Guidelines for the Energy System Transition

Recommendations for Policymakers Including the Local and Regional Approach, the National Aspects and the Energy Union Perspective - Heat Roadmap Europe 4

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2050

Heat Roadmap Europe

A low-carbon heating and cooling strategy

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D7.17: Final HRE guidelines for local, national and EU lead-users

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Project title:	Heat Roadmap Europe: Building the knowledge, skills, and capacity required to enable new policies and encourage new investments in the heating and cooling sector.
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This document combines three guideline reports, containing recommendations for the energy system transition, developed for policymakers at local/regional, national and European level respectively.

2050

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Preface

The findings of Heat Roadmap Europe 4 (HRE4) proves that a common and coordinated effort of all citizens for the transition to a low-carbon future in accordance with the Paris Agreement is not only possible, but cost-effective and affordable with existing technologies available on the market today. Therefore it would be an ethical, political and organisational failure, if the nations as well as regional and local governments together won't be able to ensure the change required to keep global warming significantly below 2 °C compared to the pre-industrial area.

In particular, current and planned policies should be aligned with the vision of a carbon emission free heating and cooling sector by 2050, as the sector corresponds to about 50% of the final energy demand in most European countries and has a crucial role to play in the connectivity and affordability of the entire sustainable energy system of the future. This includes energy, environmental, economic, tax and educational policies, while ensuring that the impact of any legislation on all levels does not hinder the development towards this goal, but instead encourages and accelerates the transition.

There is no sustainable alternative than a decarbonised, integrated energy system. Postponing the challenges will only make the transition organisationally more difficult and unnecessarily expensive, but will not make the challenge itself become obsolete. The emission targets required to meet the Paris Agreement must be reached sooner, rather than later in order for society to benefit from the improvements created. The scientific and technolocially neutral research initative Heat Roadmap Europe verifies how choosing the path of decarbonisation in an integrated manner will be beneficial for all governmental levels, wether if the main priorities are economic, social or environmental.

Based on the outcomes of Heat Roadmap Europe, the authors call for action from all politicians to accept their responsibility to take on their necessary role as leaders towards a fossil fuel free energy system by setting up the decisive framework which will guide their countries to an economically feasible, socially accepted and environmentally needed low-carbon future, in particular from sub-national authorities, urban planners and regional developers, to accept their responsibility and take on their necessary role as leaders towards a fossil fuel free energy system. Cities and regions can prove once more their committment and ability to be key drivers in the low-carbon transition. But more authorities need to engage to accelerate this process and scale up the impact. This is therefore the chance for local to regional decisionmakers to make their voices heard and guide their own municipalities and provinces to an economically feasible, socially accepted and environmentally needed low-carbon future.

Executive summary

The aim of the HRE4 project is to create the scientific evidence to support short-to long-term energy strategies and decision-making at local, regional, national and EU levels to accelerate and empower the transition to a low-carbon energy system by quantifying the impact of various options, particulary in the heating and cooling (H&C) sector. Specifically, the results are presented in terms of roadmaps and recommendations towards 2050 for the H&C sector of the 14 EU countries[1] that correspond up to 90% of the EU's thermal demand, but are also still applicable to other Member States.

These *Heat Roadmaps* [1] should not be considered as the exclusively definited and only viable future sustainable energy mix, but rather as solid, cost-effective and affordable pathway presenting how the benefits and synergetic opportunities – ready to be exploited today by taking an integrated approach in a redesign of the entire energy system – can lead to a feasible, decarbonised future in accordance with the Paris Agreement [2].

This report includes guidelines for local and regional policymakers on the steps of strategic energy planning, as well as key messages for them and other stakeholders to keep in mind during such processes. Together with the corresponding reports for national policymakers [3], this document provides an overview of recommendations on how to multi-laterally facilitate an energy system transition towards decarbonisation by 2050.

Key messages and requested actions from local and regional policymakers

1	**HRE4 shows how using already existing and mature technologies in the heating and cooling sector the total CO_2 emissions can be reduced by 86% compared to 1990. This verifies that decarbonisation in line with the commitments under the Paris Agreement is indeed possible and that the coupling of sectors is essential for the most cost-efficient, economically and socially feasible low-carbon energy system.**

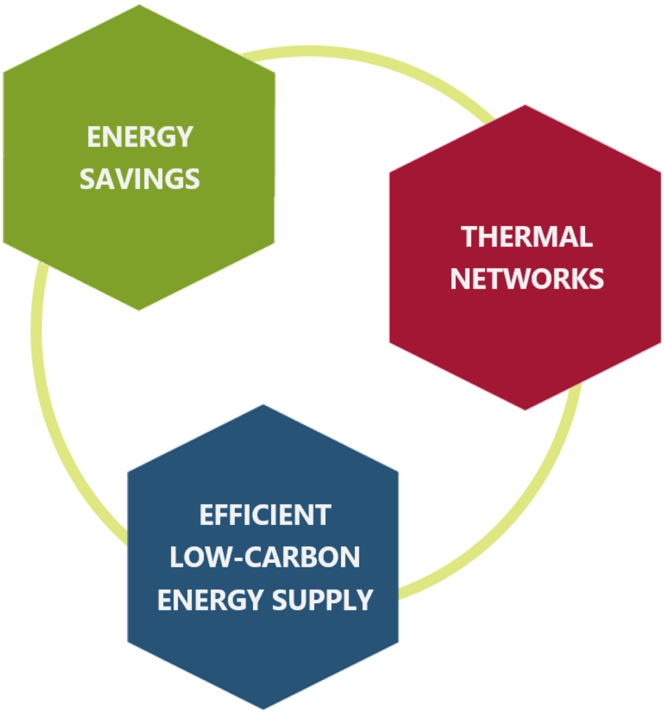
- By redesigning the heating and cooling sector the total costs of decarbonisation can be reduced by 6% annually compared to conventional methods of decarbonisation. In all future scenarios less financial resources are spent on fossil fuels and more on the infrastructure that delivers sustainable energy. This requires clear sectorial targets and policies that facilitate and

[1] Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Netherlands, Poland, Romania, Spain, Sweden and United Kingdom.

foster a fossil fuel phase-out by 2050 and a strategic redesign of the framework conditions to enable investments for an integrated, efficient and renewables-based energy system on a local, regional, national and European level.

- H&C should be politically and technically recognised as an essential component and the most cost-effective solution that allows the integration of shares of renewable energy of up to 87% and more, while supplying flexibility and ensuring the stability and security of an overall integrated sustainable energy system.

- The three main "pillars" or focus areas – energy savings, thermal networks and efficient low-carbon energy supply to enable electrification of the energy system – are especially important for policy-makers to steer the transition holistically towards a low-carbon energy system. HRE4 shows that a mix of energy savings, establishing and expanding district H&C areas, integration of low-carbon renewable and excess heat sources together with a significant electrification of the H&C sector can create synergies which are not as exploitable if one (or more) of these components is overlooked. The cross-sectoral energy planning approach of HRE reveals further points covering all three pillars, as revealed in the subsequent key messages.



2	**Energy savings are required on both the demand and supply side to cost-effectively reach decarbonisation goals. Substantial amounts of cost-effective energy savings are ready to be exploited at local and regional scales, and these are key for the successful decarbonisation of the whole energy system.**

- Substantial amounts of cost-effective energy savings are ready to be exploited and these are key for the decarbonisation of the energy system. Related national policies need to reflect the higher, but feasible energy saving targets – typically at least 30% for space heating in buildings. Consequently, also financial incentives should support this higher ambition and enable the exploitation of the potential in the residential, industry and service sector alike.

- Despite common misconceptions, introducing energy efficiency measures does not necessarily make district heating unfeasible, neither for existing nor new networks. In fact, energy efficient buildings can effectively shave expensive peaks and improve the performance and feasibility of the entire (new or existing) district energy network. Respectively, policies and financial programmes should support the efficiency for district heating systems and the integration of small- to large-scale excess heat sources, as HRE4 has identified an excess heat potential in the electricity production alone corresponding to more than the heat demand of Europe's entire building stock today.

ENERGY SAVINGS

- Where district heating is not the most cost-effective solution, mainly in rural areas, energy retrofitting of buildings should consider combining such measures with the replacement of boilers by individual heat pumps. The most efficient heat pump systems are those found in new buildings and in those that have undergone deep renovation. On top of the added value in energetic savings, such efforts will also improve the comfort level for the buildings' inhabitants. Respectively, policies and financial programmes should support the massive roll-out of heat pumps in rural areas.

3	**HRE4 identifies suggested balances between decentralised heating and cooling systems being the most cost-effective decarbonisation option in rural areas, and thermal networks in dense urban areas. Those individual supplies should mainly be based on heat pumps as they can enable the flexible integration of renewables without using scarce bioenergy resources.**

- Electrical heat pumps should be implemented to a much greater extent and up to an overall market share of about half, specifically:
  - in rural areas, where individual heat pumps should replace fossil fuel boilers;
  - in urban areas, where large-scale heat pumps should make the use of low-temperature renewable and excess heat sources and replace a fossil-based district heating supply relying on boilers and/or CHP.

- HRE has identified an excess heat potential corresponding to more than the heat demand in all of Europe's buildings. Small to large-scale excess heat sources could cover significant shares of the district heat production. 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.

EFFICIENT LOW-CARBON ENERGY SUPPLY

4	**Excess heat recovery is key to an efficient and resilient thermal sector, and has the potential to support local industries, economies and employment. The identified quantities of excess heat across Europe are with 2.4 PWh/y (8.7 EJ/y) immense and thus need to be addressed to enable integration into the energy system.**

- 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 HRE 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.

- Several renewable energy technologies benefit – or even require – large-scale installations in order to be economically viable. To exploit the full potential of large-scale and capital-intensive technologies like deep geothermal energy and solar heating, a district heating system needs to be present since for these technologies, economy of scale is key. The future energy mix will be much more diverse than in the past. A thermal grid in place will be able to integrate small- to large-scale renewable and excess heat sources in the most cost-effective way.

THERMAL NETWORKS

- Increasing the share of district H&C, in combination with cheap thermal storages, heat pumps and CHP, can stabilise the electricity grid, thus facilitating the integration of renewables when introducing more fluctuating sources such as wind and solar. Therefore, the proposed solutions *enable* significant electrification of the H&C sector rather than excluding it.

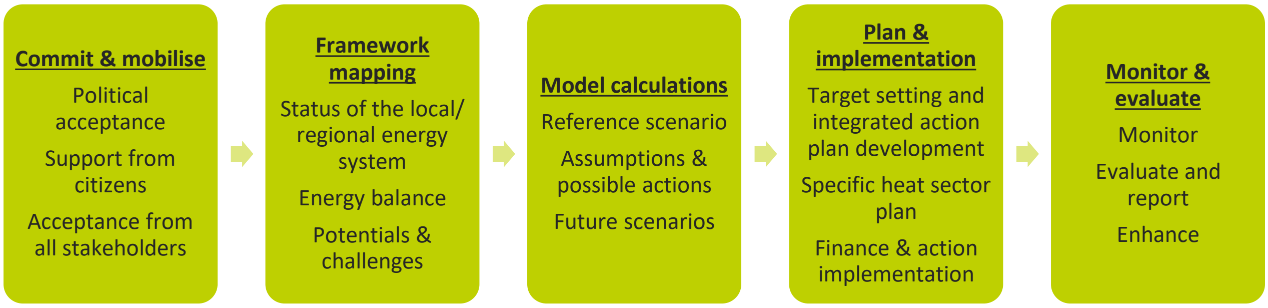
- By means of detailed spatial analyses, HRE shows that on average approximately half of each country's total building heat demand in the residential and service sectors is located in high density areas – though of course there are some countries with higher or lower shares, depending largely on their level of urbanisation. Combining cost calculations with the overall system modelling reveals the scientific evidence supporting the conclusion that more than half of European heat demand in countries can cost-effectively be supplied with district heating in 2050. Furthermore, the spatial components of HRE, in particular its Pan-European Thermal Atlas (*Peta*), which is a valuable online tool freely available to local and regional planners can even pinpoint *where* these new or expanded networks can be located.

5	**HRE4 proves that an integrated approach of all energy sectors delivers the most cost-effective decarbonisation. Consequently, stakeholders of all sectors should cooperate much more intensively, develop business models jointly and implement integrated solutions. Furthermore, local and regional authorities should establish an ambitious framework through their climate and energy targets, provide the platform and facilitate the stakeholder engagement.**

Local and regional authorities may not be directly responsible for most of the emissions in their territory or have the resources or the mandate to directly control them. However, they have the decisive coordination power and access to all actors within a defined area. Engaging the most relevant stakeholder groups in the planning process is particularly crucial at a local to regional level for the successful implementation of any decarbonisation target. The (early) involvement in planning exercises of all those actors who know best the municipal to regional conditions will reveal the beneficial opportunities for their engagement and increase their commitment and acceptance towards supporting its implementation. Key stakeholder groups could cover the following:

- Representatives (technical staff and policymakers) from the local/regional authority, its related departments and pertinent agencies of the municipality/region.
- Local stakeholder organisations (e.g. industry associations, housing companies, consumer/prosumer groups, trade unions, NGOs, etc.)
- Energy suppliers (e.g. electricity, district energy and gas companies) and transport companies.
- Technical partners (e.g. relevant technology manufacturers/installers, craftmenetc.).
- Scientific partners (e.g. universities, applied research institutions etc.).
- Financial sector (e.g. local and national banks, investors, foundations, cooperations etc.).

A general process of strategic energy planning with an emphasis on stakeholder engagement is summarised below. It includes an early stakeholder involvement ("Commit & mobilise"), preparation of stakeholder-specific information ("Framework mapping"), engagement (also) to verify assumptions for the scenario development – ("Model calculations") and writing, approving, mobilising finance and implementing a common strategic plan ("Plan & implementation"), such as a SECAP (Sustainable Energy and Climate Action Plan), integrated Climate Protection Concepts (iCPC) or REAP (Regional Energy Action Plan), followed by a monitoring and participatory evaluation process together with involved parties ("Monitor & Evaluate"). The steps within the integrated energy management cycle are indicated below:



In turn, the benefits will cover all levels of (also) the local/regional community. The arguments for supporting the energy transition include the following:

- Lowering the uncertainty of future fuel prices thereby ensuring a more stable framework for both energy producing companies, consumers on different levels (households, services and industry) as well as public investors.
- Opening the market for locally based heat sources can increase the security of supply and make the countries more resilient to geopolitical changes.
- Creation of local jobs – both directly in the energy system and in terms of strengthening the competitiveness of industries nationally as well as internationally.
- Reducing the overall energy system cost compared to alternative decarbonisation scenarios.
- Improving living standards by ensuring better air quality (locally) while also reducing emissions (globally).

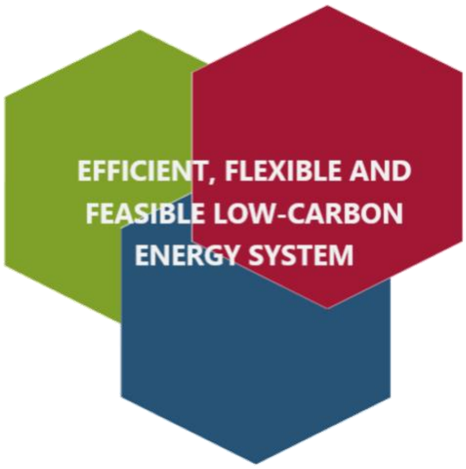
Long-term targets and aligned policies must all facilitate the energy transision towards a sustainable low-carbon society. Integrated knowledge, planning tools, business tools, innovative collaborations and incentives are needed since in most cases the barriers faced are political and regulatory rather than technical.

- A horizontal integration of these targets (into all sectors such as electricity, heating and cooling, transport etc. incl. their subsectors) combined with vertical integration of targets (throughout governmental levels) should be applied. Besides this, it is important to ensure not only targets, but actual policy implementation and realisation, with regular reporting and evaluation cycles on progress and impact.

7	**All local and regional sectors should be included in a combined decarbonisation strategy. Long-term targets for combined efforts of all these sectors must include an ambition level corresponding to the local/regional plans, as well as the necessary decarbonisation rate according to the Paris Agreement.**

- More support is also needed to ensure implementation and higher energy saving targets for both deeper renovation of the existing building stock and investments in industry. Stronger price signals (e.g. energy obligation schemes or taxes), together with information-availability (e.g. smart meters), communication (e.g. "nudging"), as well as the proper education of craftsmen and citizens, will be crucial drivers.

- National policies should incentivise flexible interaction for prosumers to help balance electricity grids and not maximise self-consumption which in some cases will be counterproductive for the overall energy system.



- Regional/local analyses of exisiting options for various consumer types and locations can help identify where there are needs for financial support and necessary interventions to overcome other types of barriers experienced in the local/regional context as well.

8	**Mandatory local and regional integrated energy plans should be aligned with national energy planning, implementation and reporting. Consequently, to maximise their combined impact over time and between energy sectors, sub-national authorities should demand resources in case there are none or these are insufficient to improve the quality and interlinkages of all governmental levels' efforts.**

- The recommended solutions should be promoted in terms of the following (combined) efforts to remove barriers:
    - Establishing continuous energy planning at local and regional levels, including regular evaluation of their status vs. targets to improve the foundation for local/regional authorities and other key stakeholders to make decisions and

implement policies, by analysing various opportunities pathways towards decarbonisation.

- Ensuring a transparent process of any energy transition activities which enables effective dialogue with affected citizens, consumers and other relevant civil society active within the community.
- Gathering additional relevant stakeholders, such as local industries and services (e.g. in the financial sector) to include their business interests in the development of a common decarbonisation strategy.
- Raising general awareness of targets and plans while formulating a common narrative for all citizens that the decarbonisation of our society is something we can and must realise together, something we and the environment around us can prosper from, and – with sufficiently ambitious targets – something we can be proud of.
- Setting up frameworks to improve qualifications and number of skilled professionals.
- Supplying easy to access and low-cost financing schemes for decarbonisation investments.
- Removing administrative barriers for stakeholders.
- Ensuring certainty (predictability) for investors, avoiding "stop-and-go" measures.
- Improving feasibility directly or indirectly (e.g. support/taxation).
- Aligning local and regional policies with each other (also to be in line with national and EU targets) to work together towards the same end-goal.

HRE resources available to support the energy transition

The HRE provides a range of new information to empower the decision processes and improve the foundation for political and technical choices on the most cost-effective and affordable pathways towards a decarbonised energy system. These include among others, detailed profiling of the present H&C demands by subsector, cost-curves for reducing the H&C demand in buildings and industries[2], and complete energy system model datasets which users can modify to investigate for themselves the likely impacts of alternative scenarios. HRE has the aim provide a transparent approach to democratise the debate on how future energy systems can and should be structured.

Guidelines for the energy system transition with a *European* and *national* approach respectively are also available, and may be useful to get an insight into variations of these recommendations from either perspective. All project reports are available at the HRE website. Two outcomes stand out in

[2] The cost-curves shows the cost of reducing the demand depending on how ambitious the target is, i.e. what are the cost of measures, when "low-hanging fruits" have been exploited and further savings are required.

particular as major results building upon the knowledge gathered from the other HRE analyses: the Pan-European Thermal Atlas (version 4) and the energy system scenarios of the 14 HRE countries.

- The Pan-European Thermal Atlas (*Peta*) represents a publicly available online interactive portal to support planners, investors and policymakers by presenting and quantifying H&C possibilities (geo)graphically for all 14 HRE countries. The following features are included:
    - Heating and cooling demand respectively on a hectare level.
    - Renewable heat resource potentials such as geothermal, solar district heating and biomass.
    - Pinpointed potential excess heat sources from conventional sources (e.g. waste incineration, power plants and industrial processes), as well as lower-grade temperatures (e.g. from wastewater treatment or metro stations.
    - Existing and prospective district heating areas incl. cost of establishing networks and indication of the recommended shares of district heating.
    - Heat synergy regions highlighting the overlap of demands and identified excess heat – indicated as an "excess heat ratio" i.e. the ratio between excess heat and heat demand within a given region.

- The development and findings of the modelled HRE 2050 decarbonisation scenarios, includes methodologies used, different energy demands, different energy supply technologies, their role within the wider energy system and how these compare with alternatives [1]. Though these reports portray data at a national level, they nonetheless provide valuable insights with certain trends being similar, and ramifications affecting the regional and local levels, too. These country-specific results, such as the recommended balance between energy savings and district heating, are included in the 14 individual country reports. Collectively, these 1+14 reports hold the title: *Heat Roadmap Europe – Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps*.

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1. Introduction

In Europe, there is a clear, long-term objective to decarbonise the energy system. The Heat Roadmap Europe 4 (HRE4) project, co-funded by the European Union (EU), seeks to enable new policies and prepare the ground for new investments by creating more certainty in relation to the changes that are required.

HRE4 provides new capacity and skills for lead-users in the heating and cooling (H&C) sector, including policymakers, industry, and researchers at local, national, and EU levels. This is done by developing the data, tools, methodologies, and results necessary to quantify the impact of implementing more energy efficient measures on both the demand and supply side of the sector.

The results of HRE4 show how a complete decarbonisation of the European heating and cooling sector is technically feasible, economically viable, and can be achieved with proven technologies already used today. The "Heat Roadmaps" representing decarbonisation pathways for 14 EU countries[3] towards 2050 (covering approx. 90% of the EU heat demand) show how this can be done, and all the available HRE outcomes such as guidelines and interactive tools can help stakeholders facilitate this transition.

This report emcompasses *key messages and recommendations* to facilitate the process towards a cost-effective decarbonisation of the heating and cooling sector targeting policymakers at municipal, city and regional levels – oftentimes the first two are jointly referred to as the "local level".

> This report, mainly focusing on local/regional level recommendation, is complemented by similar guidelines addressing the national level, including recommendations from a broader energy system perspective, which may be of interest to the reader.
>
> *Guidelines for the Energy System Transition – The National Aspects of the HRE 2050 Scenario and Associated Policy Recommendations* [3]
>
> The development and findings of the HRE scenarios, including methodologies used, different energy demands, different energy supply technologies, their role within the wider energy system and how these compare with alternatives are described in the report:
>
> *Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps* [1]

[3] The HRE4 project especially focuses on those fourteen EU countries with the highest H&C demands: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Spain, Sweden and the United Kingdom.

By profiling the energy demands it becomes evident how important the H&C sector is when aiming for a decarbonised energy system. H&C accounts for around 50% of the European final energy demand.

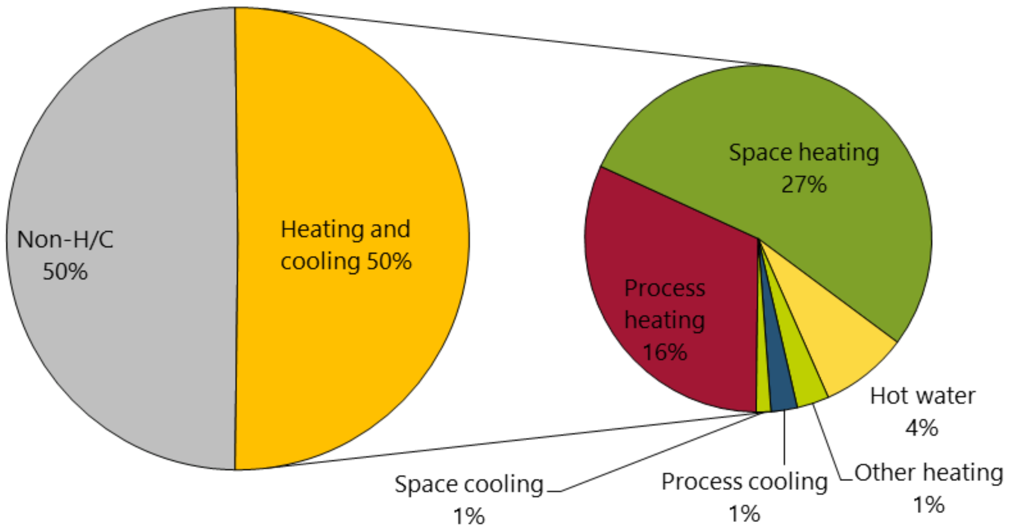

Figure 1. Heating and cooling demand in 2015 in the EU28 by end-use compared to total final energy demand [4].

2. Strategic energy planning

2.1. Overcoming barriers

To some degree, the feasibility of converting from the present fossil-based thermal energy system to a low-carbon alternative does not always seem to have enough incentives (if even positive at all) to realise the transition in practice. Nonetheless, when looking below the surface, the benefits to decarbonisation, including its economic advantages, become more apparent and make it clearer why both natural gas boilers used for space heating and inefficient direct-electric heating are strongly recommended to be phased out.

At a local/regional level, a potential starting point for the above-mentioned example could be to ban the installation of fossil-based H&C supplies in new buildings, and at the same time phase them out in existing buildings. This measure could go hand in hand with support for the shift to alternatives (e.g. financial support for the installation of a HP). In order to minimise the impact of those who have grown dependent on fossil fuels and their associated technologies, economic incentives to shift to alternatives could be implemented simultaneously in order to avoid any increased expenditures for the consumers.

A combination of regional and local strategic energy planning, all aligned to national strategies, is needed to analyse which options make the most sense for various consumer types and locations in cities and provinces. In such a way, identification of specific needs for financial support and where there are needs for help to overcome other barriers.

1	**Mandatory local and regional integrated energy plans should be aligned with national energy planning, implementation and reporting. Consequently, to maximise their combined impact over time and between energy sectors, sub-national authorities should demand resources in case there are none or these are insufficient to improve the quality and interlinkages of all governmental levels' efforts.**

In general, (inter)national fuel prices (including carbon taxation) applied as pure market mechanisms cannot be entrusted with the task of ensuring the energy transition alone, but rather function more effectively when combined with other mechanisms. Other than improving the feasibility of low-carbon solutions (in)directly (e.g. support/taxation) – possibly by applying a local/regional component to emission taxation – and supplying access to affordable financing schemes, many other, non-financial barriers must also be overcome at a local/regional level, for example by means of the following solutions:

- Developing strategic energy planning with the target of local/regional decarbonisation. This should include regular (re-)evaluation of its status, to improve the foundation for decisions and policies, while also analysing the development and identify various opportunities and alternative pathways.
- Aligning local with regional policies to work together towards the same decarbonisation end-goal as national and EU ones should have.
- Removing unnecessary administrative burdens.
- Setting up frameworks to improve the qualifications and quantity of skilled professionals working in related fields within the city/province.
- Formulating a common decarbonisation narrative to help raise awareness among local/regional citizens that the energy transition is something to be realised together, that all (and even the environment) can prosper from, and – with sufficiently ambitious targets – is a goal to be proud of and to which their community can meaningfully contribute.
- Providing certainty and predictability for investors in these sectors, avoiding "stop-and-go" measures, so that they can feel secure in providing funds to cost-effective local/regional initiatives.

2.2. Engaging stakeholders

Strategic energy and climate action planning (SECAP)[4] is a stakeholder-centred approach promoted internationally (e.g. by the Covenant of Mayors). Such an approach is generally recommended for creating long-term and sustainable transitions towards efficient/renewable energy systems, both locally and regionally (as well as taking into account their linkages to other types of climate mitigation and adaptation).

Stakeholder involvement in the planning process is crucial for the successful implementation of actions at a local/regional scale. The involvement of key actors into planning will create a sense of ownership to the actions, thereby increasing their initial acceptance and further commitment towards supporting its implementation.

The stakeholder groups could cover the following:

- Representatives (technical staff and policymakers) from the local/regional authority, its related departments and pertinent agencies of the municipality/region.
- Local stakeholder organisations (e.g. industry associations, housing companies, consumer/prosumer groups, trade unions, NGOs, etc.)

[4] Formerly, SEAPs (Sustainable Energy Action Plan) were internationally often used for municipalities. Meanwhile, the REAP (Regional Energy Action Plan) methodology is still a commonly applied standard.

- Energy suppliers (e.g. electricity, district energy and gas companies) and transport companies.
- Technical partners (e.g. relevant technology manufacturers/installers, craftmenetc.).
- Scientific partners (e.g. universities, applied research institutions etc.).
- Financial sector (e.g. local and national banks, investors, foundations, cooperations etc.).

In some cases, a more formal consortium could be established as a separate entity/project to handle the processes, keep track of the development, organise relevant meetings, possibly even raise funding, update details of the strategy along the way, etc. Expenses for such organisations could be financed (partially) by the municipality/province, through certain grants/projects and/or maybe even sponsored by relevant local/regional companies. Examples of such formal entities include the following in Denmark:

- *ProjectZero* in Sønderborg[5]. In this case the energy plan made towards a 2029 horizon includes representatives from the municipality, DH company, DSO, TSO, consulting engineers and energy-related industries.
- *EnergiPåTværs*[6] / *Gate21* in the Capital Region of Denmark + Region Zealand have developed a joint energy strategy based on partners from municipalities and energy-supply companies. The project is financed by the Capital Region of Denmark and the energy-supply companies, though municipalities supply their own staff time.
- *Energirådet*[7] (The Energy Council) in the Ringkøbing Skjern Municipality, Denmark. The municipality argues that: "An area that imports energy and sends large sums of money out of the area is worse off than an area like ours, producing its own RE and thereby increasing local cash flows benefiting citizens and businesses."

