.g. industry, waste incineration or solar thermal.

Individual heat pumps will be key to enabling resource efficiency and electrification in areas where district energy is not viable, and should provide about half of the heat demand or lower depending on the local conditions for the built environment. Since the investment required to unlock their potential is high and often borne by building owners, focus should be on policies and implementation strategies that encourage switching from individual boilers and inefficient electric heating to more efficient alternatives in non-urban areas. The policies should be targeted at areas not suitable for district heating, in order ensure the overall energy efficiency, flexibility and decarbonisation of the system. The policies should also be combined with targeted measures for energy savings as this improves the efficiency of the heat pumps and reduces the peaks in the electricity grids in cold periods. The small individual heat pumps and in practice likely to be combined with solar thermal and biomass boilers as part of the supply in some areas in Europe. However, in this study all individual heating is supplied by heat pumps as a modelling method due to the purpose of the analysis and their distinct advantage in efficiency and integration with the electricity sector. Thermal storage in combination with these are important, but the flexibility is limited compared to the district heating system with thermal storage, heat pumps, combined heat and power, etc.

The HRE project aims at democratising the debate about the heating and cooling sector by providing data, analyses, methods and information at several levels and to multiple stakeholders. The overall objective in the HRE project is to provide new capacity and skills for lead-users in the heating and cooling sector, including policymakers, industry, and researchers at local, national, and EU level. These data, freeware tools, methodologies, analyses, results, and local geographical data are made available online. By providing the scientific evidence required to support the decarbonisation of the heating and cooling sector in Europe and transferring this knowledge and tools to key lead-users across policy, industry, and research, this can enable new policies and prepare the ground for new investments in new markets.

To **create the science-based decision support** in HRE several unique methods for energy planning have been combined. Key to the project is the combination of mapping and all sectors energy systems modelling, in order to be able to understand not just the system effects of energy efficiency but also the spatial dimension. Therefore, HRE brings together energy system analysis with spatial planning tools and provides an in-depth understanding of thermal demands in built environment and industry.

This includes a **detailed spatial analysis** in order to be able to understand the local nature of heating and cooling, and in order to more accurately appreciate infrastructure costs. A Pan-European Thermal Atlas with hectare level mapping of thermal energy demands and resources has been developed in HRE, and is available online.

In addition, a **bottom-up and in depth analysis of the thermal sector** and thermal demands has been carried out for the built environment and industry using the Forecast model, since they are often overlooked in standardised statistics. This forms the basis of the strategic heating and cooling development and underlies an understanding of what kinds of energy savings are possible.

These are combined in the development of the **energy system analysis**, since an hour-by-hour energy system analysis approach including all sectors is necessary in order to ensure lower overall costs and avoid suboptimal design within the heating and cooling sectors. In HRE, an evolutionary optimisation tool (JRC-EU-TIMES) and an hourly simulation tool (EnergyPLAN) have been soft-linked to be able to use the strengths of both models. Together, this allows for a quantification of the effect of energy efficiency and decarbonisation within an integrated energy system.

Key findings in Heat Roadmap Europe

1	**The heating and cooling sector can be fully decarbonised based on technologies and approaches which already exist, are market-ready and have successfully been implemented in Europe.**

- The HRE 2050 scenarios show that a redesigned and sector-integrated heating and cooling solution can improve the European Union's energy efficiency, economy, and environmental impacts while successfully enabling the transition away from fossil fuels.
- The redesign contributes to keeping global temperature rise under 1,5-2°C as agreed in the Paris Agreement by decarbonising by about 4.300 Mtonnes per year or 86% compared to 1990 levels counting in also non-energy and other sectors such as agriculture. The energy sector emissions are reduced by about 2.700 Mtonnes of CO_2, or by 89% percent compared the 2015 reference. The redesigned energy system does not hinder but enables further implementation of renewable energy. (Figure 2)