2.3. The process of planning for an integrated energy system

There are three major phases – analyse, act and accelerate - in which stakeholder involvement is not only beneficial, but often a prerequisite for a successful decarbonisation process of the energy infrastructure[8]. The first phase is to analyse the framework conditions, develop a common long-term energy vision for the municipality/region, and identify priorities. This involves the perspectives and contributions from numerous interest groups and stakeholders. Local and regional authorities are in

[5] More information also available in English at www.projectzero.dk.
[6] Danish website: www.energipåtværs.dk. Energi På Tværs can be translated as "Energy Across", which presumably refers to the collaboration across municipal borders, stakeholder groups, etc.
[7] Danish website: www.energi2020.dk.
[8] Based on ICLEI's GreenClimateCities methodology used by local and regional governments around the world for climate mitigation and adaptation.

a suitable position to provide the platform and steer a stakeholder dialogue on a local-specific, integrated energy strategy. Energy strategies co-created in such a way often lead to concrete stipulations even in broader urban or rural development plans, which (ideally) take into account all the key interests and needs of local and regional, public, private, scientific and civic actors.

This phases into the second major step of the cyclic management process, the formulation of a SECAP, iCPC or REAP, the mobilisation of finance and the implementation of the short-term measures, which contribute to achieving the long-term vision. This involves a thorough and continuous collaboration and decision-making from key stakeholders in order to achieve a comprehensive impact within and across sectors.

The last major phase is finalising the process cycle and prepares the initiation of a new one. A participatory as well as technical in-depth evaluation, based on the monitored Key Performance Indicators, often reveals that a repetition of the whole process would be beneficial and needed to achieve the long-term vision and targets. By entering a new cycle, new developments can be reflected in the vision, plans and prioritised measures. The whole integrated assess-plan-implement-evaluate cycle may be updated and repeated as often or frequently as deemed necessary by the city or region to achieve their targets.

Elements in such a planning process could include the following points of stakeholder involvement:

- Kick-off workshop: where local/regional policymakers and other staff have an important role in convincing other stakeholder groups about the ambitions and necessity of a SECAP/iCPC/REAP development.

- Scenario workshop: The most important stakeholders discuss possible future framework scenarios for a transition to a decarbonized municipality/region. The idea is to define the most important assumptions and identify challenges and opportunities under different socio-economic development scenarios.

- Establishment of a stakeholder platform/alliance with thematic action groups
  - The creation of thematic working groups is an approach that has been proven to beneficial for many planning processes, by allowing stakeholders to contribute to covering those areas where they have the most expertise/interest (e.g. energy efficiency in buildings/industries, district energy systems, decentralised H&C, electricity/biogas production, etc.).
  - It may prove useful to generate materials (e.g. handouts) which allow other stakeholders to understand better the specific topics, their (historical) development in the local/regional context, current status, scenarios depicting different decarbonisation pathways and their expected consequences.

- Generally, each working group first provides inputs about long- and short-term objectives within their implementation area, which can be compared to the overall decarbonisation goal of the city/region through scenario calculations.
- Later, each group revises its own objectives, if necessary, and clarifies key responsibilities which will greatly facilitate a successful implementation of actions.
- Often SMART[9] indicators are used, meaning in a practical sense that it is very clear for each proposed measure: who is responsible, when it will be done/due, precisely where, who should benefit/be engaged, how it is funded, how implementation takes place, which monitoring will be in place as well as who is evaluating and reporting towards whom.

These are some recommended elements that support an integrated energy management processes leading to the creation of a common plan, broader political discussions and public acceptance.

One of the main goals of the co-creation of a common vision and plan is that, by its very nature as a collective process, a common platform for a transformative dialogue is established for all relevant interest and stakeholder groups. This contributes to build up a strong communal awareness and strengthens public acceptance of climate and energy decisions that may also be controversially discussed.

Such integrated plans can also serve as a starting point for more detailed sub-plans and actions, which can specify additional thematic objectives and provide a practical basis for decision-making. This may include very relevant topics such as a specific heat plan or an analysis of surplus industrial heat. An integrated energy plan should also analyse and highlight the synergies with other public objectives and strategies in the fields like social welfare, economic growth or smart specialisations.

Below is an example of the major elements laid out as a cyclical process with five steps: Kick-off, mapping, model calculations and plan and implementation.

[9] There are many mnemonic variations of SMART, but quite commonly it stands for: Specific, Measurable, Achievable/Assignable, Relevant/Realistic and Time-bound.

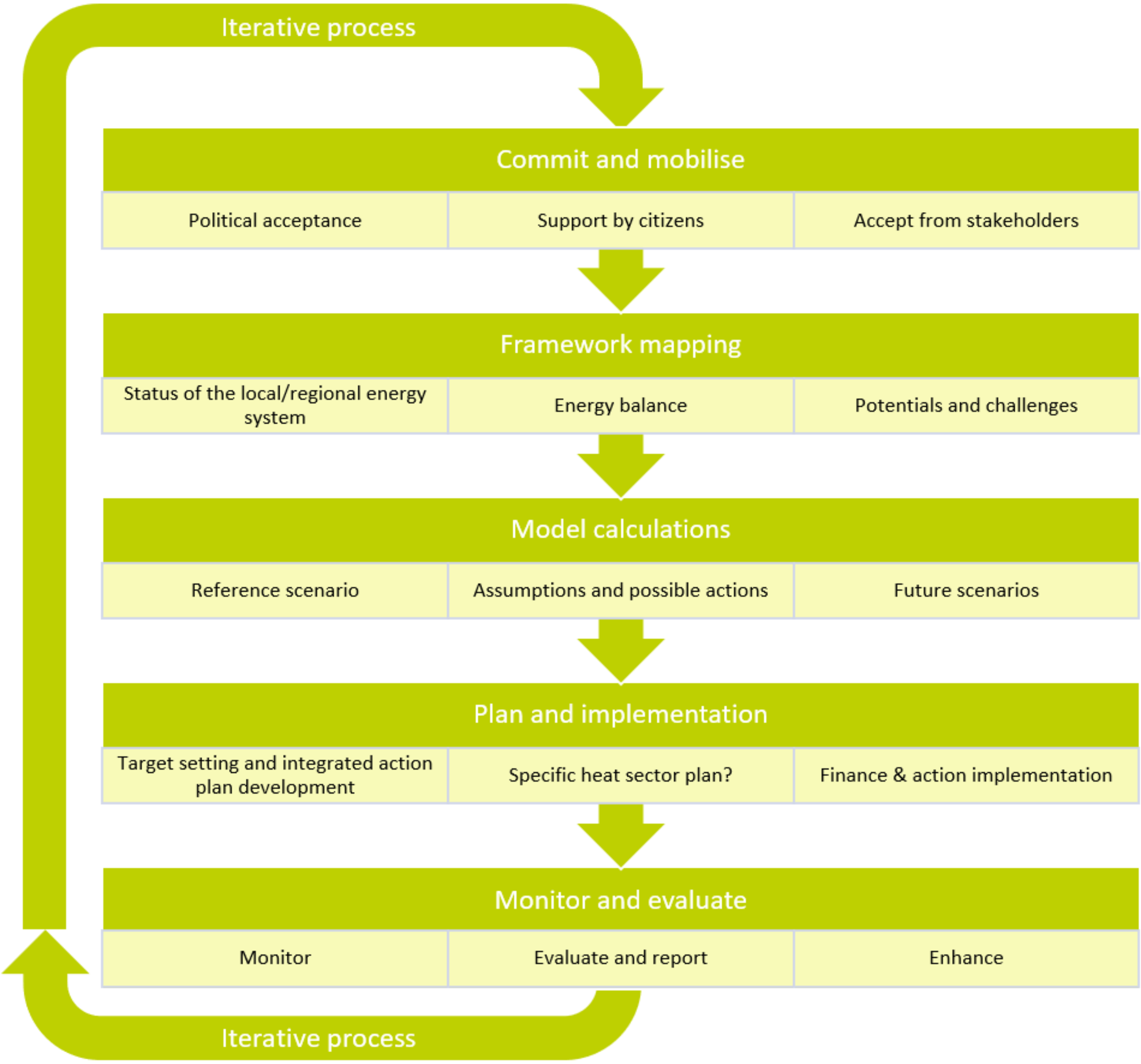

Figure 2. Process of integrated energy planning from early stakeholder involvement ("Commit & mobilise"), preparation of baseline and informative materials ("Framework mapping"), scenario development ("Model calculations"), creation of a common, integrated plan ("Plan and implementation") followed by a monitoring and participatory evaluation process ("Monitor & Evaluate").

2.4. Three main pillars to decarbonise the H&C sector

The HRE4 project identifies three main pillars, which are especially critical to address in order to facilitate the transition towards a future low-carbon H&C system. These are closely linked. Hence, in many cases the recommendations cover more than one of them. Figure 3 below sketches the pillars as well as interconnections between them. One example for each of these pillars (hexagons in Figure 3) is district heating (DH) in urban areas – fed by renewable energy (RE) or excess energy, building renovations to improve energy efficiency (EE) and heat pumps (HP) for space heating and domestic hot water in rural areas.

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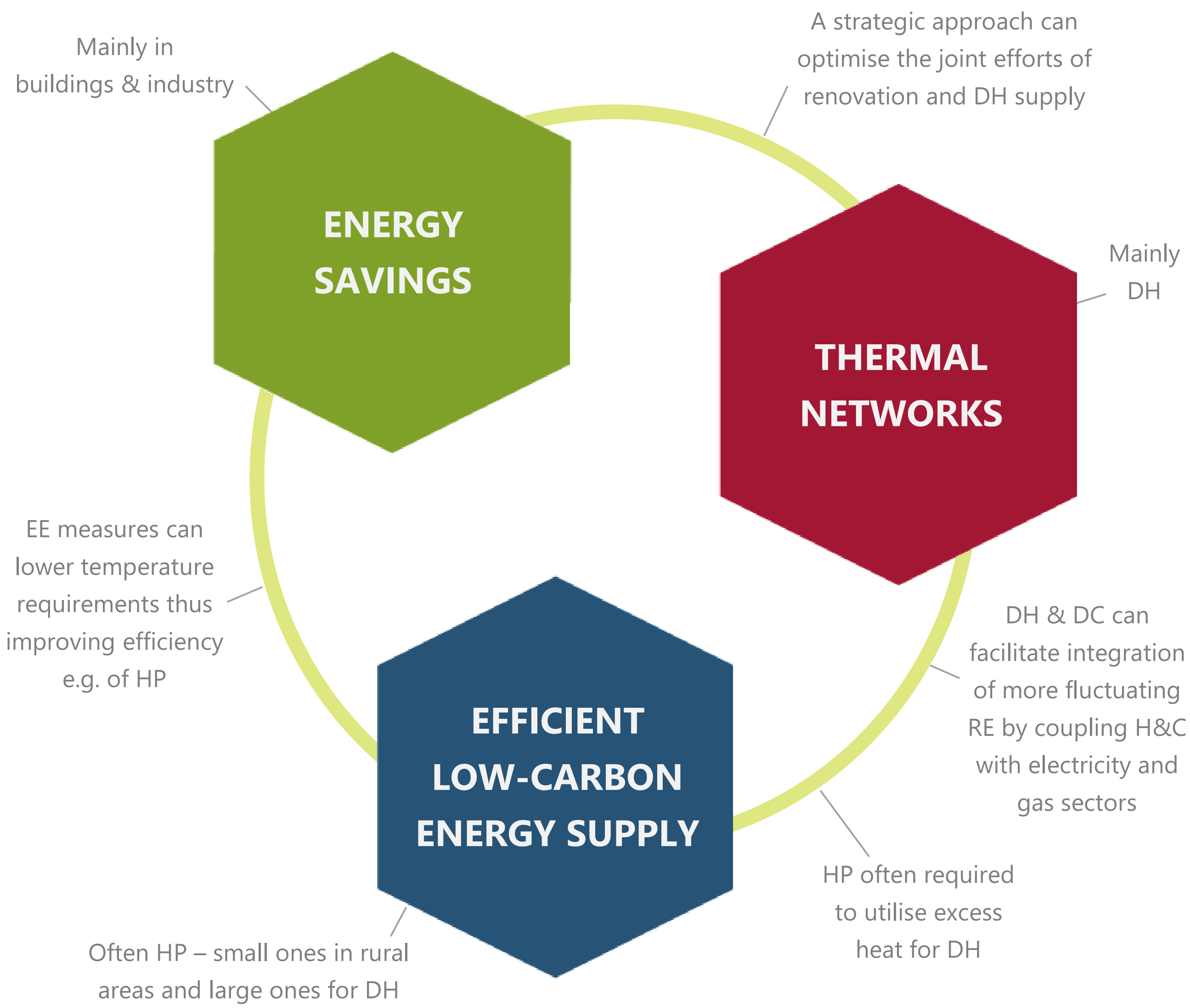

Figure 3. The three HRE "pillars" including examples of linkages between them.

The "Heat Roadmaps" of each of the 14 countries are commonly referred to as the HRE 2050 scenario. These do not aim to reject other optional pathways but rather to show possibilities incl. synergy effects when moving to sustainable future where intelligent choices today will reduce future costs and speed up "the energy transition". One aim is to democratise the debate on how future energy systems can and should be structured.

Detailed energy system modelling has made it possible to consider the connections between demands and supplies for heating, cooling, electricity and transport to optimise the overall system. HRE 2050 shows a 86% decrease in CO_2 levels compared to 1990 while introducing a RE share of 87% of the primary energy supply[10]. In this context it should be mentioned that HRE 2050 does not hinder but rather *enables* the possibility of even further implementation of renewables.

2	**The holistic HRE approach considering jointly electricity, heating, cooling and transport reveals synergies between (and within) these different sectors and shows that decarbonisation is indeed possible with existing mature and market-ready technologies.**

The cross-sectoral energy planning approach of HRE reveals the following:

- Increasing the share of district heating and cooling, including cheap thermal storages, helps to stabilise the electricity grid when introducing more (non-dispatchable) variable renewable energy (VRE).
- Substantial energy savings in different sub-sectors are possible, feasible and recommendable for each of the targeted countries.
- An integrated approach considering the energy demands for transport, electricity, heating and cooling as a whole can release larger savings as a result of synergies.
- Even without including the significant health-related and climate change-related costs [5,6], decarbonisation can be achieved at lower costs than "conventional decarbonisation"[11] only, while reaching even greater CO_2 reductions. However, it requires a massive changeover of the current system design and framework conditions to support it.

These results should subsequently encourage policymakers to choose their own prioritisation – economic feasibility, environmental impact, quality of life, etc. – but nonetheless it is expected to

[10] Since HRE4 focus on H&C though the entire energy system is considered, there is a small share of remaining fossil fuels – primarily in transport, industry and flexible CHP.
[11] The HRE 2050 scenario (one per country) can be compared with the 2015 situation, a baseline development towards 2050 and the "Conventionally Decarbonised scenario" (CD 2050). CD 2050 represents an energy system targeting 80% reduction in EU CO_2 levels compared to 1990 levels and assumes encouragement of RE but without the same focus on savings and a redesigned H&C sector as in HRE 2050, cf. [1].

reach the same conclusion regardless of priorities: that remains no reason to delay pushing this development forward.

Just like the integrated energy system approach covers the challenges and opportunities in a holistic manner, the points raised in the following text should not be considered applicable only to a single pillar, but rather something that builds upon each of them, reinforced by the interconnections.

A key point derived from the results of HRE is that the presented decarbonisation roadmaps require *combined* efforts of energy efficiency measures, an efficient low-carbon H&C supply with increased electrification and a significant deployment of more district H&C. These synergetic effects will not be realised to the full extent possible if policymakers fail to take the potentials of all pillars and their linkages into account.

3. Energy savings

3.1. Feasibility of energy savings

Substantial amounts of cost-effective energy savings have been identified and are ready to be exploited at a local and regional scale, being key for the decarbonisation of energy systems in towns and provinces. When targeting energy savings objectives, it should be remembered that the end-goal should not be simply maximising the savings on their own, but rather ultimately the emission reductions. Therefore, the extent of savings targeted should be balanced with other low-carbon alternatives, such as a RE-based supply, as illustrated in Figure 4.

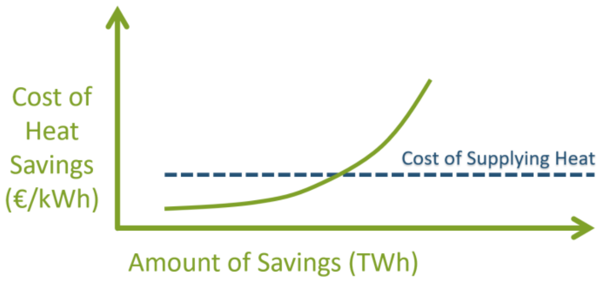

Figure 4. Illustration of the principle that savings should be realised to an extent until it becomes more relevant to apply a decarbonised heat supply.

3	**Energy efficiency is required on both the demand and supply side to achieve cost-effective decarbonisation. Local governments need to address the combination of energy efficiency measures with the decarbonisation of the energy supply.**

To engage consumers, it is recommended as a first step to get a full overview of existing support schemes at all levels, which could be applied for energy retrofitting at the scale of city districts, whole towns, wider regions, etc. If any subsidies have a strong potential for such activities, this information should be clearly presented in a way that can be effectively directed towards the target groups (e.g. private homeowners or local businesses).

Homeowners' potential benefits from energy savings should be highlighted (i.e. addressing the question "what's in it for me?") to help ensure acceptance. This could include the following:

- Increasing the property value (use and refer to local/regional examples if possible).
- Lowering costs for H&C.

- Increasing comfort options.
- Improving reputation (as a role model) within the community reducing CO_2 emissions.

Furthermore, favourable financing and installation options for homeowners and local/regional businesses could be created by facilitating wider-scale initiatives. For example, by initiating dialogues with local/regional stakeholders:

- Banks and other investors to develop other financing options which can be applied in that context.
- Relevant craftsmen, electricians or other installation contractors/companies based in your area to promote their services.

For publicly-owned buildings, a key approach to allocate public budgets towards energy savings could be to highlight the longer-term cost-savings expected, as well as the additional socially-beneficial outcomes from deep energy renovations and an improved indoor climate, such as: a better learning environment in schools, healthier elder homes, a more comfortable working environment in public office buildings, etc.

Regular follow-up evaluations on the progress and impact on local to national legislation and support schemes should be implemented to ensure that the expected targets of the municipality or province are still effectively met.

Considering the fact that once investments have already been made for the so-called "low-hanging fruit" of energy efficiency renovations, the remaining savings potentials in a city/region will usually require higher investment costs, and therefore need to be made even more attractive for end-users to ensure their realisation. Supporting the even deeper thermal renovation of buildings that will anyway undergo a more shallow level of renovation could be an important means of avoiding such missed opportunities.

Stronger price signals (e.g. energy obligation schemes) can prove to be crucial drivers to ensure the realisation of those savings needed to reach local/regional decarbonisation targets. Additional factors which cities and provinces ought to suitably address, and support, include better information-availability (e.g. smart meters), communication approaches (e.g. "nudging" consumers) and the proper education of both the craftsmen providing concrete energy efficiency services and the homeowners/businesses where it is applied.

3.2. Including industries in the decarbonisation process

The extent of attainable H&C savings within a town's/region's industry tends to be more limited than in residential or service buildings. On the one hand, the temperature levels of many industrial processes cannot be altered much. On the other hand, many of these companies often have already implemented those savings measures deemed most profitable to them (at least the "low-hanging fruit").

Nonetheless, remaining energy efficiency measures with relatively small investment costs compared to the reference technology have still been identified. Therefore, local/regional efficiency requirements and financial incentives should reflect the highly cost-effective potential for energy savings still to be found in industrial and service sectors from a socio-economic perspective.

Working towards a circular economy approach could result in an even larger share of overall savings within the whole city/province by recycling resources, both in terms of materials and energy flows. Therefore, building on the process of strategic energy planning described in 2.1 dialogues should be initiated with local/regional industries in order to understand specific industries' energy consumption needs, barriers and limitations. All of this could be the key to unlock new opportunities for them achieve (further) savings, which of course in turn should translate into clear benefits (economic, health, environmental etc.) for the wider community.

In fact, the increasing societal focus towards environmentally-aware industries can offer local/regional authorities another entry-point as an opportunity to promote those industries due to their interest in energy savings by creating a local system [7] for highlighting and communicating the energy savings achieved in these industries. This could be through for example, badges or annual awards for businesses and industries committed to supporting/implementing their own energy-saving achievements.

Figure 5. Badge for shops in the Sonderborg area committed to reduce energy consumption. [7]

Figure 6. Diplomas for different energy savings levels from companies in the Sonderborg area. [7]

Furthermore, it may be worth noting that stricter efficiency requirements related to buildings and industrial processes can prove to be advantageous, since sustainability requirements across *all* sectors tend to stimulate additional improved technologies and products in other sectors as well, thereby increasing their competitiveness (locally, regionally, nationally and globally) in the long run.

Indeed, more and more frequently, customers are demanding more sustainable technologies and production chains for the goods and services they purchase. From the perspective of a local/regional authority, general support of these transitions can be useful, but it tends to be even more effective if the authority itself adopts more sustainable procurement procedures (e.g. purchasing only RE-based energy or using only low-carbon mobility options) to drive the market.

3.3. Energy savings efforts combined with district energy/individual supply

Introducing energy efficiency measures does not necessarily make district heating and cooling unfeasible, whether for existing or new networks. In fact, energy efficient buildings can effectively shave peaks and improve the performance and feasibility of the entire (new or existing) district energy network. With new or renovated energy efficient buildings, a new network can be designed for low temperatures whereas an existing network peak demand can be reduced, while/or additional consumers can be connected to the same grid. In district heating, the relatively small number of hours per year with peak demand are often the most expensive – in terms of OPEX and/or CAPEX (since the capacity required may have few full-load hours per year).

4	**Energy efficiency measures in buildings and district energy can be complementary solutions, not in opposition to each other as commonly thought.**

Not only are low-temperature district heating networks in general more efficient, but they are also better equipped to take advantage of a wider variety of heat source input options – e.g. low-temperature excess heat with or without the need of applying heat pumps.

Similar to these synergy effects, the example of replacing a boiler with a heat pump shows that a new heat supply system can benefit from energy efficiency measures. Heat pumps run very efficiently in new buildings and in those that have undergone deep renovation (which in some cases can even be a requisite to make the building "heat pump ready"). In general, heat pumps run most efficient (expressed as the COP/SCOP[12]), if the difference between energy source and the needed supply temperature of the building is as small as possible.

[12] The coefficient of performance (COP) represents the efficiency of a heat pump – as an annual average also referred to as seasonal coefficient of performance (SCOP).

4. Efficient, low-carbon energy supply

4.1. Decarbonising individual heat supplies

Electrical heat pumps should be implemented to a much greater extent – both individual ones in rural areas where thermal networks are not feasible and in urban areas where they can make the use of low-temperature renewable and excess heat sources possible.

5	**Where decentralised heating/cooling systems are more feasible than centralised thermal networks, individual heat pumps should be promoted since they can contribute to decarbonisation and to the flexible integration of renewables.**

Avoiding the release of harmful refrigerants with high global warming potential factors (GWP) to the ambient is critical to realise the positive climate effect of heat pumps. In the HRE 2050 only low-GWP refrigerant heat pumps are used.

The Pan-European Thermal Atlas (*Peta*) is a public online interactive portal to support planners, investors and not least policymakers by presenting and quantifying the possibilities (geo)graphically for all 14 HRE countries in terms of (among other features) a) H&C demand on a hectare level and b) various heat sources to decarbonise the H&C sector such as geothermal sources, solar district heating potentials, biomass resources and excess heat from waste incineration plants, power plants and industrial processes respectively. More information on *Peta* can be found directly in the online map or in the report

Maps Manual for Leas-Users [8]

The details regarding the underlying methodology which the maps are based on is described in *Methodology and assumptions used in the mapping* [9]

Similar to section 3.1, it is recommended as a first step to get an overview of any existing national support schemes for scrapping individual boilers and/or installing heat pumps. If any direct or indirect subsidies seem to show some potential for such activities, this information should be clearly presented towards the target group (e.g. private homeowners or businesses with individual boilers). Indirect subsidies could include a tax discount on the share of the bill associated with the labour share of costs for building renovations or installation of RE-systems. Though this could be an incentive for homeowners/businesses to engage professionals within the community, it is relevant to consider if it indeed increases the number (and quality) of energy efficiency/RE measures realised, or if it simply would represent a tax discount for those who would have realised such measures anyway (e.g. tax discounts for those already wealthy enough to afford such investments). Obviously, the aim should be to generate true added-value, meaning to enable those in the community who would not (be able to) install such technologies/measures without support.

Similar to the potential benefits associated with energy savings measures seen in section 3.1, the homeowners' potential benefits from converting to a low-carbon alternative should be clarified i.e. value of property (including an example), lowered costs for heating/cooling (comparison with alternatives), increased comfort and reduced emissions (comparisons with alternatives). Likewise, the more favourable financing and installation options for homeowners can be created by facilitating large-scale operations e.g. in terms of engaging financing options and installers.

To strengthen outreach towards target groups across the city/province, the abovementioned initiatives could be communicated in a variety of ways (e.g. in informational meetings, via social media or through printed materials). It also has proven useful to offer citizens a chance to do site visits to see for themselves how technologies and measures (e.g. a heat pump installation) could appear *in situ* at their own home/business.

How to use HRE's free-to-use *Peta* platform to identify specific geographical target areas for individual heat pumps, or other decentralised RE systems, in the town/region:

1. Open the *Peta* online map as a starting point for this.
2. Use the *Peta* to explore its layers on existing district heating areas, prospective supply districts and heat demand densities.
3. In principle, decentralised heat pumps are most appropriate for areas of low to moderate heat demand density, but especially any which are located outside marked areas of the existing/prospective district heating layers.
4. Mapping all the areas with the largest volume can help create a list of "target areas".
5. Prioritisation of the list of target areas (e.g. by assessing the type of heat supply installations in each area) typically requires on-the-ground knowledge (e.g. from the local/regional authority) to formulate a valid overview of potential HP/RE installations.

4.2. Renewable energy requires and offers flexibility

With the increasing integration of VRE, the positive role which the heating and cooling sector can play to augment grid flexibility becomes increasingly important and apparent. The use of renewable electricity in the heating and cooling sector can help balance the electricity grid when more VRE is introduced. Individual heat pumps in rural areas in combination with smart controls and large-scale heat pumps in district heating networks can play an important role in this connection when operated at times of surplus electricity thus providing a demand response potential to stabilise the grid and to allow more renewable electricity in to the energy mix.

Thermal storages – being several times cheaper than electrical ones – can increase the flexibility potential. In fact, storages for district heating represent a key role to provide the flexibility required in future energy systems with an increased amount of non-controllable energy production.

6	**To provide the flexibility required when increasing the share of wind and PV power, thermal storage is important in combination with individual heat pumps. However, the potential for grid flexibility and cost-effectiveness to integrate fluctuating RE becomes even greater by using district energy together with large-scale thermal storage, heat pumps and CHP.**

4.3. Flexibility from large and small consumers/prosumers must be valued

Introducing many more consumers/prosumers[13] will result in a more decentralised and diverse energy system interacting across both sectors and the traditional stakeholder groups. New ICT solutions make market interactions with smaller consumers manageable. One example could be the use of local storage options (thermal or electric) to act as buffers to reduce peak demands for the electricity grid and the inherent dimensioning or capacity upgrade criteria to cope with this, when introducing large quantities of electric heat pumps (besides EVs etc.) The financial benefits for the prosumers should be structured to reflect the needs of the overall system. In some cases, the feasibility of electrical storages for individuals lies only in the avoidance of taxes. Household batteries should for example be able to respond to signals from the DSO instead of only maximise self-consumption. The use of RE should not be the end goal, but a mean to reach energy system emission targets – not single household targets.

7	**Policies and price signals should incentivise flexible interactions for prosumers to help balance electricity grids and not just maximise the owners' self-consumption (e.g. via household batteries). Failing to ensure that such systems respond to network balancing demands will end up being counterproductive for the overall energy system.**

It is important to ensure that the recommended (large share of) heat pumps should not purely operate as baseload. Thermal storages can cost-effectively be applied to facilitate the flexibility services requested from the heat pumps – especially when applied in large scale for district heating plants. Individual heat pumps can shift electricity from surplus to times of low demand by storing

[13] The term "prosumer" is a contraction of the words "producer" and "consumer". It reflects a consumer who sometimes produce more energy than what is consumed.

the electricity in hot water tank or in some cases in the building envelope itself. Giving this service a value, would accelerate the technology deployment.

4.4. Excess heat often politically neglected

HRE4 identifies an excess heat amount theoretically available that could supply heat for more than the entire building stock in Europe. Therefore, the avoidance as well as usage of excess heat – when not able to avoid – should receive high(er) priority and immediate attention in local to European decision-making processes, energy planning instruments and funding lines. However, the "CO_2 free" excess heat which could be gained from polluting power plants should not prolong their lifetime. What is shown by HRE4 is the massive potential to utilise current excess heat *and* renewable heat sources which planners and decision makers can evaluate in more detail to consider where the use is relevant and where not. Tapping into the excess heat potential can in many cases only be realised by applying district heating networks, which – once established – will have numerous supply opportunities – even if one excess heat source should terminate.

Two key district energy technologies can increase the potential for using excess heat in a locally or regionally scaled system:

- Large-scale (cheap) thermal storages can act as buffers to maximise the use of excess heat when the supply and demand profiles do not match.
- Large scale heat pumps can make it possible to utilise low-temperature excess heat sources in district heating networks where it is not possible to apply it directly.

When planning for the utilisation of excess heat in local/regional district energy systems, the first step is to establish an understanding of national regulative frameworks regarding such activities, which may include complicated tax considerations related to both the supplier (e.g. an industrial facility) and recipient (DH/DC company). Important components within national frameworks could be, for example, specific excess heat taxes or subsidies for integrated excess heat. Below is seen an approach for screening of excess heat sources in a local area (grey box), followed by a decision flow tree when using the screening results in an actual excess heat-to-district heating process.

Screen for excess heat sources* in your local area:

1. Use the *Peta* as starting point.
    - The *Peta* map can be supplemented with local community knowledge from e.g. local authorities or business associations to strengthen quality of screening.
2. Identify potential excess heat sources.
    - Sort by distance – longer distances require larger investment in transmission pipes.
3. For each potential heat source identified:
    - Contact owner to learn about type of excess heat (e.g. clean hot water, hot waste water, flue gas, etc.), their interest in delivering excess heat and required price level. If price level is above existing heat production price, the excess heat source is not relevant.
    - Gather data about excess heat potential. Screening results should include excess heat energy potential, excess heat temperature levels and availability profile of the excess heat.

* The *Peta* includes geographically pinpointed and categorised excess heat sources such as power production, industrial processes, waste incineration, metro stations, urban waste water treatment plants, data centres and service sector buildings. This can be used to illustrate not only *how much* excess heat potential is present, but also *where* this potential is located thereby assisting the decision process of where to investigate the utilisation of this further.

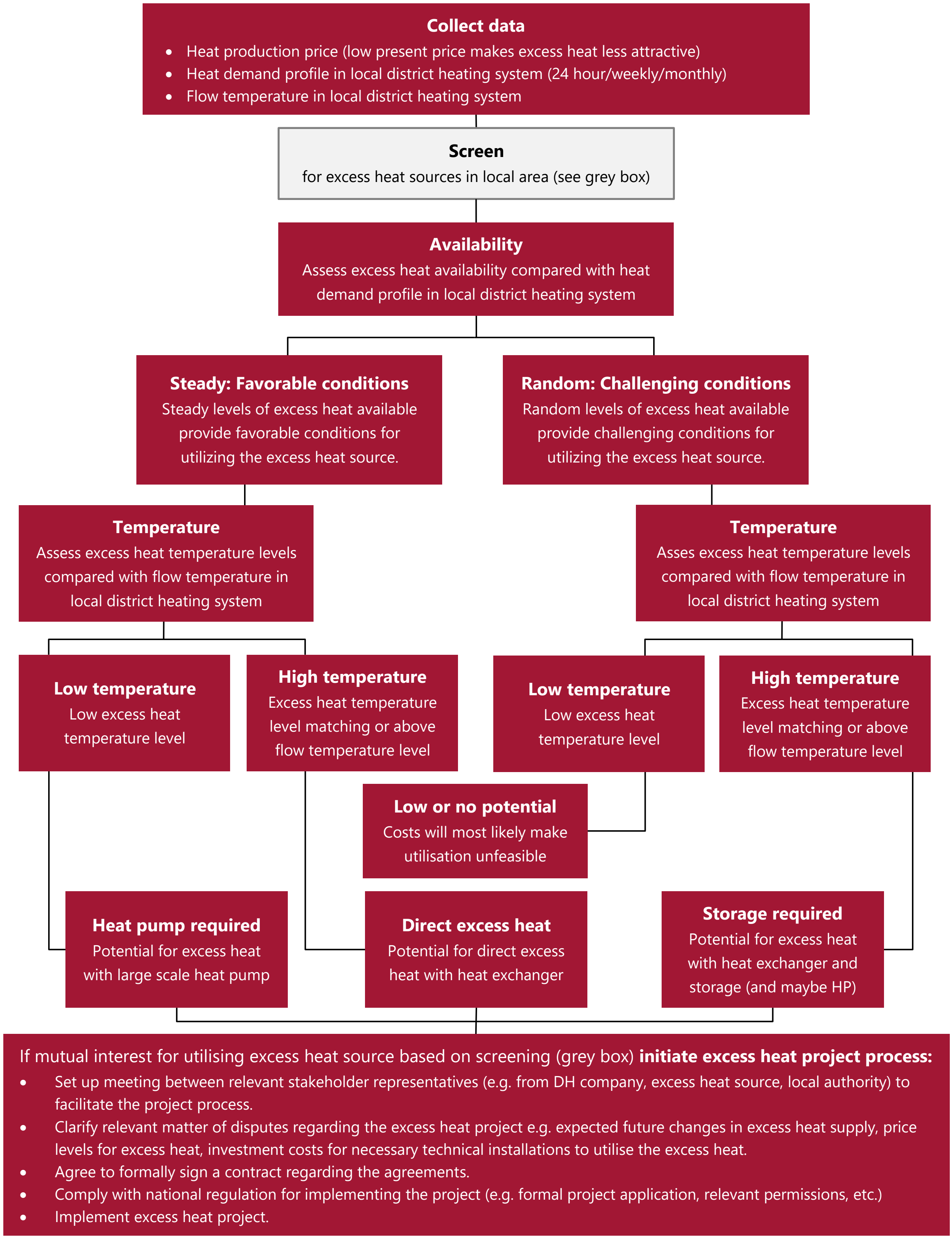

Figure 7. Decision flow tree as an approach for using the screening results in an actual process of utilising excess heat for district heating.

4.5. CHP plays a key role but is not a “one-size-fits-all solution”

In terms of utilisation of excess heat from electricity-only power plants and possibly comparing with alternative industrial excess heat options it is relevant to consider the following questions for all options: When is the excess heat source expected to be decommissioned? Is it worthwhile to utilise the heat until then even if it requires a follow-up plan from the beginning? What is required of both technical and administrative measures to realise the utilisation of this source? What are my alternatives?

When it comes to replacing electricity-only power plants with new CHP plants, one has to keep in mind if the demands of the future energy system match the properties of such plants (in terms of flexibility, fuel import/costs e.g. gas or biomass etc.) Experience has shown that with increased VRE capacity in the electricity network, the non-controllable electricity production will consequently cover a larger share of the electricity demand thus leaving fewer hours for feasible CHP operation. Introducing large scale heat pumps for district heating can significantly reduce the need for other heat production capacity. In many decentralised CHP plants in Denmark (with both gas engine and gas boiler installed) long periods with low electricity prices have in most hours made it unfeasible to run in CHP mode thus resulting in an increased share of boiler operation in these plants. Hence, careful planning is required to assess the need for the future CHP capacity – including the services it should supply (e.g. mainly baseload heat/electricity production or balancing power). Any energy system investment – supply units or infrastructure – should be considered together with the remaining system, which it will inevitably interact with throughout its lifetime – directly or indirectly.

In the future, there will likely be an increased demand for biomass as it tries to cover non-energetic gaps of several fossil-based demands of today, such as bioplastics and biofuels for transport. Therefore, the use of biomass in boilers and CHP plants should not be considered as an “easy-fix” solution to cover all of a city’s or region’s decarbonisation goals. Besides expected scarcity for the non-energy uses of biomass, strict sustainability requirements will certainly be crucial to ensure that it is sourced in a sustainable and effective manner, meaning that it does not contribute to deforestation or other harmful effects. Other combinations than CHP using the heat output from a process should also be considered in integrated energy systems.

Future power-to-gas (P2G) such as hydrogen production could be established as combined heat and gas solutions where a district heating connection ensures a higher efficiency of the P2G energy conversion. District heating can prove even more relevant in case of targeting a complete decarbonisation of EU by means of 100% RE using the Smart Energy Systems approach [10] where the production of electro-fuels for transport sector plays an important role. Hence, the HRE scenarios can serve as a step towards such a goal.

4.6. Increasing cooling demand

There is a demand for cooling throughout Europe, not just in the south, but even including (perhaps unexpected) places like Scandinavia. In fact, cooling demand is expected to increase significantly towards 2050 all across European towns and provinces. However, the advantage to this trend comes from the fact that cooling demands often offer a direct opportunity to use the extracted heat from other applications (e.g. district heating), thus representing yet another synergy opportunity, which has already been today applied in several places across Europe.

Renewable cooling should be considered in long-term planning to take into account the obvious synergy options between H&C applications (e.g. feeding excess heat from a cooling process into local/regional DH). A close collaboration with key stakeholders (e.g. cooling equipment providers) could be useful to tap into low-temperature excess heat options.

In general, sustainable technologies – for example using natural cooling, integrated systems such as district cooling and the integration of the cold chain – should be given far more attention and resources for data collection, research and the roll-out of sustainable solutions in order to address the growing demand well in advance.

4.7. Acceptance from citizens

Some degree of local ownership can increase public acceptance of RE installations such as wind turbines. One example is to include a precondition for the investor to offer a share (e.g. 20%) of the installed capacity to the municipality's inhabitants and/or the coming neighbours. By owning a share (e.g. of a wind farm) the locals may see it less "intruding". An additional option is to somehow compensate the affected local environment (e.g. by financing non-related local activities thus improving the local area).

An initial dialogue between the project developer and affected future neighbours of the installation can eliminate several prejudices and concerns based on "the unknown". Good experiences have been made by inviting affected neighbours on a viewing trip, where one could see/hear a similar facility.

In the example of onshore wind turbines, a large part of the planning process timeline can be allocated to an initial debate period among key local/regional actors, followed by a later period of public hearings where even individual citizens have the opportunity to contribute with ideas and proposals, as well as have the opportunity to comment through public consultations before the final political decision. For example, citizens may attend political meetingsto meet local/regional politicians, managers, technical staff and project developers to voice concerns/questions. An open and transparent process, and the ability to be heard, will in many cases define if a project is approved or not, since any "loud" uncertainty from citizens will often influence politicians' own concerns and how they vote for or against approving a project.

A few points are worth mentioning in this context:

- It is important to enhance fact-based and proactive communication, since social media (possibly including fake news) represents a growing challenge for municipal/regional planning processes.
- A transparent and inclusive framework for public participation in decision-making processes (public consultation procedures and consultation meetings) should/must be provided.
- Enthusiastic community members, once identified, often function well if engaged as local/regional "ambassadors" from the beginning.
- Initiatives for local/regional communities to increase and sustain acceptance should be developed (i.e. creating relatable "win-win" solutions).

4.8. Long-term benefits of capital-intensive transition

Following the energy transition is a general trend towards a more capital-intensive heat supply together with lowered operation expenses. Examples include solar heating and heat pumps – both in small scale units and large (DH) utility-scale – where the total cost of energy to a larger extent relates to the unit investment rather than the operation (compared to boilers). In relation to district heating, a shift from previous times' single fuel supply to many heat supply sources introduce a wide range of options for the operator to optimise the production and reduces the sensitivity associated with the fuel costs (and availability). Similarly, the use of heat pumps makes it possible to use (locally) produced electricity (from a wide range of RE sources) thus reducing the dependency (financially and geopolitically) on fuel import. This makes it possible to ensure more stable conditions for both consumers and investors in the long run thus also reducing the risk of energy poverty. In this context it should be noted that establishing new natural gas-grids holds considerable lock-in risks.

Thermal networks take the shift from operation-related expenses towards investment-related expenses further than what is possible with individual supply. Another result of a development towards a higher degree of energy infrastructure investments is the opportunity to create local jobs as a result of the need for installation and servicing the infrastructure. This applies both on sub-country level and in terms of improving competitiveness of European industries nationally and internationally. On top of this, the energy transition improves living standards by limiting emissions thus ensuring better air quality locally besides limiting the global warming.

However, in any project the administrative efforts required have to match the predicted benefits. This applies in small and large scale. Examples include the issue of a comprehensive administrative process which repels smaller industries from entering into agreements of supplying excess heat. Similarly, as a large-scale example, establishing new district heating networks (and possibly companies) is a long-term process requiring significant financial and manpower resources. Such financial and administrative barriers could be overcome by removing unnecessary administrative burdens, by supplying access to cheap, long-term financing and by empowering local authorities to facilitate the processes required in any (small or big) project involving several different stakeholders.

8	**Frameworks for providing low-cost financing options and avoiding (unnecessary) administratively-heavy processes is an important precondition to effectively engage communities and industries. Furthermore, local authorities should be empowered to encourage and facilitate H&C decarbonisation projects.**

4.9. Optimisation and changeover from a fossil-based DH supply

In many (old and new) DH networks, the heat is supplied by fossil fuels, which often gives DH a bad reputation in general among many citizens (at least in certain countries, regions and cities, this is often a challenge). In terms of (big) older inefficient DH networks, a strategy can be to divide the network in zones from a planning perspective. Between these zones the network temperatures can be differentiated. In some zones it may be sufficient with a lower supply temperature. Hence, the return flow in the main DH network can act as supply line for this zone. This means that this specific zone uses lower temperatures in their area while reducing the return temperature in the rest of the DH network thus improving its overall efficiency. The various reasons for the high temperature requirements can be addressed in a stepwise approach until the entire network temperature can be lowered (see section 3.3).

Local and regional, and even national, governments can support evaluation schemes where experienced consultants with knowledge of that context can investigate the possibilities for a changeover from fossil fuels to renewables and excess heat, together with energy savings measures (e.g. renovation of networks). Such screenings could form the basis of informed local/regional decision-making for the DH board members, thereby highlighting their most suitable and feasible decarbonisation options. However, before final investment decisions are made, more thorough calculations would be needed. With such measures, local to national governments could effectively support an energy transition of existing district heating networks without needing to (yet) financially support investments in equipment or infrastructure.

Different options for strengthening the local/regional economy in existing district energy systems may be available, depending on the local to national context. However, based on experiences from a state-financed project in Denmark (where district heating plants screened to be at risk of high heat-price increases are being serviced with free consultation about cost savings from the Danish Energy Agency), four key categories with cost-saving potentials for district heating plants have been identified. Based on a particular plant's current costs in each of the four categories, it may be possible to calculate an actual cost-saving potential (as € per customer per year) to be used as a basis for choosing those actions with the highest impact. The four key categories are:

1. Production and transmission
   An analysis of current costs for heat production (a quick comparison with national levels). If the result is a high cost level, an analysis is carried out to lower costs by either establishing a transmission pipe to a neighbouring DH area or installing new heat production technologies, such as large-scale heat pumps or solar thermal.

2. Customer base potential
   An assessment of potential new customers and marginal cost-savings per new customer connected within a certain DH network area (meaning 0 km of new transmission pipe is needed) and potential new customers and marginal cost-savings per new customer connected in nearby areas (X km of transmission pipe needed).

3. Distribution
   An analysis of the potential for optimising flow temperatures in the DH grid (by a flow temperature controlling system), improving cooling/return temperatures (by identifying DH customers with poor cooling and service visits) and reduced water consumption (by a specific thermography of the DH grid and use of remote meters).

4. Economic and operational cooperation
   An assessment of regular expenditures for the DH plant (e.g. if any regular administrative expense items can be shared with other DH plants) or whether restructuring loans and the depreciation rate could be used to optimise the financial situation.

5. Thermal networks create synergies

5.1. District energy to enable decarbonisation

9	**District energy can play a leading role in the energy transition since it can connect the electricity and H&C sectors, which – with the flexibility provided by thermal storages in particular – enables the integration of more fluctuating renewables such as wind and solar energy.**

The list of benefits by increasing the share of district energy is long:

- District energy in cities, and even across whole regions, is one of the least-cost & most efficient solutions for reducing emissions and primary energy use. Almost all of HRE's country-level heat roadmaps show a strong potential to economically increase the current share.
- District energy and cheap thermal storages can represent an ideal bridge between the heating, cooling and electricity sectors, while providing flexibility for the overall energy system.
- Beyond its ability to use economies of scale to take advantage of renewables, district energy systems can make it possible to utilise excess heat from industries and other sources, which is otherwise regarded as mere waste (and with possible negative impacts on ecosystems[14]).
- Because district energy is typically not strictly conditional on the availability of just excess heat or any single type of renewable source where circumstances (e.g. fuel prices) may change over time, the feasibility of establishing district energy systems is generally a solid venture and a safe investment.
- Often many different heat sources are available. Excess heat can be a cheap option with a short payback time, while other feasible alternatives can relatively easily "step in" in case this supply option is terminated.
- In case energy-savings targets are not met, district energy can supply this additional demand with renewable heat, thus increasing the certainty that overall decarbonisation goals can and will indeed be reached (i.e. representing a type of backup solution[15]).
- District energy can be completely decarbonised using renewables, large heat pumps, excess heat and CHP. In fact, several RE technologies benefit from – or even require – large-scale

[14] For instance, according to studies [11] of the Swiss Federal Institute for Technology the Rhine is one of the most heat-polluted rivers as a result of warm-water discharge from power plants.
[15] Note that this should indeed be considered a back-up plan. It is highly recommended *not* to disregard the energy-savings perspective, as it holds the key to a cost-effective decarbonisation.

installations in order to be most feasible. For example, to exploit the full potential of deep geothermal and solar thermal, DH needs to be present due to the significant economy of scale for these solutions. Similarly, DC can utilise cooling sources such as lake water or seawater thereby increasing the overall efficiency and reducing the stress on electricity grids, which is a common challenge where individual air conditioners frequently create extreme peak loads during hot periods of the year.

The *Peta* includes a visualisation of both existing DH networks and the cost of establishing DH on a hectare level. This gives lead users the ability to pinpoint where the most suitable areas to establish/expand DH are located. The costs are presented as annualised investment cost per unit of annual sold heat/cold.

In any new district heating system, remote sensors may prove to be a very feasible investment. The additional investment costs are relatively small compared to the potential energetic and financial gains which can be obtained by using real-time data from the sensors to identify errors, to evaluate opportunities for lowering network temperatures, and to analyse the needs for upgrading pipes in case of expansions in a given direction (e.g. from new built environments). Furthermore, long-term data collection enables the improvement and optimisation of the overall system in preparation for a future which will include new technologies and/or opportunities to be integrated based on data-driven decisions.

5.2. Extending DH networks

As a starting point when looking to extend a DH network, it should first be clarified how much heat demand can be connected to the DH network with the existing heat production capacity, before any additional heat production capacity is to be introduced.

If extending the district heating network requires the installation of additional heat production capacities, multiple options and their associated costs should be thoroughly investigated. Any extension is typically only considered where installation of new heat production capacities can be implemented without subsequently increasing the heat price for existing consumers.

Potential areas for extending DH networks can be identified by using the steps below.

1. Screen for potential expansion areas (see guidance in the box below)
2. Preliminarily calculate the connection shares required to ensure an economic balance in each potential (new) area.

3. Create a strategic extension plan for DH, based on knowledge from the above steps, which should address the specific extension areas and potentially an order of prioritisation.
4. Based on the areas prioritised, target groups in potential areas (typically private homeowners or businesses) should be contacted to explain the possibility, and reasoning, for DH to assess local/regional interest in connecting to DH.
    a. This can be done in various ways (e.g. informational meetings, letter campaigns, door-to-door interventions, etc.)
    b. Information should be prepared ahead of time (perhaps as printed materials) to address potential questions from target groups. For example, answering common questions about: investment costs to connect, expected heat prices, time plan, foreseen inconvenience, any required installation within the house/business, etc.
    c. It may be worth considering the possibility to increase incentives for converting to DH by making attractive deals for new customers to connect to DH networks. Reduced revenues from such discounts can be mitigated by an increased number of customers.
5. Choose which areas to extend DH and start the specific project technical (and financial) processes, including detailed technical calculations, dimensioning and plans, project application, permits, etc.

How to use HRE's free-to-use *Peta* maps to assist in the screening of potential areas to extend district heating networks:

1. The *Peta* online map acts as a starting point for this task.
2. The most useful map layers are those showing existing district heating areas, prospective supply districts and heat demand densities.
3. Identify the existing DH network(s) to be considered in the screening.
4. Identify prospective supply districts (i.e. those areas which show strong potential for DH – visually depicted with the colourful heat demand density layer[16]) located outside the selected DH area(s) within a potential distance for establishing a transmission pipe to the existing DH network. This can be measured within *Peta* using the ruler-like measurement tool on the upper-left corner of the map). A general rule of thumb is that longer distances often require higher heat demand densities to be economically viable, but there is, technically-speaking, little reason that long-distance DH systems should always be avoided. In fact, a case in point is found in southern Sweden, where Helsingborg is connected (through Landskrona) to Lund 50 km to its south to form a regional DH grid.
5. Check for additional areas with decent heat demand densities[17] located only a short distance (e.g. 2 km or less) away from the selected existing DH area(s), but outside prospective supply areas.

[16] In many cases they overlap with already existing DH.
[17] When considering new DH 120 TJ/km^2 or more is typically very cost-effective, but much lower densities may prove feasible when considering the connection to a nearby larger network.

6. Map all the identified areas, their distance to existing DH connection points and the volume of heat demand density to create a list of potential extension areas.
    a. It may be worth first prioritizing either the closest areas to the existing DH area or those areas with the largest volume (i.e. highest heat demand density and suitable size).
    b. The list of target areas could be further qualified by assessing the type(s) of heat supply installations found/feasible in each area – this knowledge would best come from local/regional experts.

5.3. Establishing new district energy networks

In areas with high H&C demand densities located too far away[18] from existing district energy networks, it may be more relevant to investigate the possibility of establishing a new district energy plant and network instead of trying to connect it to an existing one. This requires in-depth knowledge regarding the specific national regulations, and any relevant local and/or regional norms as well, about establishing new H&C production plants supplying public grids. It may prove useful to contact other (possibly newly-established) district energy plants in (nearby parts of) the country to learn about current processes. A general plan for how to analyse and set up a district energy network can be seen below in Figure 8.

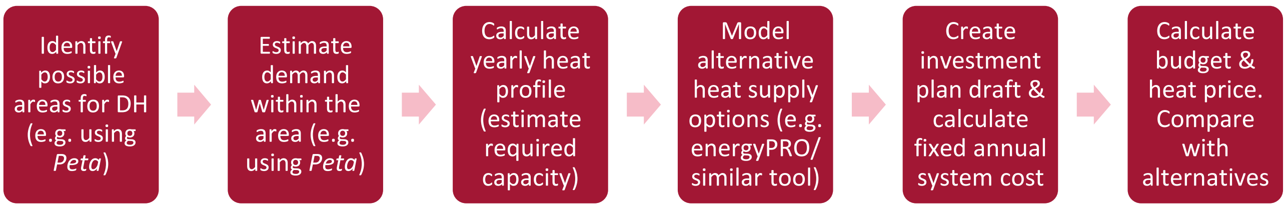

Figure 8. Illustration of a potential screening procedure for (new) district energy [12].

In general, the two most important economic parameters when establishing a new district energy plant and network are to secure low H&C production costs and a high connection share. H&C production costs are dependent on the type of technology to be installed. This decision should be based on an analysis of the relevant production solutions available in the area such as (industrial)

[18] This must be analysed for the specific area, as it varies considerably due to the local/regional context (especially heat production prices and capacities within a given DH network). A conservative rule of thumb is that 20 km away from existing DH networks rarely will be economic viable, though there are still exceptions to this rule (e.g. the 50 km Swedish example mentioned before of Helsingborg-Landskrona-Lund).

excess heat, large-scale heat pumps using various H&C sources (waste water, sea/lake water, groundwater, geothermal or air), solar thermal, etc.

It is recommended to ensure that those buildings with large heat/cold demands will indeed connect to the new district energy network so as to ensure that a base income from thermal energy sales and basic resilience of the plant being feasible from the very first day of operation. Some national regulations include a possibility to make connection to district energy network mandatory. Such regulations can be used to secure high connection share in the selected area even before construction begins. Nonetheless, even when such regulations are in place, forcing customers to connect should still be applied cautiously (and best only after public consultations and acceptance) when there is a high certainty that a low(er) heat price will result for the new district energy customers.

When mandatory connections are not regulated, or this approach is not chosen to be enforced, voluntary connection should be proactively promoted through preliminary contact with homeowners, businesses, real estate developers, etc., and perhaps even gathering signatures from potential customers expressing their interest/commitment to connect to district energy. This can be achieved in different ways, such as informational meetings, letter-campaigns, door-to-door interviews, etc. It is recommended to prepare relevant printed materials in advance to address potential concerns from target groups (e.g. about investment costs to connect, estimated heat prices, time plans, foreseen inconveniences, required installation within houses/businesses, etc.), as well as highlighting the benefits which connected consumers might expect, such as the following (see also Figure 9):

- A building's substation can be very compact (meaning saving space possibly otherwise occupied now by a boiler) and is easy to regulate (so no need to fear a loss of control).
- There are no smoke, emissions or noise from the installation (as opposed to many alternative options, such as oil boilers).
- The heat production can be effectively decarbonised (leading to an energy footprint which consumers can be proud of).
- District energy systems create multiple jobs directly benefitting the community/region (e.g. construction, installation experts, operation and maintenance of the plant, network and substations).
- There is almost no need of maintenance from the side of the consumer. Service of the substation and surveillance/repairs of any leakages is already included in the annual fee.
- District energy, largely due to economies of scale, are typically able to off lower costs of H&C compared to decentralised alternatives.

What is most important to engage consumers differs depending on country/region, but in the end often the last bullet point above is the most critical to emphasise. Therefore, in some cases it may even be advisable to consider the possibility of introducing further financial incentives for connecting to the district energy grid, by making attractive deals for new customers to achieve/ensure a high connection rate. This might mean some kind of a subsidy or tax break to join, but it does not have to be the case. For example, another option could be to simply spread the cost to consumers over a longer period of time – e.g. by (transparently) inserting part of the installation costs already into their heating bills – thereby avoiding a single, large up-front connection fees for consumers[19]. Regardless of the approach, it tends to be quite important that consumer tariffs clearly and accurately reflect the fixed part of their annual system costs. Doing this not only helps to ensure that there is no mismatch between expenses and revenues for the company, but also sensitizes customers to understand that proper H&C services have a distinct value.

In terms of consumer contracts, it may prove useful if they are defined in such a way that they only come into force if a certain share of the area (e.g. number of households/businesses or volume of H&C demand) officially agrees to connect. Therefore, the district energy company can actually withhold the right to cancel the plans for establishing a network until a certain threshold is ensured. This approach helps to avoid risks for investors while consumers will not be stuck with higher prices, in case insufficient numbers decide to connect after the network has been built[20].

Figure 9. Example of printed material from Danish DH company highlighting the benefits of DH and offering customers the chance to connect via a subscription with a fixed annual cost, instead of paying for installation costs, thereby avoiding high investment costs upfront for customers (English explanations have been added onto it for clarity.)

[19] Further info on up-front investment cost barriers and this kind of solution is found in the HRE4 report "Business Cases and Business Strategies to Encourage Market Uptake" [13].
[20] An example of documents used for this approach can be found in annex 3, 4 and 5 of [12].

5.4. Ownership structure and stakeholder engagement

A core point is the ownership structure of the district energy plant, where it is often recommendable to have a local/regional governing authority involved directly or indirectly (e.g. as full or partial owner), since it will often require significant efforts of community engagement to successfully establish a district energy company and its related infrastructure. In any case, it is important to have continuous communication between various stakeholders (e.g. informing affected citizens about plans, expected timeline and reasons for road work related to H&C services).

Regarding some level of public/community ownership of these companies, when it comes to ensuring that a district energy supply is decarbonised (e.g. to fulfil a municipality's SECAP or a province's REAP), having an agreement in place other than a traditional contract-based approach may be advantageous. In many cases, the way to realistically ensure a "green transition" is by gathering relevant government authorities, the district energy company and other key stakeholders to work together to develop a strategy towards (a certain) RE/CO_2 target, even if not as formal a document as mentioned in section 2.2. The benefit for municipalities/regions is that having the companies and others "on board" means that all are working towards the same goal, and, for example, not only the energy demands of *public* buildings are decarbonised. The benefit for the district energy companies is that their role is also somewhat ensured in the city's/province's future energy mix (e.g. a continued/extended need for district energy is ensured, as long as it lives up to the agreed RE/CO_2 targets), thereby providing long-term certainty of investments.

Often a municipality, or sometimes even a regional authority, owns all or part of the district energy company itself (i.e. production plant and network). In many countries privatisation of formerly-public-owned district energy companies has been carried out, but also in many of these, this approach has not proven to lower consumer costs. Public or community-owned district energy companies tend to focus less on a fast return of investment, but rather on maintaining a solid foundation for continued operation and low prices for customers. Therefore, some communities and/or municipal/regional authorities try to buy back previously privatised district energy companies in order to regain control (e.g. in terms of the choice of investments and targets, such as RE shares of the supply). In any case, the most suitable ownership model for a given town or province will also depend greatly on national framework conditions, the history of district energy in the city, region and/or country, public acceptance or lack thereof, the experience of public/community/private companies to provide services successfully, etc.