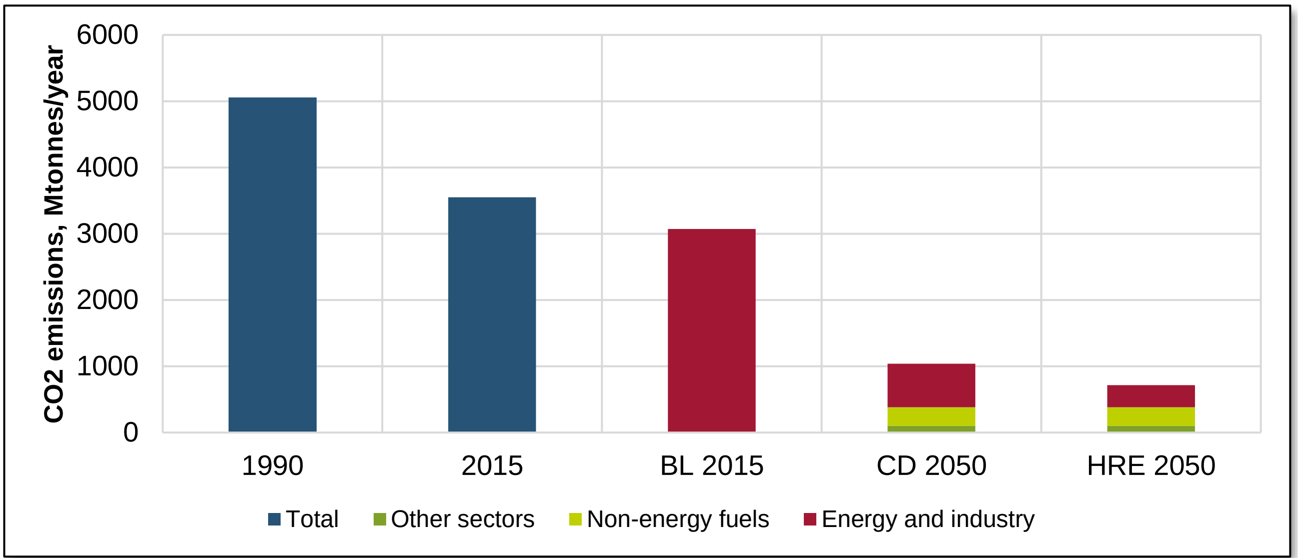

Figure 2. Historical, current and future CO_2 emissions for the 14 HRE4 countries; including the years 1990 [8] (the base year for the Paris Agreement), 2015 and the three 2050 scenarios; i.e. the Baseline (BL) 2050, which represents the development of the energy system under currently agreed policies; the Conventionally Decarbonized (CD) 2050, which represents the development of the energy system under a framework that encourages renewables, but does not radically change the heating and cooling sector; and the HRE 2050, which represents a redesigned heating and cooling system, considering different types of energy efficiency and better integration with the other energy sectors.

- Energy efficiency and decarbonisation in the heating and cooling sector is achieved with the use of already existing technologies, i.e. ambitious renovations of the existing building stock; 3rd generation district heating and cooling grids; efficient heat pumps; and better utilisation of the potential synergies between the energy sectors.

- HRE presents a robust no-regrets pathway: the technologies used are all mature, market-ready and have been implemented in parts of Europe. The challenge is to create integrated knowledge, planning tools, business tools, innovative collaborations and incentives to realise their potential. In most cases it is political and regulatory barriers rather than technical barriers.

2	**Energy efficiency on both the demand and the supply side are necessary to cost-effectively reach the decarbonisation goals.**

- End-user savings alone are not sufficient to decarbonise the heating and cooling system and will increase significantly due to higher investments. Supply side solutions alone require much higher investments in renewable energy and may not be sustainable. Energy efficiency on both the demand and supply side is necessary for a deeper decarbonisation. End-user savings reduce the energy systems' primary energy demand by around 4% (613 TWh) in HRE in 2050 and represent around 30% of total potential savings, with more efficient supply options reducing primary energy a further 8% (1.405 TWh) – which makes up the remaining 70% of total savings.
- An integrated approach to the heating and cooling sector requires more investments to establish energy efficient technologies and infrastructure compared to a focus only on achieving energy efficiency on the demand side. However, overall this reduces energy system costs by approximately 6% (67,4 billion €) annually overall. (Figure 3)
- The reduced consumption of fossil fuels in the heating and cooling strategies in the HRE 2050 scenario almost completely eliminates the dependence on imported natural gas for heating purposes in Europe. The strategies also heavily reduces the vulnerability of citizens to very high heat prices and the risks of energy poverty. Fossil fuels can be reduced by almost 10.400 TWh in 2050 compared to today. The amount of natural gas decreases in 2050 by about 87% compared to today. As comparison 54% of the energy consumption was met by imports, 88% of oil and 70% of natural gas was imported in 2016 [5]. The imported natural gas had a value of 50-65 billion €.
- The reduced expenditure on fuels and higher spending on the suggested investments in local energy efficiency and local resources has the potential to improve local employment and the European balance of payments and reduce expenditures on imported fuels.
- Achieving energy efficiency requires both goals and active policies to support the implementation of infrastructures for heating and cooling within the individual member states' own contexts on the EU level as well as the local level. The existing policies used should be monitored periodically for compliance and changed or expanded if they do not have the desired level of energy savings. A framework for

expanding and establishing thermal infrastructure should be initiated and in line with policies for gas and electricity grids, it should have an EU level and a national level.