6. Conclusion

When planning for a low-carbon future, it is evident that the entire energy system must be taken into account so as to ensure that a decarbonisation focus in one place does not simply lead to increased emissions somewhere else. The same level of consistency should be applied across all local and regional policies, which should then be considered jointly to ensure that they are aligned with national targets, e.g. to make sure they are in line with a country's commitments to the Paris Agreement. Local and regional authorities can act as the catalyst of the energy transition by bringing various stakeholders together to combine their efforts on a common decarbonisation strategy.

It is critical that barriers hindering the energy transition is removed at all levels in order to ensure that local to national stakeholders successfully overcoming one barrier are not immediately thereafter blocked by others. Periodical reviews and – if necessary – changes should be formalised accordingly in those policies, administrative processes, etc. which either now cause a particular barrier or could facilitate overcoming it. Carbon taxation and other (in)direct incentives at local/regional levels should complement those properly ensured at national levels to encourage the full achievement of energy savings, the smart integration of renewables and the implementation of efficient energy system infrastructure where most suitable.

Investments in such infrastructure to decrease fossil fuel demand via district energy networks, heat pumps and energy savings will result in the following benefits covering all levels of society:

- Lowered uncertainty of future fuel prices, thereby ensuring a more stable framework for both energy-producing companies and individual consumers/prosumers on different levels (households, services and industry), as well as for (public) investors.
- Opening of the market for locally-/regionally-based heat sources, thereby increasing the security of supply and local economic growth, while also making the countries more resilient to geopolitical changes.
- Creation of local jobs – both on a (sub-)country level and in terms of strengthening the competitiveness of industries nationally and internationally.
- Reduction of the overall energy system cost compared to alternative decarbonisation scenarios.
- Improvement of living standards by ensuring better air quality (locally), while also reducing emissions (globally).

10	**All sectors should be included in a combined decarbonisation strategy. Long-term targets for combined efforts of all sectors must include an ambition level corresponding to this end-goal.**

Though the responsibility of creating the framework which will facilitate the decarbonisation of the energy sector as a whole lies first and foremost with the decision- and policymakers at a national level, it is also the duty of local and regional authorities to make sure that national actors properly establish/maintain this framework, and that they themselves enact mechanisms which complement it. By achieving this, the country as a whole can better ready itself to embrace also increased demands caused by improved living standards and ensure a sustainable future for all inhabitants. However, this requires at all levels a stronger commitment and bolder actions in terms of truly ambitious energy and emission targets, and an intelligent choice of pathways accounting for all the demands of tomorrow. For this reason, HRE's national scenarios and Heat Roadmaps are key tools to facilitate more viable predictions and suitable solutions to address them, and still are quite useful as guidance even for sub-national levels' decision-making processes.

A common understanding of national roadmaps, and their local/regional implications, to show the determination, providing effective incentives and ensuring stable framework conditions will no doubt boost energy infrastructure investments and speed up the energy transition process, thereby benefitting both businesses and private citizens. Municipal, city and regional policymakers are therefore strongly urged to fully consider all the proven opportunities, tools and recommendations offered by HRE4 and act accordingly to make sure that each town and province contribute positively to national and international initiatives.

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8. Abbreviations

CAPEX:	Capital expendidures
CHP	Combined heat and power
CO_2	Carbon dioxide
COP:	Coefficient of performance
DC:	District cooling
DH:	District heating
DSO:	Distribution system operator
EE:	Energy efficiency
EU:	European Union
EU ETS:	European Union Emissions Trading System
GWP:	Global warming potential (factor)
H&C:	Heating and cooling
HP:	Heat pump(s)
HRE:	Heat Roadmap Europe project series starting in 2012
HRE 2050:	Heat Roadmap Scenario for 2050
HRE4	Heat Roadmap Europe 4 (H2020-EE-2015-3-MarketUptake)
ICT:	Information and communications technology
iCPC:	integrated Climate Protection Concepts
OPEX:	Operational expendidures
Peta:	Pan-European Thermal Atlas
PV:	Photovoltaics
RE:	Renewable energy
REAP:	Regional energy action plan
SEAP:	Strategic energy action plan
SECAP:	Sustainable energy and climate action plan
VRE:	Variable renewable energy

2050

Heat Roadmap Europe

A low-carbon heating and cooling strategy

Guidelines for the Energy System Transition

The National Aspects of the HRE 2050 Scenario and Associated Policy Recommendations

Deliverable 7.17-N

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Preface

The findings of Heat Roadmap Europe 4 (HRE4) proves that a common and coordinated effort of all citizens for the transition to a low-carbon future in accordance with the Paris Agreement is not only possible, but cost-effective and affordable with existing technologies available on the market today. Therefore it would be an ethical, political and organisational failure, if the nations as well as regional and local governments together won't be able to ensure the change required to keep global warming significantly below 2 °C compared to the pre-industrial area.

In particular, current and planned policies should be aligned with the vision of a carbon emission free heating and cooling sector by 2050, as the sector corresponds to about 50% of the final energy demand in most European countries and has a crucial role to play in the connectivity and affordability of the entire sustainable energy system of the future. This includes energy, environmental, economic, tax and educational policies, while ensuring that the impact of any legislation on all levels does not hinder the development towards this goal, but instead encourages and accelerates the transition.

There is no sustainable alternative than a decarbonised, integrated energy system. Postponing the challenges will only make the transition organisationally more difficult and unnecessarily expensive, but will not make the challenge itself become obsolete. The emission targets required to meet the Paris Agreement must be reached sooner, rather than later in order for society to benefit from the improvements created. The scientific and technolocially neutral research initative Heat Roadmap Europe verifies how choosing the path of decarbonisation in an integrated manner will be beneficial for all governmental levels, wether if the main priorities are economic, social or environmental.

Based on the outcomes of Heat Roadmap Europe, the authors call for action from all national politicians to accept their responsibility to take on their necessary role as leaders towards a fossil fuel free energy system by setting up the decisive framework which will guide their countries to an economically feasible, socially accepted and environmentally needed low-carbon future.

Executive summary

The aim of the HRE4 project is to create the scientific evidence to support short-to long-term energy strategies and decision-making at local, regional, national and EU levels to accelerate and empower the transition to a low-carbon energy system by quantifying the impact of various options, particulary in the heating and cooling (H&C) sector. Specifically, the results are presented in terms of roadmaps and recommendations towards 2050 for the H&C sector of the 14 EU countries[1] that correspond up to 90% of the EU's thermal demand, but are also still applicable to other Member States.

These *Heat Roadmaps* [1][2] should not be considered as the exclusively definited and only viable future sustainable energy mix, but rather as solid, cost-effective and affordable pathway presenting how the benefits and synergetic opportunities – ready to be exploited today by taking an integrated approach in a redesign of the entire energy system – can lead to a feasible, decarbonised future in accordance with the Paris Agreement [2].

Key messages – requested actions from EU policymakers

1	**HRE4 shows how using already existing and mature technologies in the heating and cooling sector the total CO_2 emissions can be reduced by 86% compared to 1990. This verifies that decarbonisation in line with the commitments under the Paris Agreement is indeed possible and that the coupling of sectors is essential for the most cost-efficient, economically and socially feasible low-carbon energy system.**

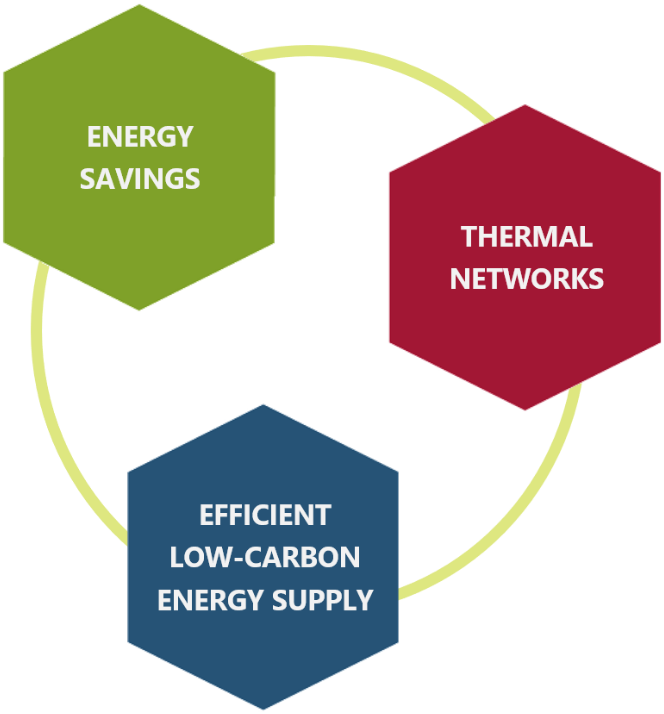
- By redesigning the heating and cooling sector the total costs of decarbonisation can be reduced by 6% annually compared to conventional methods of decarbonisation. In all future scenarios less financial resources are spent on fossil fuels and more on the infrastructure that delivers sustainable energy. This requires clear sectorial targets and policies that facilitate and foster a fossil fuel phase-out by 2050 and a strategic redesign of the framework conditions to enable investments for an integrated, efficient and renewables-based energy system on a local, regional, national and European level.

- H&C should be politically and technically recognised as an essential component and the most cost-effective solution. HRE 2050 allows the integration of shares of renewable energy of up

[1] Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Netherlands, Poland, Romania, Spain, Sweden and United Kingdom.
[2] While the main report [1] describes overall methodology and conclusions, the individual country roadmaps are found in section 0.

to 87% and more, while supplying flexibility and ensuring the stability and security of an overall integrated sustainable energy system.

The three main "pillars" or focus areas – energy savings, thermal networks and efficient low-carbon energy supply to enable electrification of the energy system – are especially important for policy-makers to steer the transition holistically towards a low-carbon energy system. HRE4 shows that a mix of energy savings, establishing and expanding district H&C areas, integration of low-carbon renewable and excess heat sources together with a significant electrification of the H&C sector can create synergies which are not as exploitable if one (or more) of these components is overlooked. The cross-sectoral energy planning approach of HRE reveals further points covering all three pillars, as revealed in the subsequent key messages.



2	**Energy savings are required on both the demand and supply side to cost-effectively reach the decarbonisation goals. HRE4 shows that the majority of recommended savings in primary energy demand can be achieved by more efficient supply options. National policies and financial framework need to coherently support both sides.**

- Substantial amounts of cost-effective energy savings are ready to be exploited and these are key for the decarbonisation of the energy system. Related national policies need to reflect the higher, but feasible energy saving targets – typically at least 30% for space heating in buildings. Consequently, also financial incentives should support this higher ambition and enable the exploitation of the potential in the residential, industry and service sector alike.

- Despite common misconceptions, introducing energy efficiency measures does not necessarily make district heating unfeasible, neither for existing nor new networks. In fact, energy efficient buildings can effectively shave expensive peaks and improve the performance and feasibility of the entire (new or existing) district energy network. Respectively, policies and financial programmes should support the efficiency for district heating systems and the integration of small- to large-scale excess heat sources, as HRE4 has identified an excess heat potential in the electricity production alone corresponding to more than the heat demand of Europe's entire building stock today.

ENERGY SAVINGS

- Where district heating is not the most cost-effective solution, mainly in rural areas, energy retrofitting of buildings should consider combining such measures with the replacement of boilers by individual heat pumps. The most efficient heat pump systems are those found in new buildings and in those that have undergone deep renovation. On top of the added value in energetic savings, such efforts will also improve the comfort level for the buildings' inhabitants. Respectively, policies and financial programmes should support the massive roll-out of heat pumps in rural areas.

3

HRE4 identifies suggested balances between decentralised heating and cooling systems being the most cost-effective decarbonisation option in rural areas, and thermal networks in dense urban areas. Those individual supplies should mainly be based on heat pumps as they can enable the flexible integration of renewables without using scarce bioenergy resources.

- Electrical heat pumps should be implemented to a much greater extent and up to an overall market share of about half, specifically:
    - in rural areas, where individual heat pumps should replace fossil fuel boilers;
    - in urban areas, where large-scale heat pumps should make the use of low-temperature renewable and excess heat sources and replace a fossil-based district heating supply relying on boilers and/or CHP.

EFFICIENT LOW-CARBON ENERGY SUPPLY

- Increasing the share of district heating in combination with cheap thermal storages, heat pumps and CHP can stabilise the electricity grid and thus facilitating the integration of renewables, when introducing more fluctuating sources such as wind and solar.

- Several renewable energy technologies benefit – or even require – large-scale installations in order to be economically viable. To exploit the full potential of large-scale and capital-intensive technologies like deep geothermal energy and solar heating, a district heating system needs to be present since for these technologies, economy of scale is key. The future energy mix will be much more diverse than in the past. A thermal grid in place will be able to integrate small- to large-scale renewable and excess heat sources in the most cost-effective way.

- By means of detailed spatial analysis HRE shows that approximately half of the total building heat demand in the residential and service sectors is located in high density areas. Some countries have higher or lower shares, depending largely on their level of urbanisation. Combining cost calculations with the overall system modelling reveals the scientific evidence supporting the conclusion that more than half of European countries' heat demand can cost-effectively be supplied with district heating in 2050. Furthermore, the spatial components of HRE and in particular its Pan-European Thermal Atlas (*Peta*) online mapping tool can even pinpoint where these new or expanded networks can feasibly be located.

THERMAL NETWORKS

4	**Excess heat recovery is key to an efficient and resilient thermal sector, and has the potential to support local industries, economies and employment. The identified quantities of excess heat across Europe are with 2.4 PWh/y (8.7 EJ/y) immense and thus need to be addressed through policies, regulations and finance that enable integration into the energy system.**

- Small to large-scale excess heat 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 HRE 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. Administrative and financial barriers to use (also low-temperature) excess heat should be removed, but of course giving priority, to sustainable excess heat sources free of fossil fuels or other negative environmental impacts.

5	**District heating and cooling in cities and towns is the least-cost and most-efficient solutions for reducing emissions and primary energy use. Through a thermal grid H&C can be completely decarbonised using renewables, large heat pumps, excess heat and CHP. Therefore, investments in the establishment and expansion of thermal grids in urban areas need to have high priority in public funding and support programmes.**

The following points indicates how HRE 2050 recommendations increase the effectiveness and resilience of each country's energy sector:

- The presented solutions of the HRE scenarios recommend the shift towards a more capital-intensive heat supply, however, with much lower operational costs due to a heat supply mainly based on renewables and excess heat. With this shift fossil fuel imports which currently amount to a value of about € 50-65 billion for natural gas alone, could be phased out and economically be replaced by local added value chains of energy efficiency and renewable energy across the European countries.

- With the comprehensive energy system modelling approach of HRE4 it was analysed how a reduced consumption of fossil fuels can be achieved in order to potentially eliminate the countries' dependence on imported oil and natural gas for heating purposes and the uncertainty related to future fuel prices.

- The decarbonisation of the H&C sector will open the market for locally based heat sources and thereby increase the security of supply and making the countries more resilient to geopolitical changes, while enabling the implementation of increased amounts of fluctuating renewables.

- The restructuring of the thermal energy system will create and maintain local jobs related to energy efficiency and renewable energy products and services. Moreover, the redesign would significantly strengthen the competitiveness of industries, nationally as well as internationally.

6	**HRE4 shows how an energy system transition can facilitate the integration of at least 87% renewables in total. The HRE 2050 scenario does not hinder but rather enables the possibility of further RE implementation by decarbonising also the remaining fossil fuel use which primarily is allocated to transport, industry and flexible CHP.**

Countries' long-term climate and energy targets of the EU must be translated into adequately ambitious short-term actions through policies that facilitate the energy transition in the electricity, thermal and transport sector. Cross-sectorial, complementary efficiency and renewable targets applied at all governmental levels will be essential for realising a sustainable low-carbon society. Integrated management, knowledge transfer, holistic energy planning tools, open business models with broader forms of collaborations and incentives are some of the most important aspects that need to be carefully addressed, since in most cases the barriers faced are political, regulatory and organisational rather than technical.

- A horizontal integration of these targets (into all sectors such as electricity, heating and cooling, transport etc. incl. their subsectors) combined with vertical integration of targets (throughout governmental levels) should be applied. Besides this, it is important to ensure not only targets, but actual policy implementation and realisation, with regular reporting and evaluation cycles on progress and impact.

- It is recommended to increase the targes of savings for space heating in buildings by 2050 to at least 30% compared to 2015 which in general requires higher annual refurbishment rate at 1.5% to 2%, and deeper renovation of existing buildings that anyway undergo a renovation.

- National policies should incentivise flexible interaction for prosumers to help balance electricity grids and not maximise self-consumption which in some cases will be counterproductive for the overall energy system.

- An investment initiative – both at EU level and at national level – for comprehensively and fast expansion and establishment of systematically new district thermal infrastructures in urban areas and roll-out heat pumps in rural areas should be initiated. This financial framework has to be aligned with policies reflecting the reduced role and appliance of natural gas and an increased importance of electricity grids.

- More support is also needed to ensure implementation and higher energy saving targets for both deeper renovation of the existing building stock and investments in industry. Stronger price signals (e.g. energy obligation schemes or taxes), together with information-availability (e.g. smart meters), communication (e.g. “nudging”), as well as the proper education of craftsmen and citizens, will be crucial drivers.

7	**HRE recommends a complete decarbonisation of H&C by 2050 and shows how this can be done. Contributions from all energy sectors have to support the implementation of such decarbonisation targets to ensure the most cost-effective and socially acceptable pathway. National governments should evaluate the outcomes of HRE4 and consider using the appropriate national Heat Roadmap, together with the Peta mapping tool, for their comprehensive assessment, especially with regard to article 14 of the EED[3].**

- Long-term targets and aligned policies must all facilitate the energy transision towards a sustainable low-carbon society. Integrated knowledge, planning tools, business tools, innovative collaborations and incentives are needed since in most cases the barriers faced are political and regulatory rather than technical.

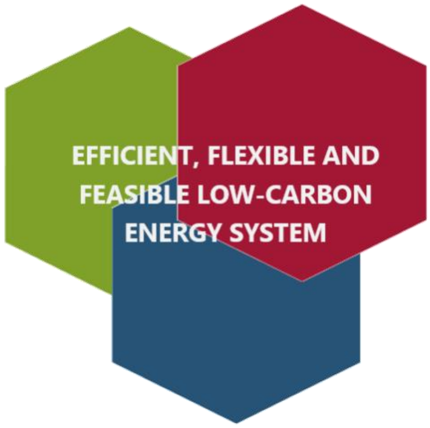
- National and regional/local analyses of exisiting options for various consumer types and locations can help identify where there are needs for financial support and necessary interventions to overcome other types of barriers as well.

8	**Mandatory National Energy and Climate Action Plans should be combined with local and regional energy planning processes. National authorities should technically and financially support the integration of knowledge and efforts of sub-national authorities. This multi-governmental approach will improve the quality and interlinkages of all planning levels and maximise their combined impact over time and across sectors.**

- The following complementary measures for the recommended key actions with the purpose to remove barriers have been identified:
  Planning and knowledge:
  - Requiring, and adequately supporting, comprehensive energy planning at local and regional levels, including mechanisms to ensure actual implementation of measures and regular re-evaluation of their status, will improve the foundation for public authorities and other key stakeholders to make decisions and implement policies, by analysing various opportunities and alternative pathways towards decarbonisation.

[3] Referring to the Energy Efficiency Directive [3].

- Aligning national with sub-national policies (of course, also to be in line with EU goals) to work together towards the same end-goal.
- Raising awareness and formulating a common narrative for all Europeans that the decarbonisation of our society is not only possible, but cost-effective and affordable with existing technologies available on the market today and much more profitable for our local economies.
- Setting up frameworks to improve qualifications and the number of skilled professionals.



Promote investments:

- Ensuring certainty (predictability) for investors, avoiding “stop-and-go” measures.
- Removing administrative barriers for stakeholders to establish district heating and cooling and excess heat recovery[4].

Remove fossil fuel competitiveness:

- All fossil fuel subsidies should be stopped immediately including also indirect support such as incentive schemes for gas and oil combustion boilers.
- Fossil fuel boilers should be phased out. Expiry dates should be set combined with banning the installation of fossil fuel boilers in new buildings. This should go hand in hand with stronger support for alternatives (e.g. renewables and sustainable excess heat) and thus potentially avoiding increased costs for end-consumers.
- Expiry dates for fossil fuel power production should be set to avoid investments in new (long-lasting) fossil-based capacity and provide certainty for the power industry to invest in sustainable solutions.
- Improving feasibility of a sustainable energy system directly and indirectly by introducing a CO_2 taxation.

- On a European level, the EU ETS[5] today does not reflect actual costs of emissions and cannot be fully entrusted with the task of making consumers or producers discard fossil-based supplies and/or adequately ensure that investors will support the uptake of energy efficiency and RE capacities needed to displace fossil fuels. Therefore, carbon taxation should be applied also at national levels to augment and complement what is covered at a larger scale by the ETS (as mentioned in the last point above).

- In general, national (and EU) financing schemes should be more closely linked to energy efficiency and emission reduction potentials of the various activities they support.

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[4] In some cases, even small industries would need the same level of approval as an electricity production utility if they are to enter an agreement on selling their low-temperature excess heat.

[5] EU Emissions Trading System [4]. In short also referred to simply as “ETS”.

HRE resources available to support the energy transition

The HRE provides a range of new information to empower the decision processes and improve the foundation for political and technical choices on the most cost-effective and affordable pathways towards a decarbonised energy system. These include among others, detailed profiling of the present H&C demands by subsector, cost-curves for reducing the H&C demand in buildings and industries[6], and complete energy system model datasets which users can modify to investigate for themselves the likely impacts of alternative scenarios. HRE has the aim provide a transparent approach to democratise the debate on how future energy systems can and should be structured.

Guidelines for the energy system transition with a *local/regional* and *national* approach respectively are also available, and may be useful to get an insight into variations of these recommendations from either perspective. All project reports are available on the HRE website. Two outcomes stand out in particular as major results building upon the knowledge gathered from the other HRE analyses: The Pan-European Thermal Atlas and the energy system scenarios of the 14 HRE countries.

- The Pan-European Thermal Atlas (*Peta*) represents a publicly available interactive online portal to support planners, investors and policymakers by presenting and quantifying H&C possibilities (geo)graphically for all 14 HRE countries. The following features are included amongst others:
    - Heating and cooling demands, each on a hectare level.
    - Renewable heat resource potentials such as geothermal, solar thermal and biomass.
    - Pinpointed potential excess heat sources e.g. from waste incineration, power plants, data centres and industrial processes.
    - Existing and prospective district heating areas including the cost of establishing network infrastructure and indications of the recommended shares of district heating.
    - Heat Synergy Regions highlighting the overlap of demands and identified excess heat – indicated as an "excess heat ratio", i.e. the ratio between excess heat and heat demand within a given region.

- The development and findings of the modelled HRE 2050 decarbonisation scenarios including methodologies used, different energy demands, different energy supply technologies, their role within the wider energy system and how these compare with alternatives [1]. Country-specific results such as the recommended balance between energy savings and district heating are included in the 14 individual country reports. Collectively, these 1+14 reports hold the title: *Heat Roadmap Europe – Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps.*

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[6] The cost-curves shows the cost of reducing the demand depending on how ambitious the target is, i.e. what are the cost of measures, when "low-hanging fruits" have been exploited and further savings are required.

Table of Contents

1. Introduction

In Europe, there is a clear, long-term objective to decarbonise the energy system. The Heat Roadmap Europe 4 (HRE4) project, co-funded by the European Union, seeks to enable new policies and prepare the ground for new investments by creating more certainty in relation to the changes that are required.

HRE4 provides new capacity and skills for lead-users in the heating and cooling (H&C) sector, including policymakers, industry, and researchers at local, national, and EU levels. This is done by developing the data, tools, methodologies, and results necessary to quantify the impact of implementing more energy efficient measures on both the demand and supply side of the sector.

The results of HRE4 show how a complete decarbonisation of the European heating and cooling sector is technically feasible and economically viable, and can be achieved with proven technologies already used today. The "Heat Roadmaps" representing decarbonisation pathways for 14 EU countries[7] towards 2050 (covering approx. 90% of the EU heat demand) show how this can be done, and all the available HRE outcomes such as guidelines and interactive tools can help stakeholders facilitate this transition.

This report emcompasses *key messages and recommendations* based on the overall HRE4 project targeting policymakers at national level. It should be noted that these will also apply beyond the boarders of the 14 analysed countries.

The overarching "pillars" of HRE (see section 2) identified to be the main focus areas each represent one section headline. These sections include key messages related to the topic including explanations of the context regarding why this is important as well as how the raised points apply to policymakers, how the HRE outputs can be used, and how to apply the outputs to policies.

> The development and findings of the HRE scenarios including methodologies used, different energy demands, different energy supply technologies, their role within the wider energy system and how these compare with alternatives are described in the report
> *Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps* [1]
>
> A guideline similar to this report only aimed at local and regional policymakers may also be of interest to the readers to get an insight in the in recommendations from this perspective:
> *Guidelines for the Energy System Transition – Recommendations for Local and Regional Policymakers* [5]

[7] The HRE4 project especially focuses on those fourteen EU countries with the highest H&C demands (around 90% of the EU's total demand): Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Spain, Sweden and the UK.

2. An integrated approach in planning and policies

2.1. Three main pillars to decarbonise the H&C sector

The HRE4 project identifies three main pillars, which are especially critical to address in order to facilitate the transition towards a future low-carbon H&C system. These are closely linked. Hence, in many cases the recommendations cover more than one of them. Figure 1 below sketches the pillars as well as interconnections between them. Examples for each of these pillars (hexagons in Figure 1) district heating (DH) or district cooling (DC) in urban areas – fed by renewable energy (RE) or excess energy, building renovations to improve energy efficiency (EE) and heat pumps (HP) for space heating and domestic hot water in rural areas.

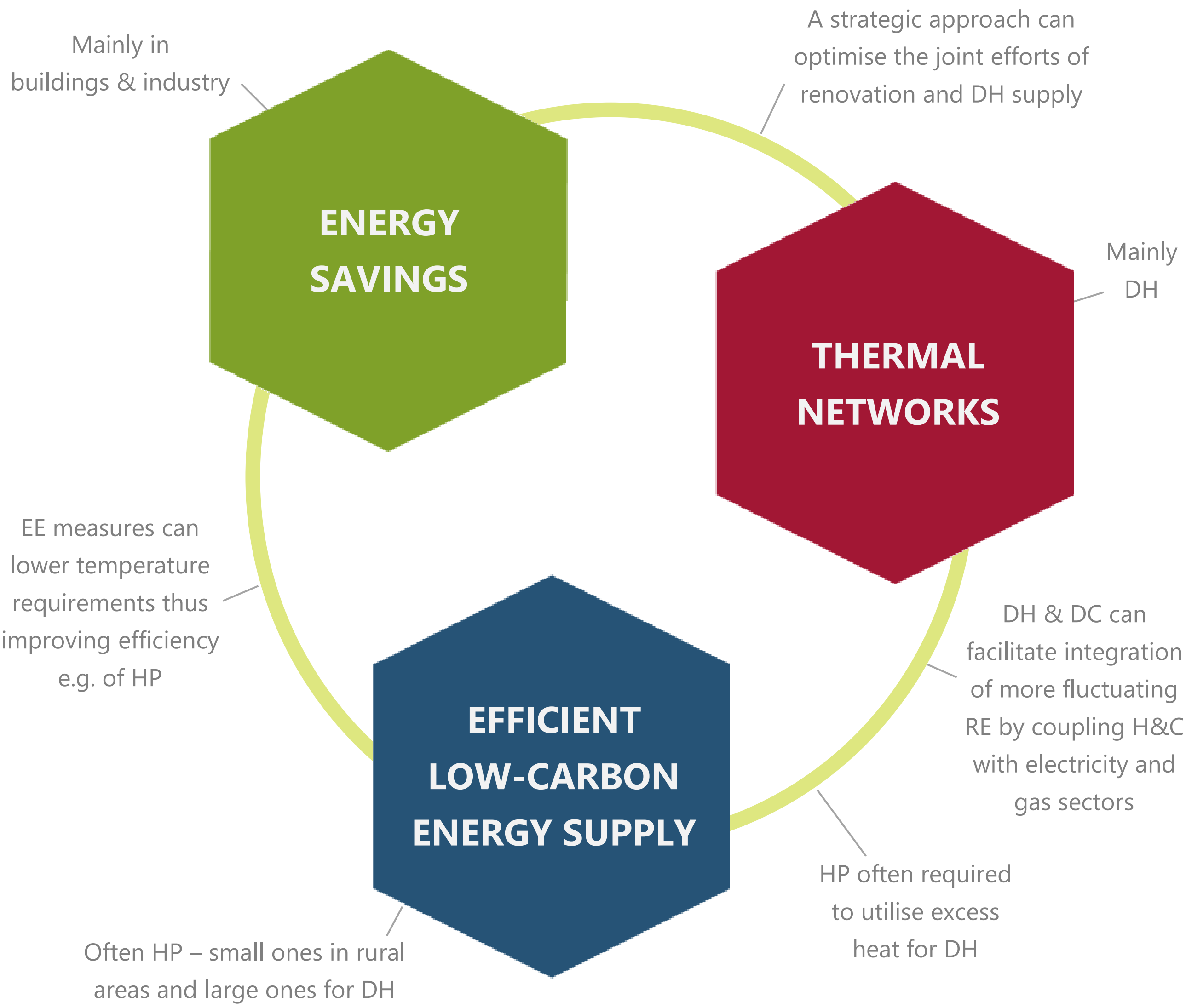

Figure 1. The three HRE "pillars", including examples of linkages between them.