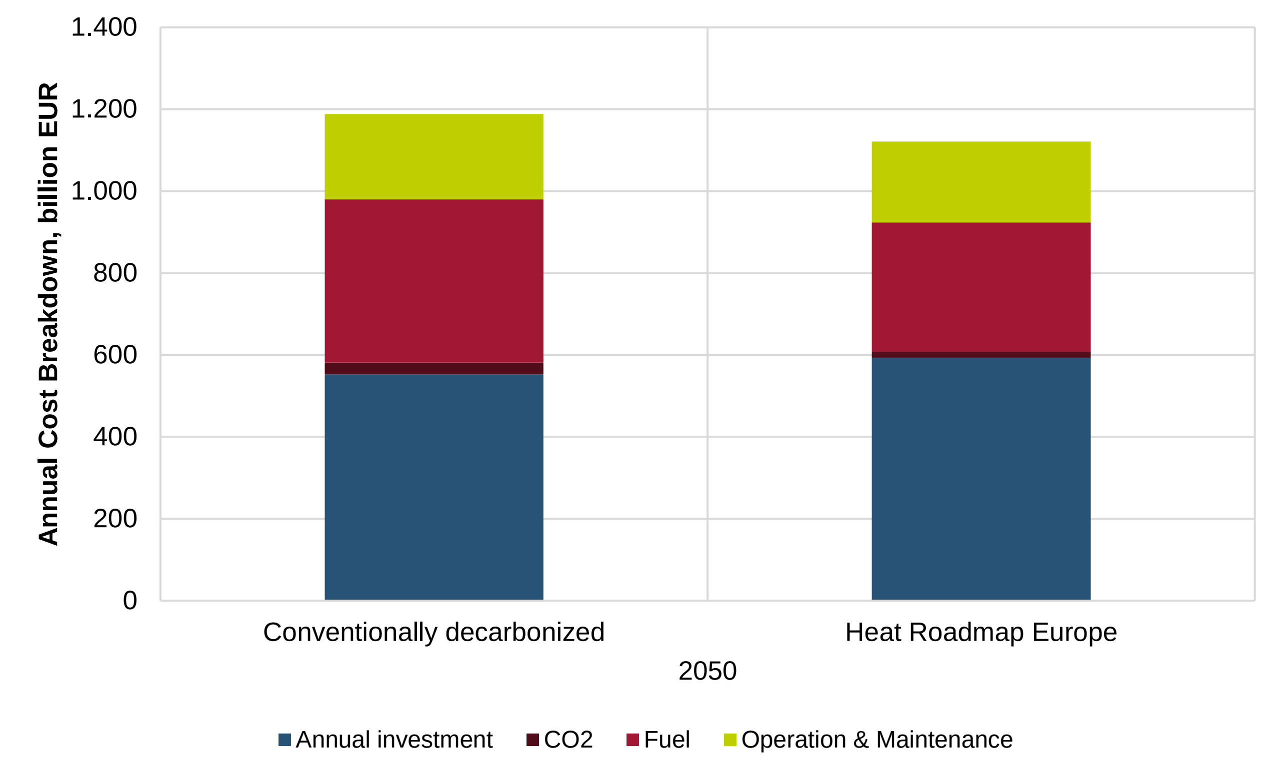

Figure 3. Annual total energy systems costs for the decarbonized 2050 scenarios. The Conventionally decarbonized energy system focusing on increasing the renewable energy penetration and some degree of energy savings reaches an 80% reduction in CO_2-emissions while the HRE 2050 scenarios reaches 86% at a lower cost using deeper renovations and an integrated new energy system design.

3 More support is needed for implementation and higher energy saving targets for deeper renovation of the existing building stock and investments in industry.

- **End use savings** are vital to efficiency, decarbonisation and affordability. In existing buildings higher renovation rates and depths are needed. With the current policies and targets, a 25% reduction in total delivered energy for space heating can be reached in 2050, also considering also an increased amount of buildings. This represents an annual refurbishment rate between 0,7% and 1,0% towards 2050, and requires that all policies are fully implemented [7]. In HRE it is recommended to increase the target to at least 30% savings for space heating in buildings. This requires a higher refurbishment rate of 1,5% to 2%, and deeper renovations when they occur [7].

- Both the current and the higher target suggested here require a shift to a much stronger focus and enhanced approach towards **policy implementation** and realisation on a country level, with regular re-evaluations of progress and impact. A higher ambition than 30% for Europe would be precautionary as experience shows that implementation may fail to succeed [9,10] and the results in HRE for most countries show that the socio-economic costs for going higher are very low and within the uncertainties of the analyses.
- HRE finds that all countries should have a higher ambition level that the current EU level target would lead to. Especially Belgium, the Czech Republic, Hungary, the Netherlands, Poland, and Romania should have a higher energy savings target. No savings are implemented in the hot water demands.