The "Heat Roadmaps" of each of the 14 countries are commonly referred to as the HRE 2050 scenario. They should not be considered as the exclusively definited and only viable future sustainable energy roadmap, but rather as solid, cost-effective and affordable pathway presenting how the benefits and synergetic opportunities can lead to a feasible, decarbonised future in accordance with the Paris Agreement. One aim is to democratise the debate on how future energy systems can and should be structured.

Detailed energy system modelling has been used to take into account short-term hourly interactions of demand and (renewable) supply and including both challenges such as balancing requirements, and opportunities such as cross-sector links, while also looking at the long-term developments of the overall energy system and its demands towards 2050. This makes it possible to consider the connections between demands and supplies for heating, cooling, electricity and transport to optimise the overall system. HRE 2050 shows a 86% decrease in CO_2 levels compared to 1990. The remaining fossil fuels are primarily in transport, industry and flexible CHP. In this context it should be mentioned that HRE 2050 does not hinder but rather *enables* the possibility of further implementation of renewables[8].

1	**The holistic HRE approach – which jointly considers electricity, heating, cooling and transport – reveals synergies between (and within) these different sectors and shows that decarbonisation is indeed possible and affordable with existing, mature and market-ready technologies.**

The cross-sectoral energy planning approach of HRE reveals the following:

- Increasing the share of district heating and cooling, including cheap thermal storages, helps to stabilise the electricity grid when introducing more (non-dispatchable) variable renewable energy (VRE).
- Substantial energy savings in different sub-sectors are possible, feasible and recommendable for each of the targeted countries.
- An integrated approach considering the energy demands for transport, electricity, heating and cooling as a whole can release larger savings as a result of synergies.
- Even without including the significant health-related and climate change-related costs [6,7], decarbonisation can be achieved at lower costs than "conventional decarbonisation"[9] only,

[8] See section 4.4.
[9] The HRE 2050 scenario (one per country) can be compared with the 2015 situation, a baseline development towards 2050 and the "Conventionally Decarbonised scenario" (CD 2050). CD 2050 represents an energy system targeting 80% reduction in EU CO_2 levels compared to 1990 levels and assumes encouragement of RE but without the same focus on savings and a redesigned H&C sector as in HRE 2050, cf. [1].

while reaching even greater CO_2 reductions. However, it requires a massive changeover of the current system design and framework conditions to support it.

These results should subsequently encourage policymakers to choose their own prioritisation – economic feasibility, environmental impact, quality of life, etc. – but nonetheless it is expected to reach the same conclusion regardless of priorities: that remains no reason to delay pushing this development forward.

> The results of the baseline scenario showing the path towards 2050 with current policies is included in the report below. Furthermore, it contains a description of the energy modelling tools that can be further used – even beyond the HRE4 project. This provides a basis for understanding how markets will likely develop under current policy, and which markets need further development of their framework conditions in order to contribute to full decarbonisation.
> *Baseline scenario of the total energy system up to 2050* [8]
>
> For users who want to evaluate, elaborate or adjust these models themselves, the freeware and baseline scenario *input files* are publicly available, presenting hourly energy system models for each of the 14 countries for both 2015 and 2050.
> *Hourly energy system models for each of the 14 MSs for the business-as-usual scenario* [9]

The following sections represent the main findings and associated policy recommendations covering these three complementary pillars based on the complete energy system modelling of each of HRE's 14 target countries.

Just like the integrated energy system approach covers the challenges and opportunities in a holistic manner, the points raised in the following text should not be considered applicable only to a single pillar, but rather something that builds upon each of them, reinforced by the interconnections.

A key point derived from the results of HRE is that the presented decarbonisation roadmaps require *combined* efforts of energy efficiency measures, an efficient low-carbon H&C supply with increased electrification and a significant deployment of more district H&C. These synergetic effects will not be realised to the full extent possible if policymakers fail to take the potentials of all pillars and their linkages into account.

2.2. National leadership required to set the bar higher

Though national governments may wish to push for sustainable development, they may at the same time be concerned with risking (short-term) reduced competitiveness for their own country's industries if hard taxation and/or sustainability criteria are applied without any corresponding support to facilitate their transition towards sustainability. Even with the aim to balance support and taxation for the involved local to national stakeholders to steer the energy transition, some stakeholders in the countries will be negatively affected more than others, and thus oppose the change. Long-term political goals and corresponding stable frameworks (e.g. "raising the bar" continuously), can let these stakeholders plan ahead already and thereby start making wiser (transition) decisions now to avoid cost increases in the future.

Whereas private stakeholders often focus on short return-of-investment periods, national governments are more amenable to investments with a longer time horizon. It is therefore up to these authorities to facilitate, and even lead, the transition towards a decarbonised society, and not focus merely on the next annual budget for the country. By developing both short- and long-term energy planning, countries can base their chosen pathway on informed choices whereby economic savings, profits and even non-financial improvements[10] become more evident.

2	**Though some national governments are reluctant to pursue ambitious energy and climate targets, HRE calls upon national policymakers to develop and support the required planning, consider the long-term benefits and act accordingly by enabling other national stakeholders to contribute in the transition towards a decarbonised society.**

Stricter efficiency requirements applied to products related to buildings and industrial processes, can prove to be an advantage for countries' exports[11] since sustainability requirements across *all* sectors will create improved technologies and products thus increasing the competitiveness globally in the long run where sustainable technologies and production chains are indeed the only viable option.

[10] Such improvements can include higher living standards and quality of life in a broader sense.
[11] In accordance with one of the objectives of The Energy Union – to make the EU the world number one in renewable energy and lead the fight against global warming.

3. Realising essential and feasible energy savings

3.1. Energy savings is not a single-player game

HRE identifies substantial amounts of cost-effective energy savings ready to be exploited and highlights that these are key for the decarbonisation of the energy system. It is recommended to target at least 30% savings for space heating in buildings by 2050 (compared to 2015) which requires a higher refurbishment rate of 1.5% to 2%, and deeper renovations when they occur. As a precaution, such a target could be set somewhat higher since the results of HRE show only little difference in socio-economic costs while there is an inherent risk that whatever targets are set, the savings realised may fall short of reaching these. However, when targeting energy savings objectives, it should be remembered that the goal should not be the savings per se, but rather emission reductions. Hence, the extent of savings should be balanced with alternatives such as RE-based supply as illustrated in Figure 2.

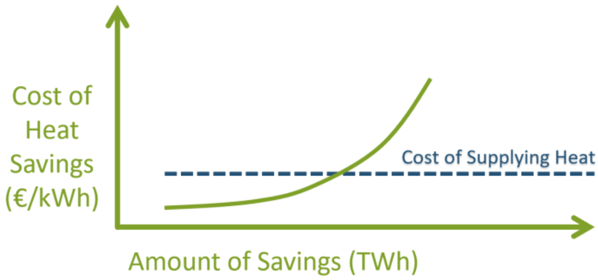

Figure 2. Illustration of the principle that savings should be realised to a certain extent, until it becomes more relevant to apply a decarbonised heat supply.

3	**Energy efficiency is required on both the demand and supply side to cost-effectively reach decarbonisation goals. To meet its greenhouse gas emission reduction target by 2050, the EU needs to combine energy efficiency measures with the decarbonisation of the energy supply.**

Decarbonising Europe's building stock is not an "either/or" decision between energy efficiency and the deployment of renewables, but needs a system focus on both. The balancing of necessary investments to achieve demand reductions vs. a decarbonised energy supply should be optimised.

Cost of savings should be balanced with cost of decarbonised supply. It is important not to promote one over the other in an unbalanced way, among others in relation to EPBD. Building performance assessments and similar sets of rules as well as the EU framework on cost-optimality calculations for nearly-zero energy buildings must consider systemic measures and individual measures, efficiency and renewables, and onsite and offsite energy solutions equally. This means for example that primary savings through using waste heat and through a more efficient building need to be compared on a non-discriminatory basis while taking into account more than just one individual building. Similarly, individual RES solutions like PV panels should not be considered as energy savings as it is the case, when using a purchased energy approach. On the contrary, RES onsite and offsite must be treated in a non-discriminatory way that reflects the actual contribution to a better performing building.

When considering the contribution of sustainable energy sources, be it RES or excess, the use of primary energy factors (PEFs) has a key influence on the way this happens. They are crucial in policies implemented in relation to both the EED and to EPBD. It must be ensured that methodologies in general reflect the real energy mix and it is worthwhile to consider seasonal variations in the use and supply of energy.

Similar to the case of PEFs, also other indicators must treat all options in a fair manner. The smartness readiness indicator[12] should consider heat and electricity equally e.g. in a way that *demand side management* and *demand response* solutions are included[13].

> By investigating the energy savings potentials – including their sub-sectors, type of savings and associated costs – HRE4 has evaluated how the costs increase as the energy efficiency ambition-level rises. This is graphically represented as "cost-curves" which naturally vary from country to country. The information can be used when developing national scenarios targeting a certain savings potential. The same methodology is applied across all countries, which makes the cost-curves of different countries directly comparable. This can be used to identify suitable policymaking and other solutions from third countries which may have a potential for replication. The report below describes how to relate investments to delivered energy savings.
>
> *Cost-curve Guide for Lead-Users* [10]

3.2. Ensuring the implementation of savings

By investigating the potential and corresponding cost of a wide range of concrete energy savings measures (sub-groups within residential, tertiary and industry) it has been analysed to which extent these can be implemented economically including a comparison with alternative means of covering demands (e.g. supplying more RE instead of implementing some of the savings). The results show that in some countries the ambitious policies passed on since the 2010 EPBD[14] are already enforced

[12] Article 8 of the 2018 EPBD states the following: "The [smart readiness] rating shall be based on an assessment of the capabilities of a building or building unit to adapt its operation to the needs of the occupant and the grid and to improve its energy efficiency and overall performance."

[13] See also section 4.5 regarding consumer flexibility.

[14] Directive 2010/31/EU on the energy performance of buildings.

in national laws meaning that the baseline scenario includes roughly the same level of savings as in the Heat Roadmaps. To achieve these savings the focus needs to shift from encouraging ambitious policy targets towards ensuring *implementation* to the extent of complete achievement of these goals. It is vital that defining the goals does not become a pretext for inaction.

4	**While Belgium, the Czech Republic, Hungary, the Netherlands, Poland and Romania need to significantly enhance their current legislation on energy efficiency, other countries already-passed policies that would lead to a substantial, cost-effective reduction in residential heating demand. Therefore, the latter group should focus on the effective implementation of these policies.**

HRE4 finds that in Belgium, the Czech Republic, Hungary, the Netherlands, Poland and Romania there is a need to significantly improve/upgrade current legislation to increase their energy savings efforts, while (as in all countries) keeping a focus on supporting policies to ensure that the expected savings are reached in practice. Regular follow-up evaluation on the progress and impact on legislation and support schemes is important to ensure that expected targets are met.

Considering the lifetime of buildings compared to other investments, planning is needed for 2050 in which the development of built area quantities including types of demand, renovation rates, and uncertainty of compliance should be taken into account. Once investments have already been made for "low-hanging fruit" in energy efficiency renovations, the remaining savings potentials will have higher investment costs, and therefore need to be made attractive for end-users to invest in them. It is relevant to distinguish between refurbishment *rates* of 1.5%-2% per year and refurbishment *depth*.

5	**Supporting deeper thermal renovation of buildings that will anyway undergo a renovation could avoid an important missed opportunity. Financial incentives should be combined with increased awareness and education of related companies and craftsmen.**

Stronger price signals (e.g. energy obligation schemes or taxes), together with low-cost financing schemes for decarbonisation investments, information-availability (e.g. smart meters), communication (e.g. "nudging"), as well as the proper education of craftsmen and citizens, will be crucial drivers to ensure realisation of the necessary savings to reach the decarbonisation goals across Europe. These are not technical barriers but can all be addressed if the political will and required efforts are put into the processes.

The Heat Roadmaps use the abovementioned cost-curves for each of the 14 countries highlighting to which extent energy savings should be applied in the context of various energy system configuration alternatives. The report below can support policymakers by presenting the costs and benefits of targeting various (sub-)sector-specific efforts relevant to establish suitable frameworks to steer a development towards recommended savings levels.
Cost-curves for heating and cooling demand reduction in the built environment and industry [11]

3.3. Feasible heat savings potential in industry

By assessing the cost of heat savings depending on penetration level and sectors (Figure 3), HRE4 finds that energy savings in industry are highly cost-effective from a socio-economic perspective. Since industries often benefit from economies of scale (e.g. larger equipment, greater demands and/or higher annual full-load hours) not found in the residential or tertiary sector, the result is that smaller investment costs are needed for industrial heat savings than in residential buildings within most countries.

Figure 3 below shows for all 14 HRE4 countries the 2050-cost curves for industrial heat savings. All curves start in the bottom-right corner representing the demand in the baseline. Moving left along a curve corresponds to reducing the demand (i.e. applying savings) as seen in the primary axis. The associated costs[15] per MWh saved can be read from the secondary axis. At some point all “low-hanging fruit” has been “picked” and the cost of reducing even further becomes higher. Where the curves are almost vertical, additional savings becomes extremely expensive. This way the cost of adding additional savings can at all times be compared with the cost of supplying low-carbon heat (cf. Figure 2). It is seen that low-cost savings are possible for all countries. Similar analyses have been made for cooling demands and the residential and service sector.

[15] Specific costs are based on the annualised investment costs divided by the heat savings; energy and operation and maintenance costs are excluded.

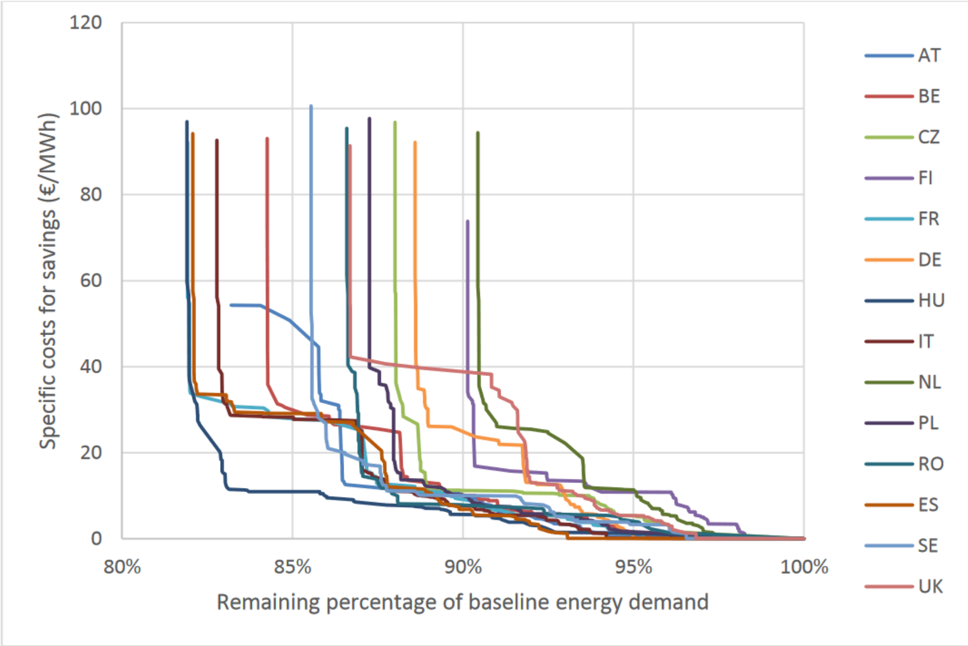

Figure 3. 2050-Cost curves for industrial heat savings for the 14 HRE4 countries [11].

The extent of heat savings in industry tends to be more limited than in buildings, because the temperature levels of many industrial processes cannot easily be lowered (and some savings have already been implemented). However, energy efficiency measures with small investment costs compared to the reference technology have been identified e.g. increased paper recycling and a shift from blast furnace steel to electric arc steel. Efficiency standards and/or financial incentives for process heat savings should be ensured to realise this potential. Up to now energy prices are still too low in Europe to serve as an economic incentive for industry to proactively investigate the potential integration of excess heat into existing or new district heating systems. Obtaining the permission to provide excessive heat to consumers should also be facilitated.

> Specific industrial savings categories including the potentials and cost levels per kWh saved is described in section 3.4 of the report mentioned above:
> *Cost-curves for heating and cooling demand reduction in the built environment and industry* [11]

Working towards a circular economy approach to the energy sector, could result in an even larger share of savings by recycling resources, both materials and energy.

6	**Efficiency standards and financial incentives should reflect the highly cost-effective potential for energy savings in industry and the service sector from a socio-economic perspective. Excess heat should be regulated, as the quantities of energy losses are contradicting not only the climate targets, but also enable the affordability of the decarbonisation of the economy in Europe.**

3.4. Energy savings and district energy combined

Introducing energy efficiency measures does not necessarily make district heating and cooling unfeasible, whether for existing or new networks. In fact, energy efficient buildings can effectively shave peaks and improve the performance and feasibility of the entire (new or existing) district energy network. With new or renovated energy efficient buildings, a new network can be designed for low temperatures whereas an existing network peak demand can be reduced, while/or additional consumers can be connected to the same grid. In district heating, the relatively small number of hours per year with peak demand are often the most expensive – in terms of OPEX and/or CAPEX (since the capacity required may have few full-load hours per year).

7	**Energy efficiency measures in buildings and district energy can be seen as complementary solutions, not in opposition to each other as commonly thought.**

Not only are low-temperature district heating networks in general more efficient, but they are also better equipped to take advantage of a wider variety of heat source input options – e.g. low-temperature excess heat with or without the need of applying heat pumps.

3.5. Energy savings and individual heat supplies

Similar to the synergy effects highlighted in 3.4 above, the combination of energy efficiency in buildings and an energy efficient individual supply can contribute to the overall efficiency and decarbonisation of the heating/cooling systems more than either one on its own. One example is the replacement of a boiler by a heat pump. Heat pumps run very efficiently in new buildings and in those that have undergone deep renovation. In all other cases, a proper assessment of the energy demand is necessary for a proper heat pump system design. If the operation temperatures of the heating system are low enough, the necessary energy can be provided by a heat pump. If not, energy efficiency measures should be applied to the building envelope and the heat distribution system before installing the heat pump.

In general, heat pumps run most efficient (expressed as the COP/SCOP[16]), if the difference between energy source and the needed supply temperature of the building is as small as possible. Optimising the building envelope and/or the heat distribution system can in some cases be a requisite to make the building "heat pump ready" and thus enhance the technologies application area – on top, it will improve the comfort level of inhabitants.

[16] The coefficient of performance (COP) represents the efficiency of a heat pump – as an annual average also referred to as seasonal coefficient of performance (SCOP).

4. Ensuring an efficient, low-carbon energy supply

4.1. Electrification of H&C is a key piece of the puzzle

Electrical heat pumps should be implemented to a much greater extent – both individual ones in rural areas where thermal networks are not feasible and in urban areas where they can make the use of low-temperature renewable and excess heat sources possible.

8	**Where decentralised H&C systems are more feasible than centralised thermal networks, individual heat pumps should be promoted, since they can simultaneously contribute both to direct decarbonisation and to the flexible integration of renewables.**

The results of the Heat Roadmaps show that a too uniform energy transition focusing only on few solutions (such as full electrification without integrating district heating) would not result in the most cost-efficient future energy system configuration. All the "players on the field" should be considered as possible contributors of the (optimum) energy mix, and energy system modelling should fully take into account specificities of the H&C sector – only then can potential synergies be obtained. Revealing these opportunities requires knowledge on the various demands, available sources and costs of infrastructure – all in high spatial resolution – as well as detailed energy modelling in a short timewise resolution combined with a long-term horizon. Such a combination of mapping and modelling is essential to analyse the heating and cooling sectors but should be expanded to other parts of the energy system in the future.

The Pan-European Thermal Atlas (*Peta*) is a public online interactive portal to support planners, investors and policymakers by presenting and quantifying the possibilities in a (geo)graphical manner for all 14 HRE countries in terms of, among other features: a) H&C demand densities on a hectare level and b) various heat sources to decarbonise the H&C sector, such as geothermal sources, solar district heating potentials, residual biomass resources and excess heat from waste incineration plants, power plants and industrial processes respectively. More information on *Peta* can be found directly in the online map or in the report

Maps Manual for Lead-Users [12]

The details regarding the underlying methodology which the maps are based on is described in *Methodology and assumptions used in the mapping* [13]

4.2. A sustainable supply is required for all future demands

Not only a conversion of the existing energy demands is required. Targets and corresponding planning should reflect the future supply needs taking into account the increasing demands following economic growth and increased electrification for heating, cooling, transportation – e.g. electric vehicles (EVs) and industries such as datacentres. A renewable electricity capacity to cover 100% of the existing electricity demands would therefore not be enough.

By profiling the energy demands it is shown how important H&C is when aiming for a decarbonised energy system. With a final energy demand (FED) of 6,350 TWh in 2015 (22.9 EJ), H&C accounts for around 50% of the EU28 FED.

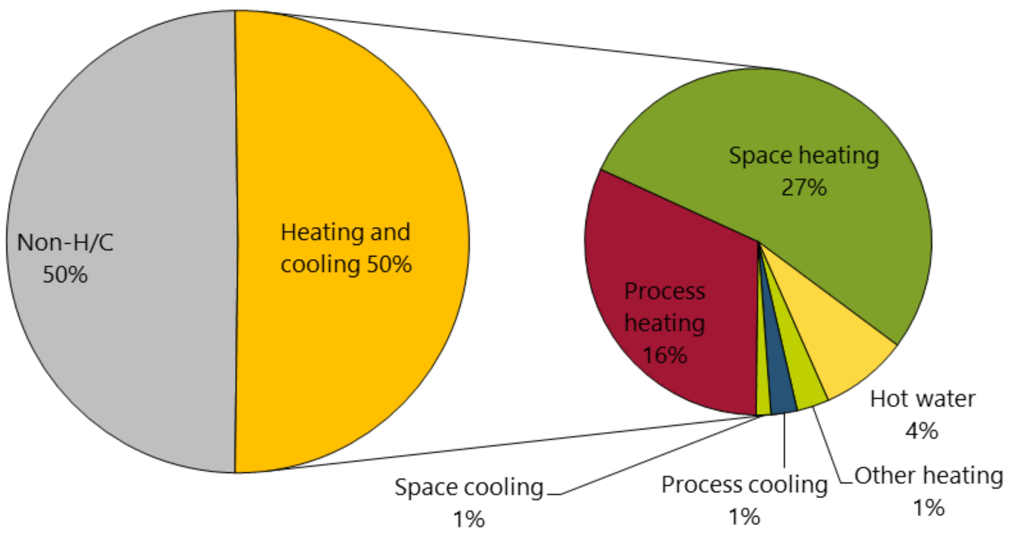

Figure 4. H&C demand in 2015 in the EU28, by end-use, compared to total final energy demand [14].

HRE4 presents a wide extent of freeware data for anyone to use for further analyses. This includes the descriptions of profiling the 2015 energy demand for H&C developed by calculating energy balances for all 28 EU countries. Besides the report including a methodology and summary of main results, the 2015 H&C profiles for all EU28 member states are freely available for download as interactive spreadsheets.

Profile of heating and cooling demand in 2015 [14]

Besides this, the scenarios of current policies are presented towards 2050 (i.e. targets and measures concerning RE H&C and energy efficiency, which have already been agreed or implemented at the latest by the end of 2016). These are described in:

Baseline scenario of the H&C demand in buildings and industry in the 14 MSs until 2050 [15]

> A guide for how lead-users can utilise the demand data for 2015 and 2050, technology datasheet, and FORECAST tool is described in the report
> *FORECAST Guide for Lead-Users* [16]

The use of biomass in boilers and CHP plants should not be considered an "easy-fix" solution to cover all the decarbonisation demand. In the future there will be an increased demand for biomass as it will have to cover several fossil-based demands of today such as bioplastics and biofuels for transport. For any biomass demand purpose, strict national and European sustainability rules will be crucial to ensure that it is sourced in a sustainable and effective manner, preventing deforestation and other harmful effects.

4.3. Carbon taxes and investor security

Across all pillars a consistent and reoccurring argument from various stakeholders is that an adequate carbon tax is needed to make the recommended decarbonisation solutions economically feasible and to accelerate their deployment in the medium to long run. If state revenues from such increased carbon taxation is fed back to the same stakeholder groups in the form of support for decarbonisation solutions, it can minimise the overall negative economic impact on the affected companies/end-users. This way the focus can be on the support scheme(s) and common goal(s) rather than what may be a (general) negative impression of increased taxation.

As a simultaneous and important step, all fossil fuel subsidies should be stopped immediately since these are directly counterproductive to the agreed climate targets.

For all the additional capacity needed as explained above (section 0) what is needed for investors is *certainty*. Feed-in tariffs could prove efficient to ensure stakeholder engagement (i.e. continuous RE capacity deployment) even when the RE shares are increased and electricity prices become harder to predict. The price of EU ETS allowances does not in itself provide the certainty for investors to promote new RE capacity. The dilemma of applying feed-in tariffs (to ensure that investors get a minimum price) or not can be boiled down to who should cope with the uncertainty of future energy prices – investors or MSs. Allocating the entire risk to investors may result in additional overall cost of the energy transition (included by investors to cover the risks) and/or to prolong the required changes.

In many cases the feasibility of converting from the fossil-based status quo to a low-/non-carbon alternative is simply not incentivising enough (if even positive) to realise the transition in practice. One example is the widespread use of natural gas boilers used for space heating which is recommended to be phased out (along with inefficient direct electric heating). Though taxation is a strong mean to encourage sustainable choices for the industry, residential and service sector, it cannot stand alone as the only mean promote the energy transition but should rather be considered as one part of a complete package towards decarbonisation.

A starting point for the abovementioned example is to ban the installation of fossil-based heat supplies in new buildings and phase out the ones in existing buildings. This measure – together with increased fossil fuel taxation – could go hand in hand with support for the shift to alternatives (e.g. subsidies or tax discounts). In order to minimise the impact of those who are used to their fossil fuel demand (e.g. natural gas) and associated costs, the economic incentives to shift to alternatives could be implemented simultaneously in order to keep a similar level of expenditures for the consumers.

To achieve this in a feasible manner, a combination of strategic national planning and local energy action-planning is needed to analyse which precise options are most suitable for various consumer types and locations within the country. Such an approach could help identify the exact needs of financial support in a country, and in which manner that various barriers could be overcome. HRE's country-level Roadmaps and its *Peta* mapping platform can be very useful resources to do this, providing a solid first impression to guide future work to be done. National governments should evaluate HRE outcomes and take advantage of the appropriate Heat Roadmap for their country, together with exploring the *Peta* tool within their territories since this approach can prove particularly useful for countries' comprehensive assessment related to article 14 of the EED[17]. In any energy system transition process easy and free (online) access to energy data and visualisation of the information should be made available to enable and facilitate decision-making beyond political boundaries and between stakeholders. Tools like *Peta* or similar should be used for the thermal planning.

9	**Mandatory National Energy and Climate Action Plans should be combined with local and regional energy planning processes. National authorities should technically and financially support the integration of knowledge and efforts of sub-national authorities. This multi-governmental approach will improve the quality and interlinkages of all three planning levels and maximise their combined impact over time and between sectors.**

On a European level, the EU ETS[18] today does not reflect actual costs of the damaging effect of emissions (and obviously distinguish between those polluters covered by the ETS and those who are not). At the same time industries are granted with free quotas allowing for continuous fossil fuel-based production. There is a need to plan for the phase-out of this fossil fuel demand already now.

[17] Article 14 of the EED states that MSs should carry out a comprehensive assessment of the potential for the application of high-efficiency co-generation and efficient district H&C.
[18] In short also referred to simply as "ETS".

Defining long-term plans including a continuous increase in emission taxes could be a signal to investors showing what is considered a sustainable path forward and what is not, thus providing a more solid foundation for decision makers.

Though the ETS can play a key role in the energy transition, it is important to avoid the shift of CO_2 emissions from ETS to non-ETS sectors. Whereas the (typically centralised) electricity production required for these heat pumps are covered by the ETS, the residential use of fossil fuels (e.g. gas boilers) are not. This represent an unfair advantage favouring fossil fuel-based heat supply. Taxation should cover also emissions beyond ETS to promote decarbonisation outside urban areas.

In general, carbon taxation and pure market mechanisms cannot be entrusted with the task of ensuring the energy transition alone, because of the following points:

- Other than improving the feasibility of low-carbon solutions (in)directly (e.g. support/taxation) and supplying access to affordable financing schemes, many other, non-financial barriers must also be overcome, for example by means of the following solutions:
    - Requiring, and supporting, comprehensive energy planning at local and regional levels, including regular re-evaluation of their status, to improve the foundation for decisions and policies, while also analysing various opportunities and alternative pathways towards decarbonisation.
    - Aligning sub-national to national policies (as well as to EU ones) to work together towards the same end-goal.
    - Removing unnecessary administrative burdens.
    - Setting up frameworks to improve the qualifications and quantity of skilled professionals working in related fields.
    - Formulating a common decarbonisation narrative to help raise awareness among all citizens that the energy transition is something to be realised together, that all (and even the environment) can prosper from, and – with sufficiently ambitious targets – is a goal to be proud of.
    - Providing certainty and predictability for investors in these sectors, avoiding "stop-and-go" measures, so that they can feel secure in contributing funds.

- Broad market mechanisms will have a smaller and smaller impact as the RE share is increased. As the RE share increases in some countries/regions while others will lack behind, the price of ETS allowances will not be enough ensure the appropriate continuous push towards decarbonisation. To reach ambitious targets, milestones should push the threshold continuously. Emission taxation needs to follow this development by having a local aspect.

Though taxation (including ETS) cannot stand alone, it may prove to be one of several effective tools if the price of emissions is high enough. A decision to attain full decarbonisation (e.g. by 2050), followed by the associated implementation of adequate policies to ensure a stable increase in emission taxes, can make a transition to RE-based solutions and energy efficiency investments a more certain venture, which is a critical point to engage investors and convince them to contribute.

4.4. Renewable energy requires and offers flexibility

With the increasing integration of VRE, the positive role which the heating and cooling sector can play to augment grid flexibility becomes increasingly important and apparent. The use of renewable electricity in the heating and cooling sector can help balance the electricity grid when more VRE is introduced. Individual heat pumps in rural areas in combination with smart controls and large-scale heat pumps in district heating networks can play an important role in this connection when operated at times of surplus electricity thus providing a demand response potential to stabilise the grid and to allow more renewable electricity in to the energy mix.

Thermal storages – being several times cheaper than electrical ones – can increase the flexibility potential. In fact, storages for district heating represent a key role to provide the flexibility required in future energy systems with an increased amount of non-controllable energy production.

10	**To provide the flexibility required when increasing the share of wind and PV power, thermal storage is important in combination with individual heat pumps. However, the potential for grid flexibility and cost-effectiveness to integrate fluctuating RE becomes even greater by using district energy together with large-scale thermal storage, heat pumps and CHP.**

Avoiding the release of harmful refrigerants with high global warming potential factors (GWP) to the ambient is critical to realise the positive climate effect of heat pumps. In the HRE 2050 only low-GWP refrigerant heat pumps are used.

4.5. Flexibility from decentralised consumers and prosumers must be valued

Introducing many more consumers/prosumers[19] will result in a more decentralised and diverse energy system interacting across both sectors and the traditional stakeholder groups. New ICT solutions make market interactions with smaller consumers manageable. One example could be the

[19] The term "prosumer" is a contraction of the words "producer" and "consumer". It reflects a consumer who sometimes produce more energy than what is consumed.

use of local storage options (thermal or electric) to act as buffers to reduce peak demands for the electricity grid and the inherent dimensioning or capacity upgrade criteria to cope with this, when introducing large quantities of electric heat pumps (besides EVs etc.) The financial benefits for the prosumers should be structured to reflect the needs of the overall system. In some cases, the feasibility of electrical storages for individuals lies only in the avoidance of taxes. Household batteries should for example be able to respond to signals from the DSO instead of only maximise self-consumption. The use of RE should not be the end goal, but a mean to reach energy system emission targets – not single household targets.

11	**Policies and price signals should incentivise flexible interactions for prosumers to help balance electricity grids and not just maximise the owners' self-consumption (e.g. via household batteries). Failing to ensure that such systems respond to network balancing demands will end up being counterproductive for the overall energy system.**

In order to create new business models, which facilitate connections between the thermal and electricity sectors, national authorities should help ensure that the provision of demand side flexibility becomes more interesting in an economic sense. This may be achieved by offering variable electricity tariffs to end-users or aggregators, among other solutions. In some countries, the share of consumers' electricity bills associated with electricity production is small compared to the overall cost (mainly consisting of taxes and fixed tariffs). Therefore, simply following the electricity spot-market prices may not be incentivising enough to engage consumers and convince them to contribute to services supporting system flexibility.

Individual heat pumps can shift local to national electricity consumption by absorbing its surplus in times of low demand through storage in a hot water tank, or in some cases within the building envelope itself. Giving this grid-flexibility service a true economic value would accelerate the technology deployment as more individuals and enterprises seek to profit from heat pumps and/or thermal storage.

Flexible prices could reflect the strain on network and the balancing needs besides the production costs e.g. by introducing a tariff differentiation depending on periods or the user's maximum power peak. However, it is important *not* to structure cost schemes in a way that repels the interest of building owners to install a heat pump in the first place (where this is recommended). One option is to include an electricity tax discount on some of the bills (approximately the share for heating) for residential owners where their building is registered as supplied by a heat pump.

When a country aims for a (recommended) increase in the use of heat pumps – both for individual buildings and in district H&C networks – their inherent flexibility should be properly reflected in appropriate price-signals according to the needs of the (decarbonised) energy system. It is important to ensure that a given country's recommended (large) share of heat pumps should not purely operate as a baseload supply. Instead, thermal storages can also cost-effectively be applied to facilitate the flexibility services requested from heat pumps. If the incentives are purely focused on lowering expenses (in the case of electric heat pumps, lowered electricity costs) this will mean two things:

- High efficiency becomes less important compared to the capital costs, which may actually decrease interest in more expensive, but better performing, heat pumps. Case in point: District H&C companies may choose air-source heat pumps with a lower SCOP instead of utilising excess heat (with/without the need of a heat pump having a high SCOP) if electricity prices are deemed to be (too) low.
- Low operation costs alone will mean that tariff variations (reflecting the *need* of flexibility in the system) will have little economic impact, thus perhaps not (sufficiently) incentivising the dimensioning of a heat pump to be able to provide flexibility-services throughout a large share of the year. In other words, a heat pump may in practice be dimensioned to have as many full-load hours as possible, though in fact the overall system needs it to have an even larger capacity but running fewer hours per year.

However, the two above-mentioned caveats should *not* keep national governments from incentivising heat pumps (and other low-carbon solutions). Instead, they should rather be seen as arguments for why incentivising flexibility services and improved feasibility of various "decarbonisation solutions" should (at least) include also the rising polluters-pay costs solution, as described in section 4.3. Taxation should be based on analyses from a system-wide perspective, leading consumers in the direction of what is beneficial to the overall society.

The relevance of detailed, long-term strategic energy planning, including regular follow-up analyses, is underlined by the need for evaluating how the recommended increase in the use of heat pumps can be combined with careful tax and tariff schemes. This approach can ensure that such developments follow the expected path (including the HPs' interactions with the remaining energy system), as well as avoiding other negative externalities, such as the release of harmful refrigerants with high global warming potential factors (GWP) into the environment. In the HRE 2050 scenario, only low-GWP refrigerant heat pumps are included.

4.6. Excess heat is often politically neglected

HRE4 identifies an excess heat amount theoretically available that could supply heat for more than the entire building stock in Europe. Therefore, the avoidance as well as usage of excess heat – when not able to avoid – should receive high(er) priority and immediate attention in local to European decision-making processes, energy planning instruments and funding lines. However, the "CO_2 free" excess heat which could be gained from polluting power plants should not prolong their lifetime.

What is shown by HRE4 is the massive potential to utilise current excess heat *and* renewable heat sources which planners and decision makers can evaluate in more detail to consider where the use is relevant and where not. Tapping into the excess heat potential can in many cases only be realised by applying district heating networks, which – once established – will have numerous supply opportunities – even if one excess heat source should terminate. HRE shows that at least 25% of the district heating production could be covered by excess heat considering the location of the sources.

Large-scale (cheap) thermal storages can act as buffers to maximise the use of excess heat when the supply and demand profiles do not match. Large scale heat pumps can make it possible to utilise excess heat sources at lower temperature in district heating networks where it is not possible to apply it directly.

HRE's *Peta* mapping platform includes geographically pinpointed and categorised excess heat sources such as power production, industrial processes, waste incineration, metro stations and urban waste water treatment plants. By clicking on the specific excess heat source, more information on the selected source is presented for the user. This can be used to illustrate not only *how much* excess heat potential is present, but also *where* this potential is located, thereby assisting the decision process of where decision-makers should investigate its utilisation further. More info on excess heat sources is found in the *Peta* itself, and in the following reports representing a user guide and a methodological description respectively.

Maps Manual for Lead-Users (section 5.3.3) [12]

Methodology and assumptions used in the mapping (section 2.2.1) [13]

4.7. CHP plays a key role, but is not a "one-size-fits-all" solution

In the Heat Roadmaps, it is shown how CHP could cover around a third of the district heat generation in 2050 operating only in response to the needs of the electricity markets. The differentiation between the type of CHP as well as its timeline is important. In terms of utilisation of excess heat from electricity-only power plants and possibly comparing with alternative industrial excess heat options it is relevant to consider the following questions for all options: When is the excess heat source expected to be decommissioned? Is it worthwhile to utilise the heat until then even if it requires a follow-up plan from the beginning? What is required of both technical and administrative measures to realise the utilisation of this source? What are my alternatives?

When it comes to replacing electricity-only power plants with new CHP plants, one has to keep in mind if the demands of the future energy system match the properties of such plants (in terms of flexibility, fuel import/costs e.g. gas or biomass etc.) Experience has shown that with increased VRE capacity in the electricity network, the non-controllable electricity production will consequently cover a larger share of the electricity demand thus leaving fewer hours for feasible CHP operation. Introducing large scale heat pumps for district heating can significantly reduce the need for other heat production capacity. In many decentralised CHP plants in Denmark (with both gas engine and gas boiler installed) long periods with low electricity prices have in most hours made it unfeasible to run in CHP mode thus resulting in an increased share of boiler operation in these plants. Hence, careful planning is required to assess the need for the future CHP capacity – including the services it should supply (e.g. mainly baseload heat/electricity production or balancing power). Any energy system investment – supply units or infrastructure – should be considered together with the remaining system, which it will inevitably interact with throughout its lifetime – directly or indirectly.

It should be noted that future power-to-gas (P2G) such as hydrogen production could be established as combined heat and gas solutions where a district heating connection ensures a higher efficiency of the P2G energy conversion. District heating can prove even more relevant in case of targeting a complete decarbonisation of EU by means of 100% RE using the Smart Energy Systems approach [17] where the production of electro-fuels for transport sector plays an important role. Hence, the HRE scenarios can serve as a step towards such a goal.

4.8. Cooling demand should not be overlooked

There is a demand for cooling throughout Europe including Scandinavia. Across Europe the demand is expected to increase significantly towards 2050 and this has to be strategically addressed today. However, even in the most southern of the 14 HRE countries heat demand continue to dominate the H&C sector. The cooling demand differ from heating by being more balanced between space cooling and process cooling and dominated by services and industry. District cooling (DC) can in some places be a cost-effective solution and has a high potential to reduce greenhouse gas emissions by replacing individual applications in households, commerce and industry. Cooling demands often offer a direct opportunity to use the extracted heat in other applications e.g. district heating thus representing yet another synergy opportunity. However, further research is needed in terms of data for cooling demands as well as the possibilities for combining cooling and heating in spatial analyses.

In general, sustainable technologies – for example using natural cooling, integrated systems such as district cooling and the integration of the cold chain – should be given far more attention and resources for data collection, research and the roll-out of sustainable solutions in order to address the growing demand well in advance.

> Datasheets for performance and cost data of space cooling technologies in the residential and service sectors, and district cooling networks is available from the report:
> *Space Cooling Technology in Europe* [18]

4.9. Inclusive transition leaving no one behind

With the energy transition comes the need to avoid that some countries, regions, sectors and/or citizens get “left behind”, meaning that efforts must be made to ensure that those affected negatively (e.g. workers in fossil fuel industry) or more difficult access to modern energy technologies (e.g. poorer families/areas) are helped in contributing to *their own* transition, too (e.g. workers educated to take on jobs created in the RE sector instead or families/areas supported in installing more efficient H&C solutions). Such changes are needed, and it is critical to make sure that energy development is inclusive to avoid any growing discontent among European populations and politicians.

12	**Support to upgrading skills on different levels (energy/urban planners, craftsmen, etc.) will support a positive public opinion towards the energy transition. Labourers in the fossil fuel industry should not be neglected in the restructuring process.**

Some degree of local ownership can increase public acceptance of RE installations. One example is to include a precondition for the investor to offer a share (e.g. 20%) of the installed capacity to the municipality’s inhabitants and/or the nearest neighbours. By owning a share (e.g. of a wind farm) the locals may see it as less “intrusive”. An additional option is to somehow compensate the affected local environment (e.g. by financing non-related local activities, supporting cultural activities or homeless shelters, thus improving the local area).

4.10. Long-term benefits of capital-intensive transition

Following the energy transition is a general trend towards a more capital-intensive heat supply together with lowered operation expenses. Examples include solar heating and heat pumps – both in small scale units and large (DH) utility-scale – where the total cost of energy to a larger extent relates to the unit investment rather than the operation (compared to boilers). In relation to district heating, a shift from previous times’ single fuel supply to many heat supply sources introduce a wide range of options for the operator to optimise the production and reduces the sensitivity associated with the fuel costs (and availability). Similarly, the use of heat pumps makes it possible to use (locally) produced electricity (from a wide range of RE sources) thus reducing the dependency (financially and geopolitically) on fuel import. This makes it possible to ensure more stable conditions for both consumers and investors in the long run thus also reducing the risk of energy poverty. The Heat Roadmaps could eliminate the dependence on imported natural gas for heating in Europe. With this in mind, establishing new natural gas-grids holds considerable lock-in risks of potentially lost investments in the future, once countries finally transition away from fossil fuels completely.

Thermal networks take the shift from operation-related expenses towards investment-related expenses further than what is possible with individual supply. Another result of a development towards a higher degree of energy infrastructure investments is the opportunity to create local jobs as a result of the need for installation and servicing the infrastructure. This applies both on sub-country level and in terms of improving competitiveness of European industries nationally and internationally. On top of this, the energy transition improves living standards by limiting emissions thus ensuring better air quality locally besides limiting the global warming.

However, in any project the administrative efforts required have to match the predicted benefits. This applies in small and large scale. Examples include the issue of a comprehensive administrative process which repels smaller industries from entering into agreements of supplying excess heat. Similarly, as a large-scale example, establishing new district heating networks (and possibly companies) is a long-term process requiring significant financial and manpower resources. Such financial and administrative barriers could be overcome by removing unnecessary administrative burdens, by supplying access to cheap, long-term financing and by empowering local authorities to facilitate the processes required in any (small or big) project involving several different stakeholders.

13	**Frameworks for providing low-cost financing options and avoiding (unnecessary) administratively-heavy processes is an important precondition to effectively engage communities and industries. Furthermore, local authorities should be empowered to encourage and facilitate H&C decarbonisation projects.**

4.11. Changeover from a fossil-based DH supply

In many (old and new) DH networks, the heat is supplied by fossil fuels, which often gives DH a bad reputation in general. National governments can support evaluation schemes where experienced consultants with local knowledge can investigate the possibilities for a changeover from fossil fuels to renewables and excess heat, together with energy savings measures (e.g. renovation of networks). Such screenings could form the basis of informed decision-making for the district heating board members, thereby highlighting their most suitable and feasible decarbonisation options. However, before final investment decisions are made, more thorough calculations would be needed. With such measures, governments could effectively support an energy transition of existing district heating networks without needing to financially support investments in equipment or infrastructure.

5. Thermal networks create synergies

5.1. District heating playing key role in decarbonisation roadmaps

HRE's spatial analysis shows that approximately half of European countries' total building heat demand in the residential and service sectors is located in high density areas (e.g. urban centres and inner-city areas) [13]. Such details, combined with cost-calculations and whole-system modelling, form the scientific conclusion that more than half of European heat demand[20] can cost-effectively be supplied with district heating in 2050. Furthermore, by exploring it further, for example in the *Peta* mapping platform, it's possible to see precisely *where* these new/expanded networks should be located.

Beyond just the residential and service sector, it has been identified that approximately a quarter of the heat demand in countries' industrial sectors is needed for space heating or process heat at lower-grade temperatures (i.e. below 100 °C). Some of this demand could therefore add to the district heating potentials if these industries are suitably located and integrated into the system.

Introducing or expanding thermal networks means that numerous synergy options come into play, e.g.: balancing of electricity grids in a future with much more VRE, utilisation of excess heat otherwise wasted and integration of RE sources which may only be feasible in large-scale. As a result of this, the HRE 2050 scenario shows that district H&C should be deployed to a much larger extent in most countries, since it represents a feasible and effective way to ensure the deployment of a low-carbon heat supply in large scales.

14	**Due to higher urban densities, district energy in cities is one of the least-cost and most-efficient solutions for reducing emissions and primary energy use. Almost all countries' Heat Roadmaps show a strong and viable potential to economically increase the current share of district energy.**

The list of benefits by increasing the share of district energy is long:

- Beyond its ability to use economies of scale to take advantage of renewables, district energy systems can make it possible to utilise excess heat from industries and other

[20] Based on the 14 countries included in HRE4 corresponding to 90% of the total EU heat demand.

sources, which is otherwise regarded as mere waste (and with possible negative impacts on ecosystems[21]).

- Often many different heat sources are available. Excess heat can be a cheap option with a short payback time, while other feasible alternatives can relatively easily "step in" in case this supply option is terminated.
- Because district energy is typically not strictly conditional on the availability of just excess heat or any single type of renewable source, the feasibility of establishing district energy systems is generally a solid venture and a safe investment.
- In case energy-savings targets are not met, district energy can supply this additional demand with renewable heat, thus increasing the certainty that overall decarbonisation goals can and will indeed be reached (i.e. representing a type of backup solution[22]).
- District energy and cheap thermal storages can represent an ideal bridge between the heating, cooling and electricity sectors, while providing flexibility for the overall energy system.
- District energy can be completely decarbonised using renewables, large heat pumps, excess heat and CHP. In fact, several RE technologies benefit from – or even require – large-scale installations in order to be most feasible. For example, to exploit the full potential of deep geothermal and solar thermal, DH needs to be present due to the significant economy of scale for these solutions.

This leads to the recommendation that relevant national financing mechanisms should be created, or updated if already in place, so that they effectively enable intelligent system integration, e.g. in the frame of district H&C projects. In general, national financing (of various kinds) could be more closely linked to those H&C options with the most emission reduction potentials within the country.

Furthermore, national market regulations should enable various ownership models, since the most suitable structure of H&C provision and distribution to achieve social, economic and environmental targets will depend on the local to national framework conditions, as well as the country's own historical tradition and status of district energy.

> Ways that identified barriers to the market uptake of recommended solutions can be addressed are described in:
>
> *Business cases and business strategies to encourage market uptake* [20]
>
> The *Peta* online mapping tool also includes a visualisation of both existing DH networks and the cost of establishing DH on a hectare level. This gives lead-users the ability to pinpoint where the

[21] For instance, according to studies [19] of the Swiss Federal Institute for Technology the Rhine is one of the most heat-polluted rivers as a result of warm-water discharge from power plants.

[22] Note that this should indeed be considered a back-up plan. It is highly recommended *not* to disregard the energy-savings perspective, as it holds the key to a cost-effective decarbonisation.

most suitable areas to establish/expand DH are located. The costs are presented as annualised investment costs per unit of annual sold heat.

The *Peta* platform also includes a layer showing *Heat Synergy Regions* highlighting those regions with high synergies between excess heat and heat demand (indicated by an "excess heat ratio", i.e. the ratio between excess heat and heat demand within a given territory). The purpose is to provide an overview of where these assets and demands are in balance with each other or could even be "exported" to nearby regions.

Other features of *Peta* include the cooling demand densities on a hectare level and potential H&C synergy sources. More info on Heat Synergy Regions and cost of district H&C networks is found in:

Map of the heat synergy regions and the cost to expand district heating and cooling in all 14 MS [21]

Updated Peta atlas for each MS with the final level of district heating recommended in WP6 [22]

5.2. Increasing cooling demand

Cooling demands in general remain much lower than heating also in 2050 but becomes increasingly important than they are now (i.e. in the 2015 baseline). Especially for Italy, Spain and France HRE4 expects a significant future potential to apply district cooling, though such networks are not only relevant in the Southern part of Europe. In existing cases (e.g. in Sweden) sea or lake water is used as a cold source.

Renewable cooling should be strongly considered in long-term planning to take into account the obvious synergy options between H&C options (e.g. feeding excess heat from a cooling process into a DH network). A close collaboration with key stakeholders (e.g. cooling equipment providers) could be useful to tap into low temperature excess heat options.

5.3. A holistic planning approach optimising the energy system – not only specific units, districts or sectors

As described in section 3.4 energy efficiency measures and DH should be coupled rather than seen as competitors. Energy efficient buildings with a lower demand per m^2 compared to non-renovated ones, make it possible to reach a larger number of consumers with the existing main DH network. This way a declining demand from the DH network *per building* may actually represent a business opportunity for the DH company – provided that DH is (made) attractive enough for new consumers.

At the same time a more modern DH system with lower temperatures will also be better at utilising (cheap) excess heat i.e. potentially more excess heat sources available at low temperatures, and higher COP of large-scale heat pumps when they supply heat to a low-temperature DH grid.
To disregard thermal networks as a key player in the integrated energy system will result in costlier and/or insufficient decarbonisation while failing to take into account the opportunities of renewable sources and utilising excess heat from industries and power generation thus limiting the overall system efficiency.

15	**National governments should initiate an actionable framework for expanding and establishing thermal infrastructure and it should be aligned with national (and EU) policies for gas and electricity grids.**

6. Country-specific results of HRE 2050

Though clear trends exist in creating general recommendations of future energy systems across all 14 of HRE's target countries, there are also significant differences to be found between them which are worth noting. Below is described how each of these countries stands out by highlighting selected characteristics and possibilities which are special for each of them. As an introduction to each country, the following parameters from their national HRE 2050 scenarios are shown in one chart each and where relevant, the 2015 reference status is indicated in form of black line for comparison:

- Proportion of heating and cooling in total energy demand in 2015.
- Reduction in space heating demand in 2050 compared to 2015 baseline.
- Recommended approximate proportion of heat production in 2050 supplied by DH.
- Proportion of heat production in 2050 supplied by heat pumps. This is the combination of individual HPs and HPs for DH. Hence, there is an overlap between the shares of DH and share of HP production. This, however, does not account for the proportion of industrial excess heat that can be utilised as a heat source for the heat pumps.
- Renewable energy proportion of primary energy supply (PES) in HRE 2050.
- Total CO_2 emission reduction in 2050 compared to 1990 level.

This provides a quick overview of how important the H&C sector is together with key numbers for each country's re-designed energy system.

6.1. Austria

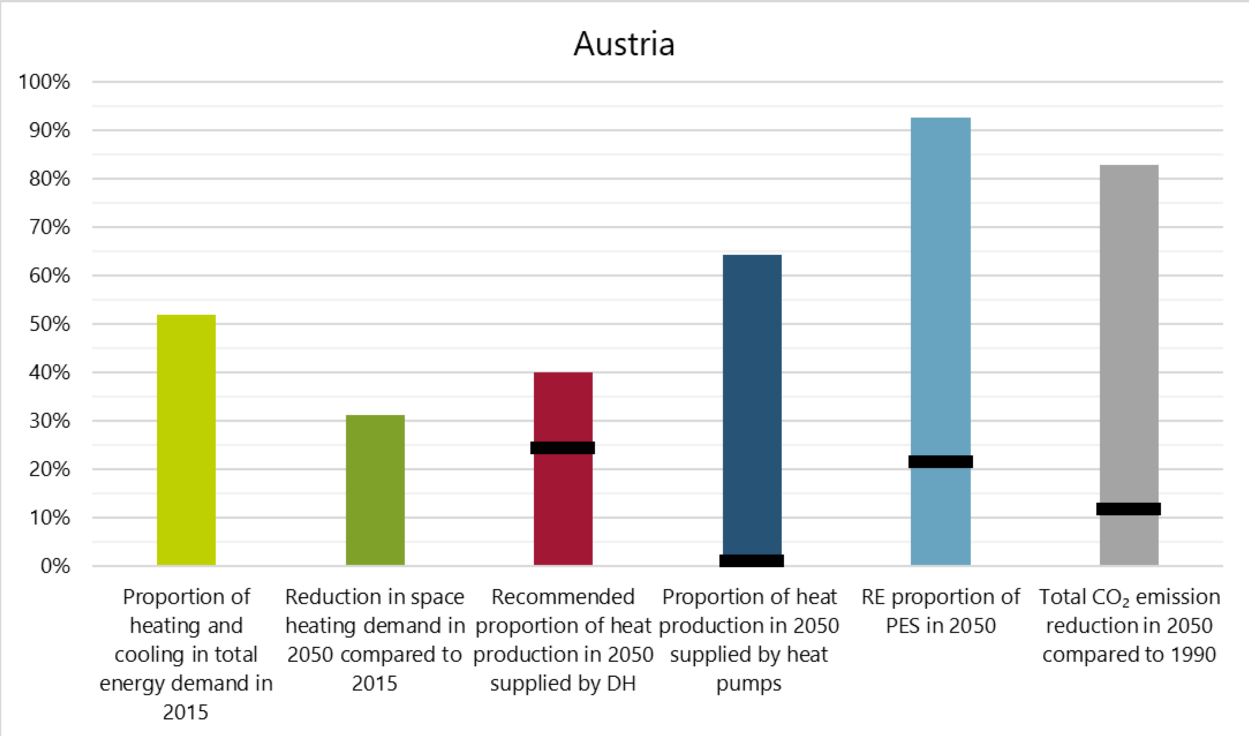

Figure 5. Overview of the H&C sector in Austria and its anticipated changes, according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.1.1. Energy savings

The 52% consumption for H&C in Austria comprises the majority of the country's final energy demand. In HRE 2050, space heating demand is to be reduced by circa 31% by 2050 compared to 2015. Introducing energy efficiency measures on the demand side is not the only mean to decarbonise the building stock. It should be balanced with increasing savings on the supply side as well, for instance deployment of renewables.

National policymakers should focus on combining energy efficiency measures with the decarbonisation of the Austrian energy supply. Moreover, the cooling sector should capture more attention due the anticipated potential of doubling the current space cooling demand in Austria until 2050.

6.1.2. Thermal networks

Austria still has a solid level of potential for developing even more district heating infrastructure until 2050, with the HRE 2050 scenario suggesting it should cover a 40% share of Austrian heat production. The (direct) utilisation of available excess heat from industrial facilities (estimated at around 7% of the district heat production[23], or 230 MW_{th}) is most appropriate to feed into district heating systems, where it can provide additional energy and cost savings. However, thermal networks (whether supplied from excess heat, large heat pumps or other renewables) should still be supplemented by energy efficiency improvements of buildings in order to shave heat demand peaks and optimise the size of Austrian district H&C systems. Furthermore, there is an immediate need for providing stronger efficiency standards and financial incentives for improving process heat savings.

6.1.3. Low-carbon heat supply

Austria has currently a negligible amount of installed capacity for heat pumps. If installed in larger proportions, heat pumps could contribute significantly to the overall energy efficiency and decarbonisation of H&C systems, reaching up to a 64% share of the heat production mainly as decentralised systems, but also with large HPs supplying thermal networks. Thus, Austrian cities should be encouraged to follow the positive example set by Vienna (winner of the European "Heat Pump City of the Year" award in 2017 [23]), heat pumps are particularly more efficient alternative to gas boilers and electric heating in rural areas where district heating is not as financially viable a solution.

National policymakers should incentivise flexible interactions e.g. for HP owners such as flexible electricity taxes and/or electricity discounts to apply demand response.

HRE 2050 shows how Austria can integrate a RE share of a massive 92%. By doing this, CO_2 emissions can be reduced by 83% compared to 1990 levels whereas the 2015 level only have managed 11%. This underlines the urgency of applying the various recommended measures of HRE4. The total RE share of primary energy supply in HRE 2050 for Austria is 92%.

Details on the results of the Austrian H&C scenarios are described in the report:
Heat Roadmap Austria [24]

[23] Notice that this share only covers supply temperatures high enough for direct DH supply, whereas low-temperature excess heat utilised by means of heat pumps are categorised as heat pump-based production.