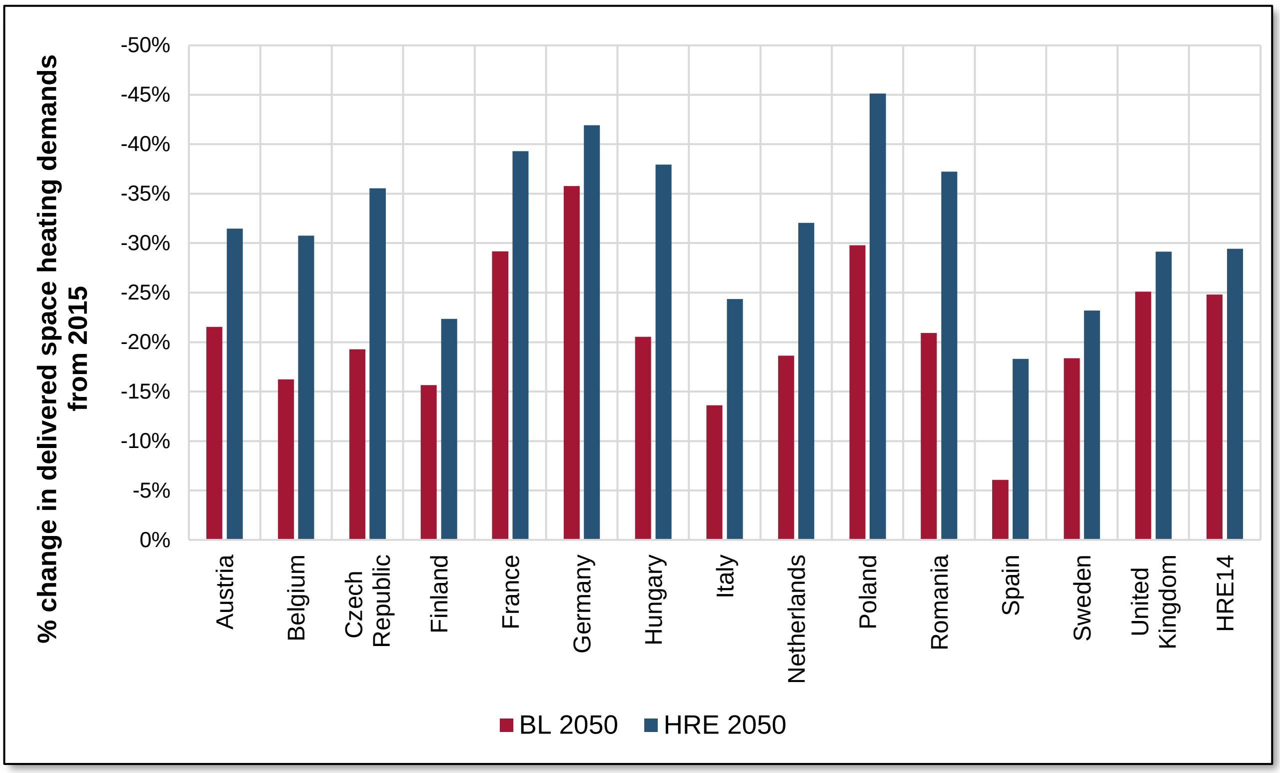

Figure 4. Heat Roadmap Europe and Baseline 2050 (current policies) changes in the delivered space heating in 2050 if fully implemented.

- The HRE4 results show that energy savings in industry and the service sector are highly cost-effective from a socio-economic and energy perspective, meaning that efficiency standards and financial incentives for process heat savings should also be ensured in member states. The savings recommended in Heat Roadmap Europe are 8% for process heating, which is the highest considered technically feasible within the proven-technology approach in HRE. Like for space heat savings, a strong focus on implementation can be recommended. (Figure 5)

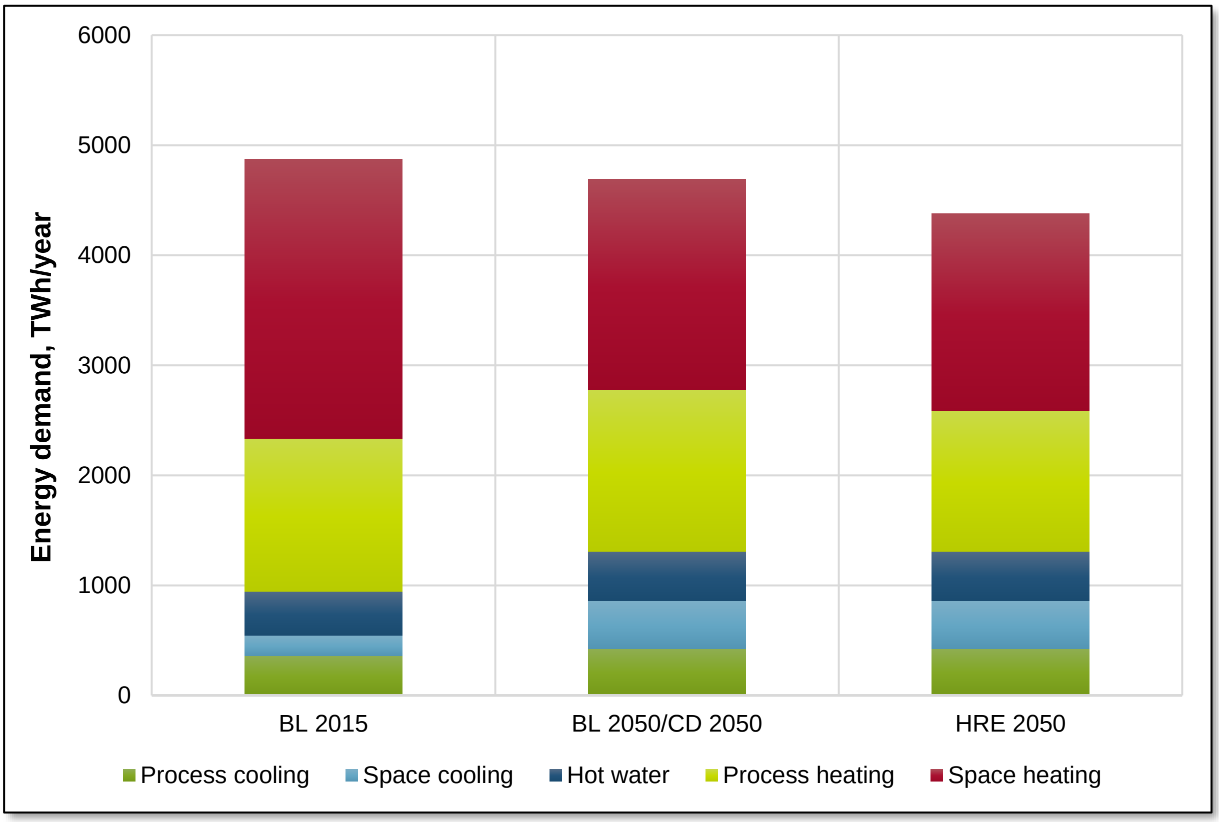

Figure 5. Heating and cooling demands reductions in the baseline (BL) and decarbonized (CD) scenarios and in Heat Roadmap Europe 2050.

4 **In the vast majority of urban areas, district energy is technically and economically more viable than other network and individual based solutions, and can be 100% decarbonised through the use of renewables, large heat pumps, excess heat, and cogeneration.**

- The analyses show that district heating cost-effectively can provide at least half of the heating demand in the HRE4 countries while reducing the primary energy demand and CO2-emissions. For the 14 HRE countries combined, a 0,5% total cost change interval gives a market share of district heating in a 32-68% range in combination with the 30% end demand energy savings. The scenario level (45%) where about half of the heat market is covered with district heating is based on economic metrics and effects on the energy system only.
- Due to a number of additional strategic benefits, such as security of supply as well as jobs and industrial development it can be recommended to go beyond the

modelled or current district heating share towards 70%. While there are differences from country to country, going beyond the modelled level towards the maximum feasible level can further lower the price fluctuations citizens will experience, lower geopolitical tensions connected to energy supply and create an even more fuel-efficient system. (Figure 6)