6.2. Belgium

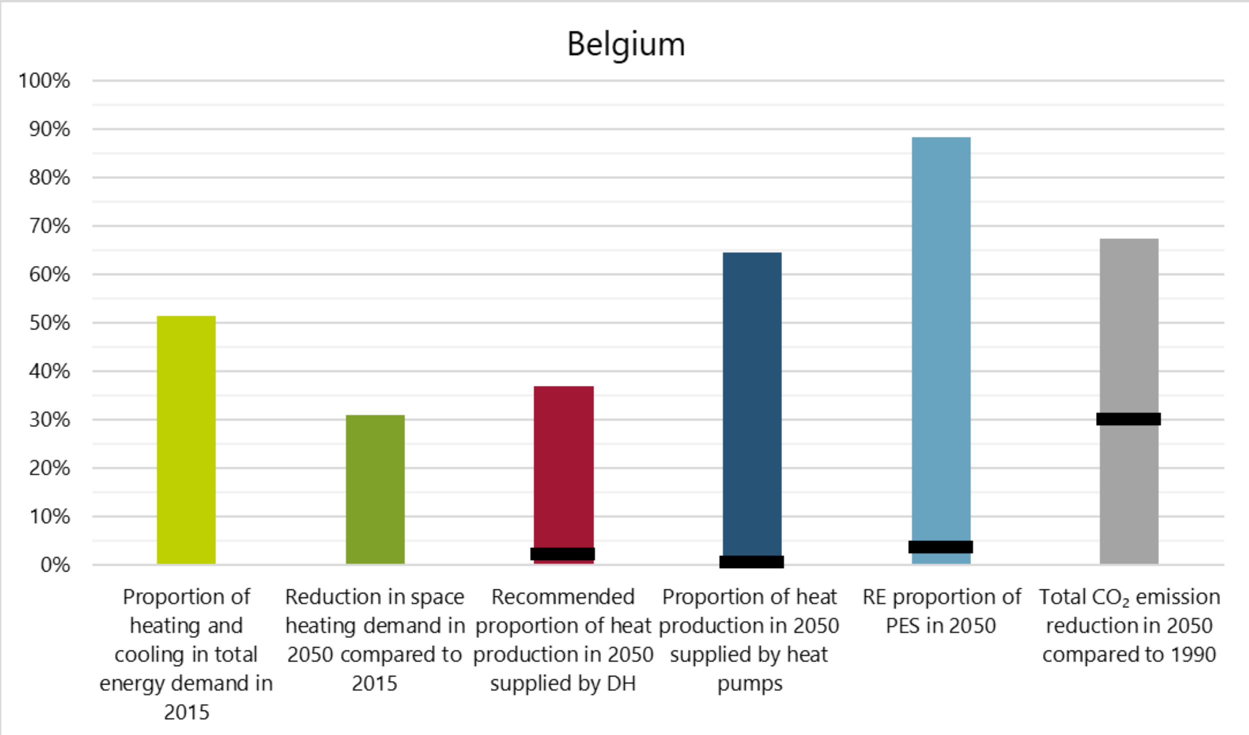

Figure 6. Overview of the H&C sector in Belgium and its anticipated changes, according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.2.1. Energy savings

In Belgium, H&C represent 51% of the country's final energy demand. Space heating demand should be reduced by circa 31% in HRE 2050. Though this point is not depicted in Figure 6, the HRE 2050 space heating reductions is actually twice the initial country target expected in the baseline 2050 scenario, which indicates that Belgium should have a higher energy-savings ambition than it currently has in place. However, energy efficiency measures should be implemented on both the demand and supply sides in order to balance the cost of building refurbishments with the deployment of sustainable energy resources.

6.2.2. Thermal networks

With Belgium currently only having a 2% share of district heating in the country's heating market, its decarbonisation targets could be largely achieved by focusing specifically on thermal network investments to cover the gap towards the 37% share envisioned in the HRE 2050 scenario. Such a relatively high investment cost for new district heating infrastructure could be mitigated by the optimisation of networks' sizes, accurate estimations of energy demands and an in-depth understanding of the built environment and industries. This requires a stronger emphasis on the energy efficiency improvement of Belgian buildings to shave heat demand peaks, as well as spatial analyses and comprehensive investigation of existing energy systems in the country.

6.2.3. Low-carbon heat supply

Belgium has a great potential for replacing local heat generation with low-carbon alternatives, such as heat pumps, which could contribute greatly to the overall energy efficiency and decarbonisation of H&C systems. It is estimated that about 64% of the total heat production for the built environment in both urban and non-urban areas could be supplied by heat pumps. National authorities should facilitate a collaboration between industries by bringing together planners, regulators, finance and technical experts in order to encourage future investments, as well as possibly support training schemes of installers and other professionals to ensure that market deployment is not hindered by any poor examples of malfunctioning or poorly-dimensioned installations.

Belgian electricity prices, which are among Europe's highest [25], may hinder the cost-effectiveness of operating heat pump systems compared to other solutions. Therefore, national policymakers should incentivise flexible interactions between consumers to help stabilise the electricity grid, e.g. through demand response. This could also include a financial stimulation for HP owners, such as electricity tax discounts.

Reaching "only" 67% CO_2 savings, compared to 1990 levels, reflects a significant share of Belgian emissions from "non-energy" and other sectors such as agriculture. However, when considering the category "energy and industry" by itself, then the HRE 2050 scenario corresponds to a CO_2 reduction for Belgium of 85% compared to the 2050 baseline. The total RE share of primary energy supply in HRE 2050 for Belgium is 88%.

Details on the results of the Belgian H&C scenarios are described in the report:
Heat Roadmap Belgium [26]

6.3. Czech Republic

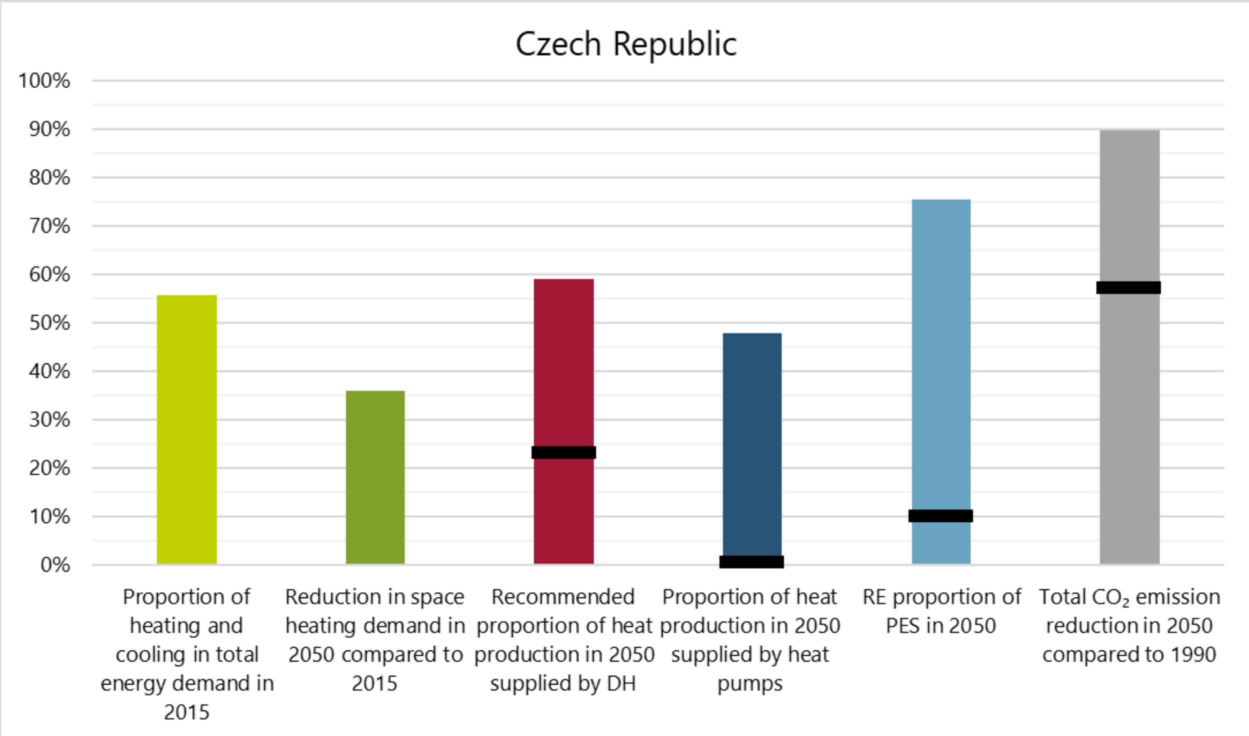

Figure 7. Overview of the H&C sector in the Czech Republic and its anticipated changes, according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.3.1. Energy savings

Czech H&C needs constitute some 56% of the country's total energy demand at the moment. This should be rather considerably reduced by 2050 with the aimed 36% drop in space heating demand – almost double the initial country's target set, as seen in the baseline 2050 (though not depicted above in Figure 7), which indicates that the Czech Republic should have more ambitious energy savings targets and emphasise the importance of improving energy efficiency in its buildings.

National policymakers should introduce stronger price signals and energy metering tools, as well as focus on improving a communication between stakeholders and educating Czech craftsmen and end-consumers. However, such measures should be coupled with energy efficiency measures for the supply side, for instance by supporting the uptake of renewable and low-carbon technologies and refurbishing existing heat networks. Moreover, the cooling sector should capture even more attention with an anticipated tripling from the current space cooling demand until 2050.

6.3.2. Thermal networks

A great potential of unutilised excess heat (~13% share of 2050 district heat production[24]) from Czech industries has been identified which could be combined with district heating (a 59% share in 2050, up from the current 23%) and thermal storage to supply up to 570 MW_{th} to the building stock. Therefore, the usage of excess heat should gain higher priority and immediate attention among national policymakers, planning instruments and funding lines. Large-scale thermal storage could contribute to the expected increase in consumers with variable demand, and thereby act as a thermal buffer to maximize the use of RE and/or excess heat in the Czech Republic.

6.3.3. Low-carbon heat supply

Relatively low electricity prices [25] and a circa 48% potential for electric heat pumps to contribute to Czech heat production create an opportunity for implementing the technology to a much greater extent. This can include both individual heat pumps in less-urbanised areas where thermal networks are not as feasible, and large-scale ones (tied to district H&C) in the Czech Republic's urban areas where they can take advantage of low-temperature renewable and excess heat sources.

A RE share of 76% can facilitate the achievement of a 90% CO_2 reduction compared to 1990. The total RE share of primary energy supply in HRE 2050 for Czech Republic is 76%.

> Details on the results of the Czech H&C scenarios are described in the report:
> *Heat Roadmap Czech Republic* [27]

[24] Notice that this share only covers supply temperatures high enough for direct DH supply, whereas low-temperature excess heat utilised by means of heat pumps are categorised as heat pump-based production

6.4. Finland

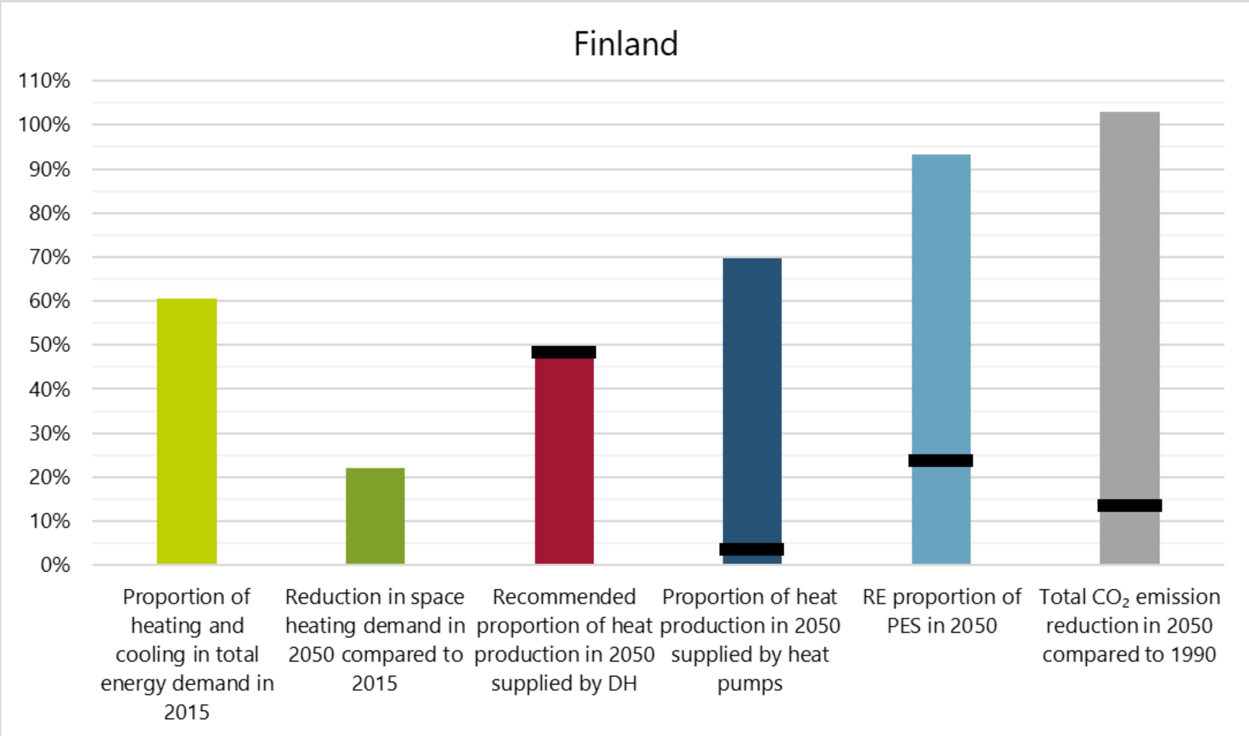

Figure 8. Overview of the heating and cooling sector in Finland and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.4.1. Energy savings

Finland's heating and cooling consumption is in the top highest proportion among other HRE countries reaching 60% of the country's final energy demand. Over a half of that energy volume is used for space heating in buildings and this should be reduced by over 20% until 2050 meaning that the country should have a somewhat higher energy savings ambition on the demand side while ensuring that energy savings targets are in fact met in practice. Unawareness of low-cost energy efficiency measures and lack of financial support among building's owners should be addressed with a priority by national policymakers. This entails introducing efficiency standards and financial incentives for maximising heat savings.

Energy retrofitting should be considered in combination with the replacement of boilers with individual heat pumps. The most efficient heat pump systems are in new buildings and in those that have undergone deep renovation.

6.4.2. Thermal networks

According to HRE 2050 and country's objectives the thermal networks in Finland reached a suitable level. However, there is still room for improvements e.g. by refurbishment of the existing heat networks, utilisation of the excess heat from the industrial sites and most importantly, by integration of large-capacity heat pumps.

6.4.3. Low-carbon heat supply

Finland has a great potential of replacing local heat generation with a low-carbon alternative as heat pumps which could contribute to the overall energy efficiency and decarbonisation of heating and cooling systems. Circa 70% of the heat production for the built environment in non-urban areas can be supplied by either individual and dispersed units or the large-scale installation integrated with the exiting heating networks. National authorities should facilitate a collaboration between the industries including planners, regulators, finance and technical experts in order to encourage future investments.

HRE 2050 shows how Finland can integrate a significant 93% share of RE. By doing this, CO_2 emissions can be reduced by more than 100% compared to 1990 levels whereas the 2015 level only have reached 13%. This underlines the urgency of applying the various recommended measures of HRE4. The carbon emission reduction in HRE 2050 was estimated at more than 100% due to the calculation methodology of CO_2 which includes carbon sinks in non-energy sectors i.e. reductions related to land use, land-use change and forestry (LULUCF) as well as emissions from international maritime transport.

Details on the results of the Finnish H&C scenarios are described in the report:
Heat Roadmap Finland [28]

6.5. France

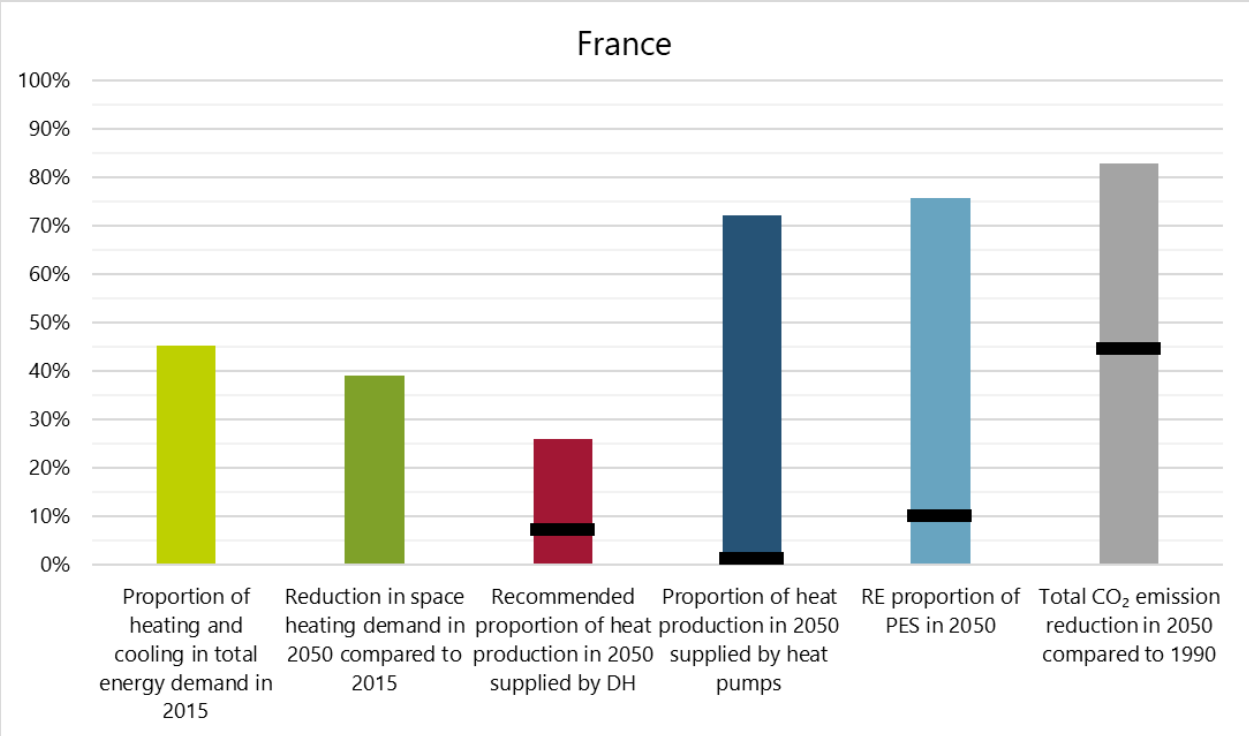

Figure 9. Overview of the heating and cooling sector in France and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.5.1. Energy savings

Nearly a half of the country's final energy needs is comprised by heat and cooling consumption which France should be aimed at a significant reduction until 2050. This includes almost a 40% drop in space heating demand.

National policymakers should maintain a balance between both low-carbon heat supply and energy savings. Achieving an efficient infrastructure for heating and cooling is one of the major goals for 2050 horizon and this should be supported by the government through building a coherent and integrated system methodology towards sustainable heating and cooling solutions.

Moreover, the cooling sector should capture more attention with the anticipated potential of doubling the current space cooling demand until 2050.

6.5.2. Thermal networks

France still has a capability for expanding district heating infrastructure, however, the country's major focus should be kept on creating a synergy between the existing thermal networks and dispersed low-carbon technology. The new DH investments should prioritise integration with heat pumps, biomass, CHP and thermal storage which would provide the necessary stability of the power grid which is increasingly challenged by the integration of fluctuating renewables. Integration of direct excess heat capacity could be boosted by 2050 up to 1,500 MW_{th}. Such cheap heat supply could balance the upfront investment cots in DH.

6.5.3. Low-carbon heat supply

The planned extensive investments in the RE should be coupled with a thermal storage and electric heat pumps. This is to provide a system flexibility in the face of variable operation of renewables. The excess grid electricity could feed the heat pumps which then would store heat output in the integrated heat buffers. France has a great potential for heat pumps development as over 70% of overall heat production in 2050 can be supplied by this low-carbon technology. The total RE share of primary energy supply in HRE 2050 for France is 76%.

> Details on the results of the French H&C scenarios are described in the report:
> *Heat Roadmap France* [29]

6.6. Germany

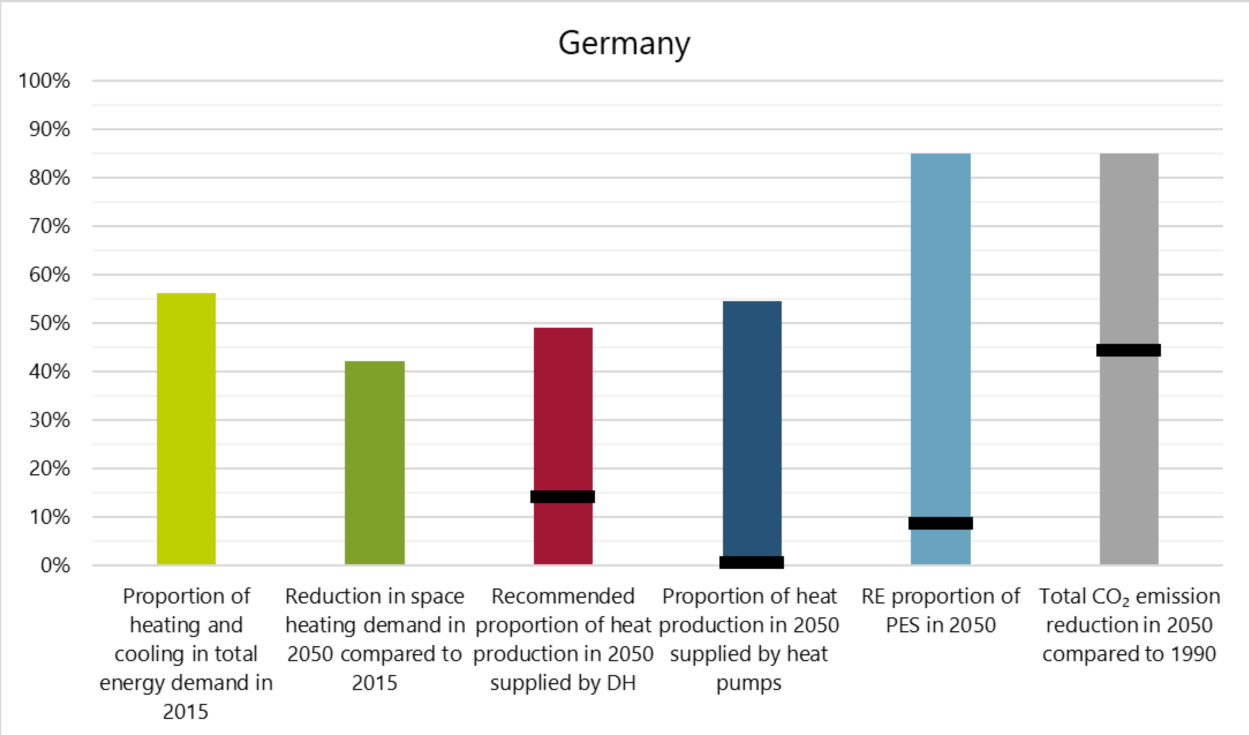

Figure 10. Overview of the H&C sector in Germany and its anticipated changes, according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.6.1. Energy savings

Germany has one of the highest shares of H&C demand in its final energy demand, when compared with the other HRE countries. Over half of that energy volume is used for space heating in buildings, though this is aimed to be reduced by over 40% by 2050.

Achieving an efficient infrastructure for German H&C is one of the major goals for the 2050 horizon and this should be supported by the national government by building up a coherent and integrated system methodology towards sustainable H&C solutions. The high level of expected savings, combined with a large share of both district heating and HPs, suggests that the country needs a strong commitment in terms of incentivising energy infrastructure investments while still managing to balance supply and demand sides.

6.6.2. Thermal networks

From HRE's spatial analysis [13] it is seen that approximately 56% of the German building heat demand in the residential and service sectors is located in high density areas, which explains why there is a significant potential to feasibly increase the share of district heating from 14% of total heat production in 2015 to 49% by 2050, as shown by HRE's detailed system modelling. Hence, Germany should set an ambitious target for developing thermal networks, by tripling the proportion of H&C production supplied by district energy. Though its demand is much smaller than for heating, as is the case for most countries, the German cooling sector should capture more attention due to an anticipated doubling of current space cooling demands until 2050. Meanwhile, heat networks tapping into the highly under-utilised capacities of industrial excess heat can be estimated to reach a feasible 11% share of DH heat production in 2050 (which equals to almost 3,500 MW_{th} of thermal heat capacity) by following the HRE 2050 scenario. This could bring significant cost savings and improve cost-effectiveness of DH investments in Germany. A national district heating strategy aligned with policies for other parts of the energy system could contribute to overall cost-performance improvements and a significant decarbonisation of the German H&C sector.

6.6.3. Low-carbon heat supply

A holistic approach to combine thermal networks and heat demand reduction measures with (also decentralised) heat pumps seems to be the most adequate solution to meet the energy decarbonisations targets of Germany. Despite the negligible contribution of heat pumps to the country's heat production at the moment, this technology deserves more attention from national policymakers due to the recommended 2050 share rising to 55%. Specifically, there is a need to include a financial stimulation for HP owners, such as flexible electricity taxes and/or electricity discounts to apply *demand response*. Besides this, there is a need for incentivising flexible interactions between prosumers e.g. to help stabilise the electricity where local electricity generation and storage are applied. Financial incentives should engage prosumer interactions which support the overall energy system – e.g. by reducing stress on the electricity distribution grid when needed – not simply promoting maximum self-consumption of renewables. In the example of household batteries e.g. to store electricity from household PV systems, these distributed systems should be encouraged to respond to grid balancing needs.

HRE 2050 shows how Germany with a transition to a flexible, integrated low-carbon energy system can incorporate a RE share of 85% thereby reaching 85% CO_2 reduction compared to 1990 levels while enabling even further reductions in the future.

Details on the results of the German H&C scenarios are described in the report: *Heat Roadmap Germany* [30]

6.7. Hungary

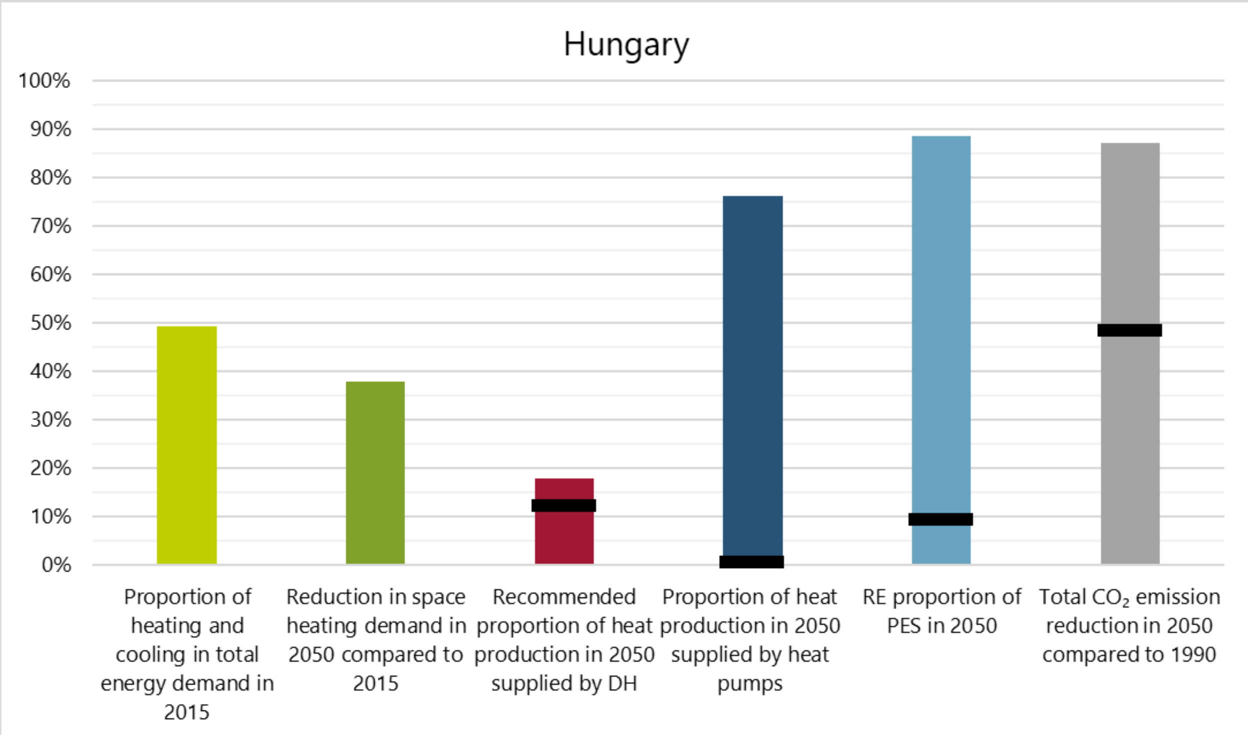

Figure 11. Overview of the heating and cooling sector in Hungary and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.7.1. Energy savings

Heating and cooling needs of Hungary constitutes almost a half of the country's total energy demand. This, however, should be dramatically reduced by 2050 with approximately 38% drop in space heating demand which means that the present country targets should be almost doubled as seen in the baseline 2050 (though not depicted above in *Figure 11. Overview of the heating and cooling sector in Hungary and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.*Figure 11). The discrepancy indicates Hungary should have a higher energy savings ambition and emphasize the importance of both setting more ambitious energy savings targets and ensure the framework conditions to realise these in practice.