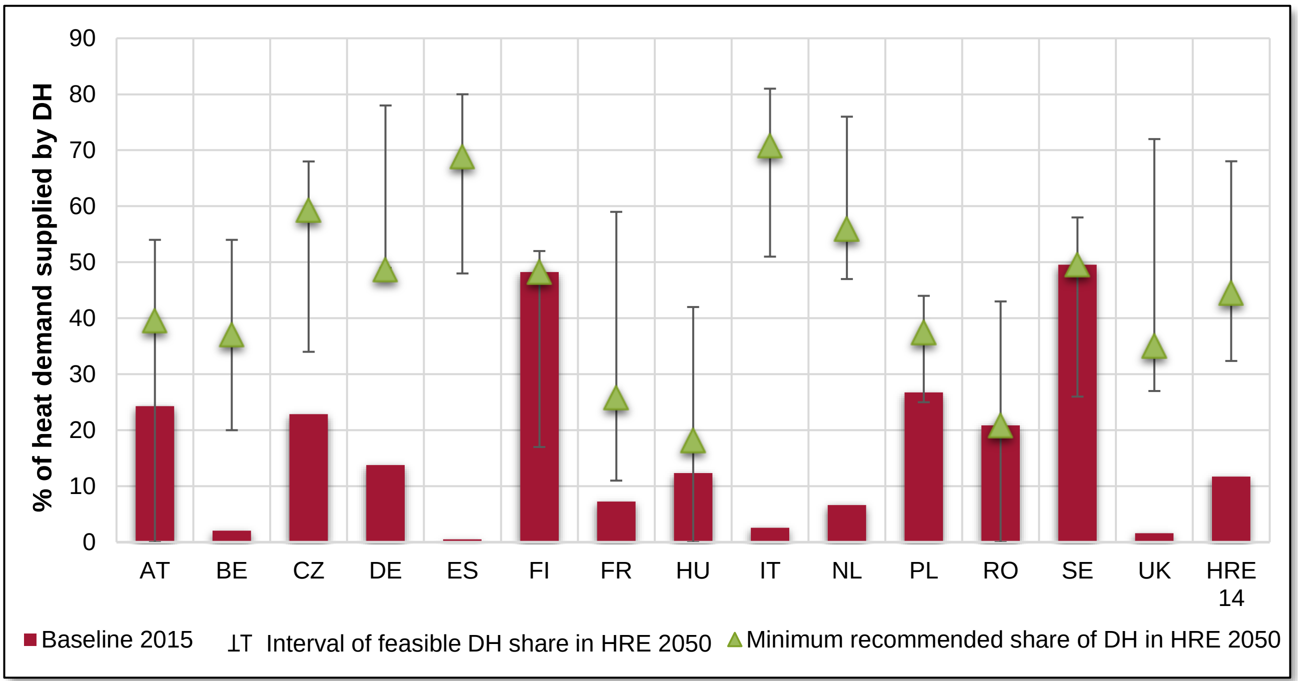

Figure 6. Baseline share of district heating in 2015 and the minimum recommended level of district heating share in HRE4. The range bars represent the amount of district heating that is economically feasible within a 0,5% total annual energy system cost change sensitivity. The recommended minimum levels take into account cost efficient levels and current level of district heating. Going beyond this level can generally increase energy efficiency.

- The level of district heating recommended is robust against a situation where the implementation of energy savings and refurbishments fails.
- Future production and storage units for district heating must be more varied and versatile to integrate low-carbon sources and enable flexibility. Excess heat from electricity production (CHP) covers 25-35% of the heat generation, large heat pumps covers 20-30% using mainly renewable energy. The remaining heat supply is from industrial excess heat (25%) and other renewable sources such as geothermal and solar thermal heating (5%). Renewable sources such as deep geothermal energy and solar thermal heating are geographically and temporally constrained, and can only be exploited to their full potential in the energy system if district heating is present. The capacity of boilers can cover the peak demands over the year. Heat only boilers play a marginal role in the heat supply mix (less than 6%).
- The most important thermal energy storage to consider is in local feasibility studies can cover on average 2-8 hours in larger cities and 6-48 hours in smaller cities.

These types of short-term storages are crucial to balance the electricity grid as well as to handle fluctuating local low value heat sources. Seasonal storages may be relevant to locally increase the coverage of excess heat otherwise it is wasted in the summer period from e.g. industry, waste incineration or solar thermal.

- Full electrification of the heating supply is more costly and neglects the potential to recover energy from industry and power generation, limiting the overall efficiency of the system and possibility for coupling electricity, heating and using heat storage. With 50% district heating or more in combination with electrification overall the grid costs are spread between thermal and electricity grids. Lower shares of district heating will increase the cost for electricity grids in decarbonised energy systems. A further benefit of higher district heating shares are potential higher usages of domestic fuel or EU fuels creating a better balance of payment and potential increase in jobs.

5	**In areas with limited district heating and cooling feasibility, individual supplies should be from heat pumps that can contribute to the integration of variable renewables.**

- In rural areas, heat pumps should become the preferable individual solution based on their high efficiency, providing about half of the heat demand or lower. The level depends on the local conditions for the built environment. High standards of energy performance and deep renovations are necessary in order to implement heat pumps effectively and ensure high coefficients of performance (COPs) along with a high level of comfort.
- Heat pumps reduces the dependency on fuel boilers in a bioenergy-scarce decarbonised future and increases the use of fluctuating renewable electricity sources. It can also to some extent contribute to the energy system flexibility [11]. While these heat pumps can in reality be combined with solar thermal and biomass boilers as part of the supply in some areas in Europe, in this study all individual heating is supplied by heat pumps as a modelling method due to the purpose of the analysis and their distinct advantage of efficiency and integration with the electricity sector.
- Thermal storage in combination with these are important, but the flexibility in these storage is limited compared to the district heating system with larger thermal storage that have much lower costs, larger heat pumps, combined heat and power, etc. [12,13].
- Operational incentives for building residents should first and foremost promote energy savings and then flexible interaction for consumers to help balance the electricity grid and not maximise self-consumption since optimising in the building level will most likely result in higher costs for the overall energy system [14].

6	**Cooling demands are less significant compared to the heating demands, but are expected to increase in the future. The knowledge about solution designs is expected to improve in the future.**

- Cooling demands are expected to increase in all countries according to the saturation levels, which could more than double. However, even in the most southern HRE4 countries, heat demands dominate the sector, as in 2050 cooling represents 20% of the thermal energy demand in the modelled scenarios.
- In HRE4, a full overview is presented for the first time of the potential cooling technologies looking towards 2050 [15]. These solutions contribute to the efficient use of energy through high seasonal efficiency, absorption of different types of excess energy, and the recovery of energy from seawater and lakes.
- The cooling demands differ from heating in that they are more balanced between space cooling and process cooling, and dominated by the service and industries rather than the residential sector. This requires a broader understanding of how district cooling could be modelled and replicated on a spatial level.

7	**The heating and cooling sector can play an important role by integrating the increasing shares of variable renewable energy and enhance the grid flexibility.**

- HRE has an integrated approach, which aims utilise the synergies between the energy sectors through the use of heat pumps, thermal storage, combined heat and power, and industrial heat recovery.
- The use of renewable electricity and thermal storage in the heating and cooling sector can help balance the electricity grid when high levels of variable renewable energy are introduced.
- The modelling shows that an energy system with a strategically decarbonised heating and cooling sector can support a similar amount of wind capacity as a conventionally decarbonised energy system. At the same time up to 30% more of the electricity produced by the installed variable renewable energy capacity can be functionally absorbed and used in the energy system due to the enhanced flexibility in the heating and cooling sector.
- The redesign of the suggested European energy system represents a step that can enable a deeply decarbonised energy system. Extending the HRE designs to use a Smart Energy Systems approach to include transport and electrofuels could provide a pathways towards 100% renewable energy to fully decarbonise the Energy Union [16–18].

8	**Tools and methodologies that are specific to the sector are necessary in order to coherently model, analyse, and design the heating and cooling system within the energy system. This is an important part of developing pathways and strategic plans that contribute to a decarbonised energy system for the future**

- Heating and cooling is the largest sector in the European energy system, and without a decarbonisation of this sector it will not be possible to achieve the reductions in CO_2 emissions needed to prevent global temperature rises.
- This includes detailed spatial analysis in order to be able to understand the local nature of heating and cooling, which is necessary since infrastructure costs for thermal energy are higher and thermal energy sources cannot travel well without increased losses.
- An in-depth and bottom-up understanding of the built environment and industries is necessary to understand and analyse the thermal sector and thermal energy demands. This forms the base of any strategic heating and cooling development and creates an understanding of possible energy savings.
- An energy system analysis approach is necessary to ensure that a decarbonised energy system does not exist in isolation. A combination of a tool that can model energy systems as they evolve through time, and a simulation tool that can analyse the hourly variations of demands and resources (and necessary capacities) has allowed for a coherent analysis of the design and development of a heating and cooling sector that can be integrated into a wider decarbonised energy system.

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