The cooling demand in Hungary was estimated to increase nearly six times by 2050. This fact should draw attention of national policymakers towards building a coherent and integrated system methodology for sustainable heating and cooling solutions.

6.7.2. Thermal networks

Future developments in district energy should be concentrated on building cooling networks to meet increasing cooling needs in the country. This requires relevant regulations for increasing a stakeholder engagement in both heating and cooling markets and facilitating the entry of investors in these sectors.

6.7.3. Low-carbon heat supply

One of the largest potentials for heat supply by electric heat pumps among the HRE countries (76%) creates an opportunity for implementing the technology to a much greater extent. This can include both, individual ones in rural areas where thermal networks are not feasible and in urban areas where they can make the use of low-temperature renewables and excess heat sources. Local and regional authorities should encourage and facilitate a collaboration between the industries including planners, regulators, finance and technical experts. Cost of future investments in low-carbon technologies needs to be balanced by energy efficiency improvement of buildings to shave heat demand peaks.

As can be seen in *Peta* Hungary holds significant geothermal resources across almost the entire country. Hence, this could be a resource to consider to a larger extent. The total RE share of primary energy supply in HRE 2050 for Hungary is 89%.

Details on the results of the Hungarian H&C scenarios are described in the report:
Heat Roadmap Hungary [31]

6.8. Italy

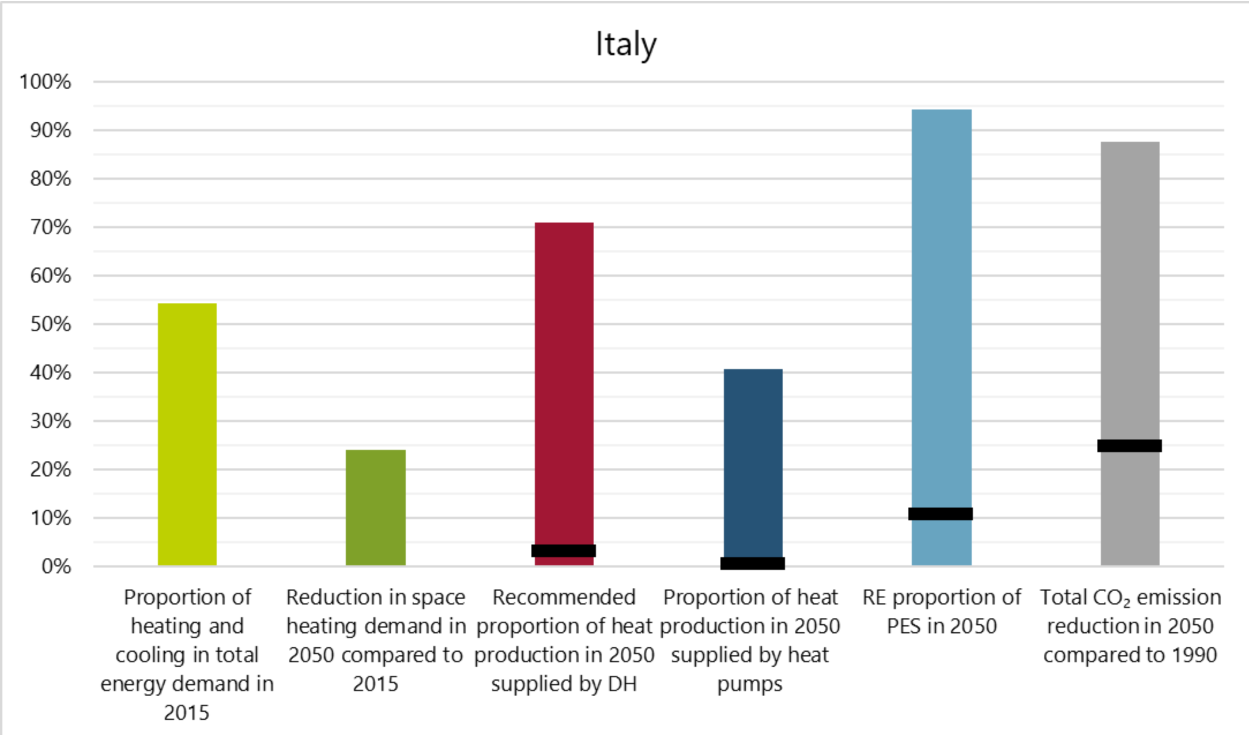

Figure 12. Overview of the heating and cooling sector in Italy and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.8.1. Energy savings

More than half of country's final energy demand is comprised by cooling and heating consumption. A reduction in the space heating demand of about 24% by 2050 is included in THE 2050. However, national policymakers should maintain a balance between both savings and decarbonised supply by taking an integrated approach when targets and plans are made for their future energy system.

6.8.2. Thermal networks

In Italy 65% of the building heat demand in the residential and service sectors are located in high density areas. This makes district heating networks very feasible and forms the basis of a recommendation that Italy should draw more attention to developing this low-carbon heat supply infrastructure since there is a very negligible share of district heating in the country's present heating system. Nearly 70% of total heat production in the country can be supplied via DH until 2050. Introducing or expanding thermal networks entails a number of benefits such as utilising excess heat, flexibility by connecting to different and dispersed energy sources and with the use of thermal storages and low-carbon resources, heat networks can create a synergy between heating, cooling and electricity sector thereby facilitating the integration of RE (e.g. wind and solar energy). National policymakers should introduce adequate regulations for increasing the market for district heating e.g. by setting up a national framework programme for planning and establishing district energy networks while aligning this with policies for the remaining energy system.

6.8.3. Low-carbon heat supply

In the rural and non-urban areas where thermal networks investments are expensive and infeasible, decentralised heating and cooling should be considered. The key focus should be kept on electricity-driven heat pumps that can also contribute to the flexible integration of renewables.

With the great increase in DH share, a range of heat supply options comes into play. This includes the opportunity to apply large-scale solar district heating (due to the favourable solar radiation conditions). Besides this, from *Peta* it is seen that geothermal sources are more suitable in Italy than in other countries. The total RE share of primary energy supply in HRE 2050 for Italy is 94%.

> Details on the results of the Italian H&C scenarios are described in the report:
> *Heat Roadmap Italy* [32]

6.9. Netherlands

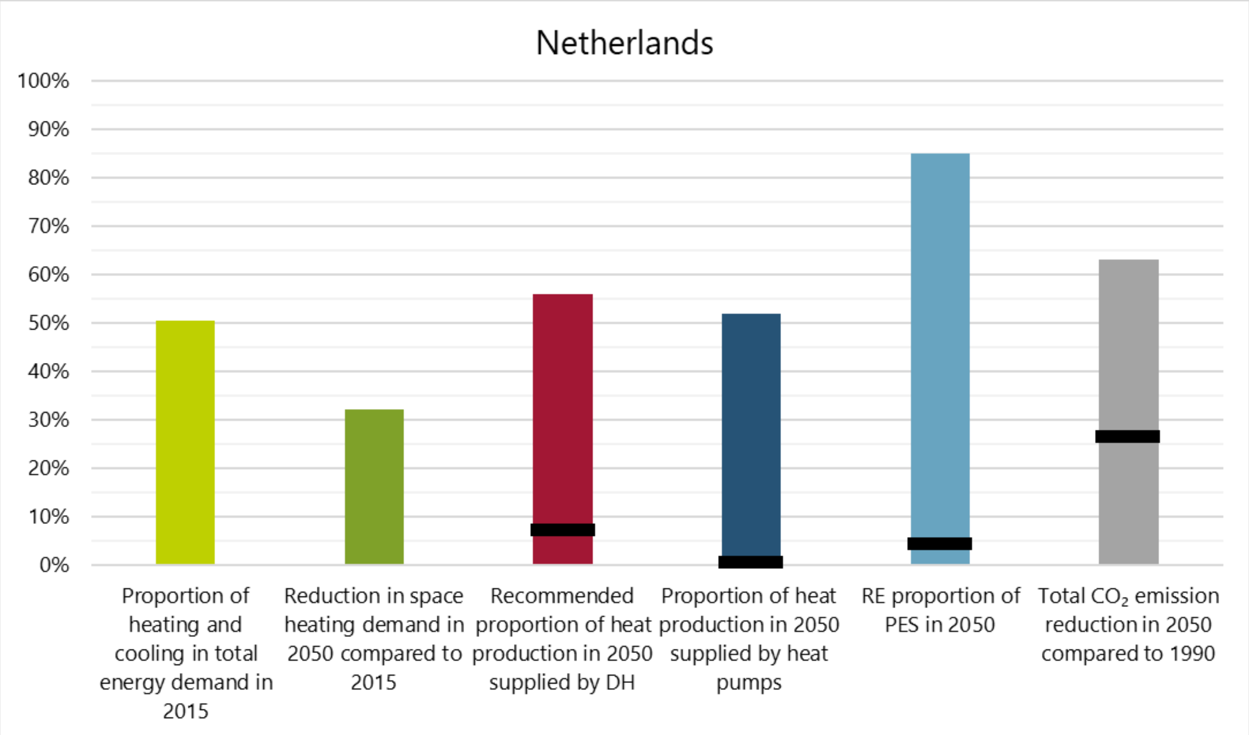

Figure 13. Overview of the heating and cooling sector in Netherlands and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.9.1. Energy savings

Half of the Netherlands' final energy demand is used for cooling and heating needs. Based on HRE 2050 it is recommended that the largest proportion which is space heating is reduced by approximately 32% until 2050.

Energy retrofitting should be considered in combination with the replacement of boilers with individual heat pumps. The most efficient heat pump systems are in new buildings and in those that have undergone deep renovation (though this is not necessarily a precondition for the heat pump).

6.9.2. Thermal networks

With the current only 7% share of heat production covered by district heating, it is recommended to focus specifically on thermal network investments to achieve an energy-efficient integrated cost-effective decarbonisation. A high up-front investment cost of the district heating infrastructure can be mitigated by the use of various cheap low-carbon heat sources. A national strategy and corresponding political framework to convert the large amount of individual (typically gas) boilers to district heating is needed.

6.9.3. Low-carbon heat supply

The planned extensive investments in district heating should be coupled with a thermal storage and electricity-fuelled heat pumps to provide a system flexibility in the face of variable operation of renewables. The excess grid electricity could feed the heat pumps which then would store heat output in the integrated heat buffer storages. Netherlands have a great potential for heat pumps development as over 52% of overall heat production on 2050 can be supplied by this low-carbon technology.

The total RE share of primary energy supply in HRE 2050 for the Netherlands is 85%. Reaching "only" 63% CO_2 savings, compared to 1990 levels reflects a significant share of Dutch emissions from "non-energy" and other sectors such as agriculture. HRE 2050 assumes transport and non-H&C industry sectors as in a conventionally decarbonised scenario. Hence, the changes were made primarily in H&C and to a lesser degree the electricity sector [33]. With further integration of the sectors, higher levels of decarbonisation can be reached. When considering the category "energy and industry" by itself, the HRE 2050 scenario corresponds to a CO_2 reduction for The Netherlands of 81% compared to the 2050 baseline.

Details on the results of the Dutch H&C scenarios are described in the report:
Heat Roadmap Netherlands [33]

6.10. Poland

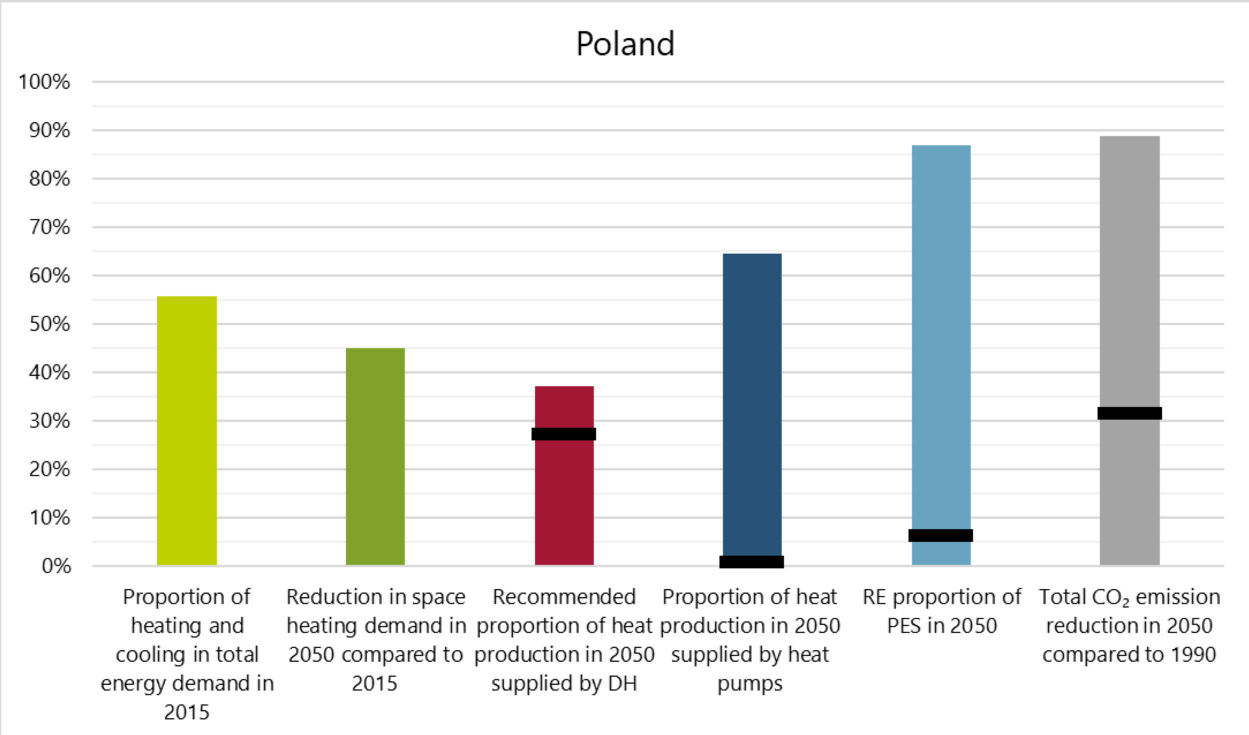

Figure 14. Overview of the heating and cooling sector in Poland and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.10.1. Energy savings

Poland has one of the highest shares of heating and cooling demand in the final energy demand when compared with the other HRE countries. Over a half of that energy volume is used for space heating in buildings and this is proposed to be reduced by over 45% in HRE 2050.

The cooling demand in Poland was estimated to increase nearly four times by 2050. This fact should draw attention of national policymakers towards building a coherent and integrated system methodology towards sustainable heating and cooling solutions.

6.10.2. Thermal networks

District heating supplies nearly one third of the total heat production in the country. For this topic, a future energy strategy should focus mainly on refurbishment of the existing infrastructure and increasing its efficiency.

A combination of heat demand reduction investments with modernisation of district heating systems can create an opportunity for incorporating low-carbon technologies. Excess heat from the industry and waste incineration, CHP, heat pumps, etc. used in district heating can provide a synergy between heating, cooling and electricity sector, and optimise a cost-effectiveness of the entire system.

6.10.3. Low-carbon heat supply

Poland has one of the largest potentials for heat supply by electric heat pumps among the HRE countries (65% of total heat production) which creates indicates an opportunity for implementing the technology to a much greater extent than today. This can include both individual ones in rural areas where thermal networks are not feasible, and in urban areas where they can make the use of low-temperature renewable and excess heat sources. National governments should ensure a transition of fossil-based, inefficient supply by requiring and supporting that local and regional authorities encourage and facilitate a collaboration between industries, planners, regulators, financial sector and technical experts to develop strategies and corresponding joint efforts towards decarbonising the H&C sector. The total RE share of primary energy supply in HRE 2050 for Poland is 87%.

> Details on the results of the Polish H&C scenarios are described in the report:
> *Heat Roadmap Poland* [34]

6.11. Romania

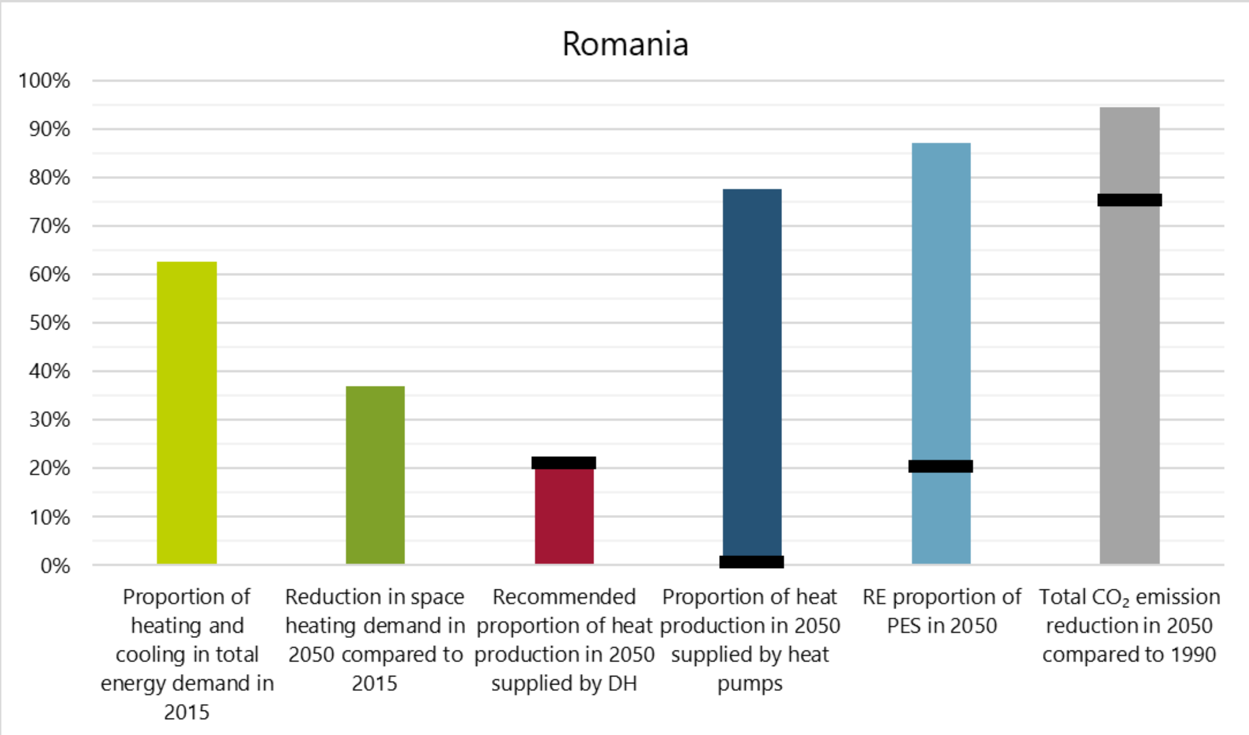

Figure 15. Overview of the heating and cooling sector in Romania and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.11.1. Energy savings

Romania has the highest share of H&C demand in the final energy demand compared with the other HRE countries exceeding 60%. Over a half of that energy volume is used for space heating in buildings and this should be reduced by nearly 40% until 2050. A focus should also be on improving a communication between stakeholders and educating craftsmen and end-consumers. Moreover, the cooling sector should capture more attention with the anticipated potential of tripling the current space cooling demand until 2050.

6.11.2. Thermal networks

According to HRE 2050 and country's objectives the thermal networks in Romania reached a suitable level. However, the further decarbonisation targets should be fulfilled by refurbishment of the existing heat networks, utilisation of the excess heat from the industrial sites and most importantly, by integration of large-capacity heat pumps.

6.11.3. Low-carbon heat supply

The highest potential for heat supply by electric heat pumps among the HRE countries is found in Romania in HRE 2050 (~78% of total heat production). This shows the big opportunity to implement the technology to a much greater extent. This can include both individual ones in rural areas where thermal networks are not feasible and in urban areas where they can make the use of low-temperature renewable and excess heat sources possible. The cost of future investments in low-carbon technologies needs to be balanced with energy efficiency improvement of buildings – on a practical level e.g. to shave heat demand peaks, and in general to realise the most cost-effective decarbonisation of the H&C sector. A large share of the decarbonisation compared to 1990 levels is already achieved by 2015, but more efforts are needed to decarbonise the H&C sector. Besides heat pumps applied in DH, large-scale solar thermal solutions could be an option for a feasible decarbonisation of DH [35]. The total RE share of primary energy supply in HRE 2050 for Romania is 87%.

> Details on the results of the Romanian H&C scenarios are described in the report:
> *Heat Roadmap Romania* [36]

6.12. Spain

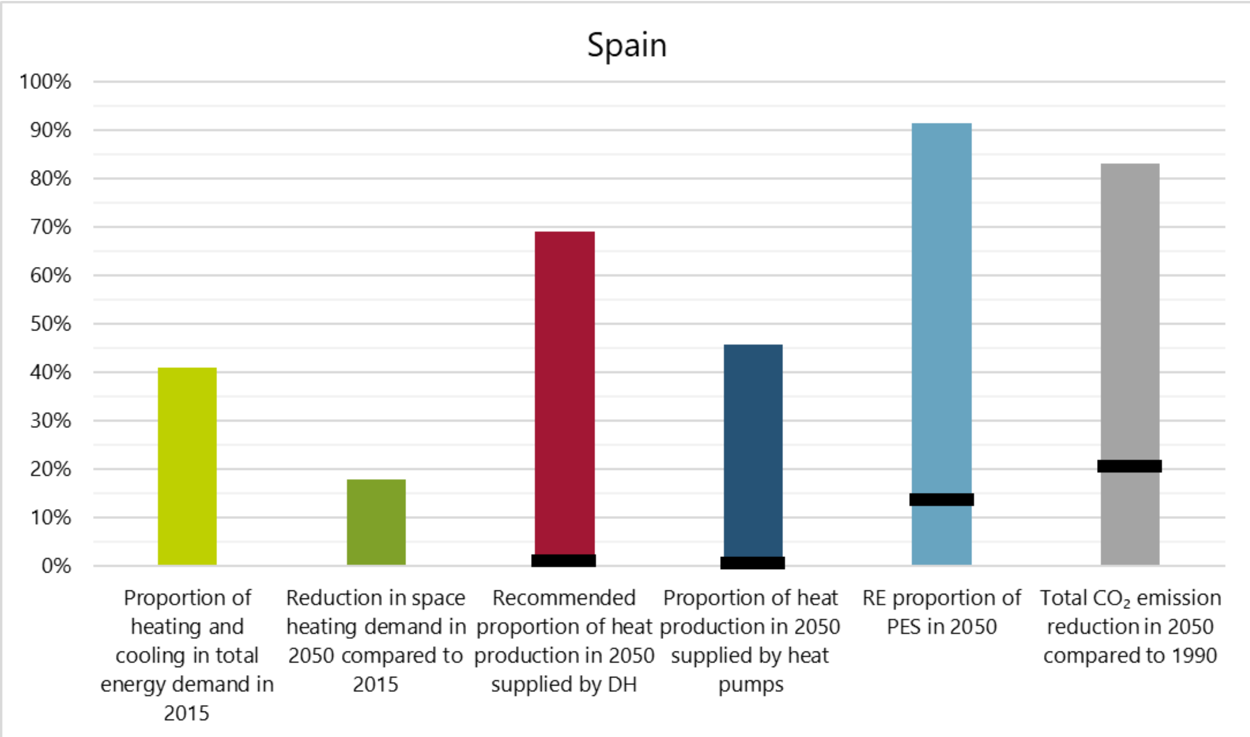

Figure 16. Overview of the heating and cooling sector in Spain and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.12.1. Energy savings

Consumption of cooling and heating in Spain comprises 41% of the country's final energy demand. Until 2050, the space heating demand is recommended to be reduced by circa 18% and this target triples the initial country's aim. This indicates that national authorities should set higher energy savings targets matching EU ambition level for 2050.

Implementation of energy efficiency measures on both, demand and supply-side aims to cost-effectively achieve the decarbonisation goals. Energy retrofitting and renewability of the energy supply side should be combined with the heat network development and replacement of boilers with individual heat pumps. Energy efficient buildings can shave peaks and improve the performance and feasibility of the entire district energy network. National policymakers shall focus on providing a coherent and integrated system methodology towards sustainable heating and cooling solutions.

6.12.2. Thermal networks

As indicated in Figure 16 Spain has the highest recommended district heating share in total heat production among all the 14 HRE countries. National policymakers should introduce adequate regulations to increase the market share of district heating significantly. With a very negligible share of district heating in the country's heating system, Spain should draw more attention to developing this while basing it on a low-carbon heat supply. Introducing or expanding thermal networks entails numerous benefits such as utilising and distributing excess heat, a flexibility of connecting to different and dispersed energy sources and with the use of integrated thermal storage and low-carbon resources, heat networks can create a synergy between heating, cooling and electricity sector.

A very high potential of direct excess heat supply from the industry sector, estimated at approximately 780 MW_{th} (which represent circa 8% of DH heat production) should find a priority in heat source mapping for district heating. The excess heat availability needs to be further investigated by region and align with the thermal networks development planning. Notice that this share only covers supply temperatures high enough for direct DH supply, whereas low-temperature excess heat utilised by means of heat pumps are categorised as heat pump-based production.

6.12.3. Low-carbon heat supply

Spain has a great potential of replacing local heat generation especially in rural areas with heat pumps. This low-carbon alternative technology could contribute to the overall energy efficiency and decarbonisation of heating and cooling systems. An estimated nearly 46% proportion of the final heat demand for the built environment can be supplied by electric heat pumps. National authorities should facilitate a collaboration between the industries including planners, regulators, finance and technical experts in order to encourage future investments. The total RE share of primary energy supply in HRE 2050 for Spain is 91%.

> Details on the results of the Spanish H&C scenarios are described in the report:
> *Heat Roadmap Spain* [37]

6.13. Sweden

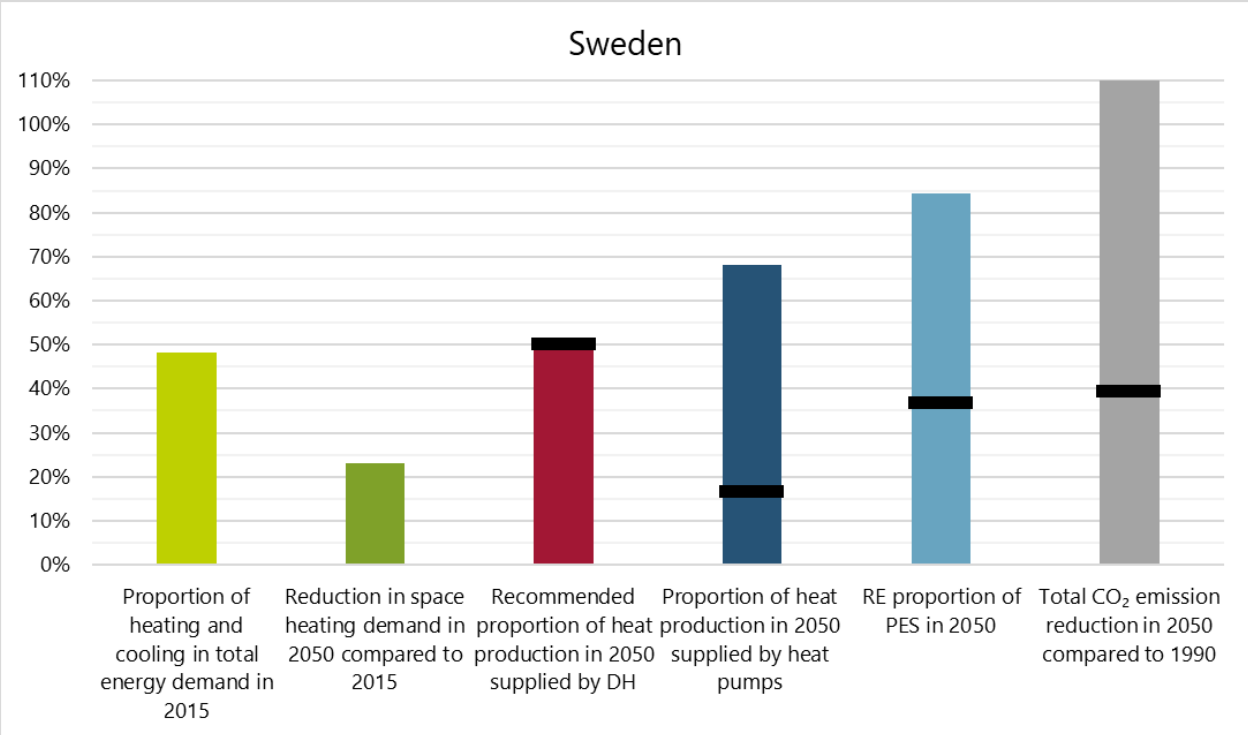

Figure 17. Overview of the heating and cooling sector in Sweden and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.13.1. Energy savings

Nearly half of Sweden's final energy demand is used for cooling and heating needs and its largest proportion which is space heating is in HRE 2050 reduced by circa 23%.

Only implementation of energy efficiency measures on both, demand and supply-side enable to cost-effectively achieve the decarbonisation goals. National policymakers should maintain a balance between both and promote an integrated approach in maximising energy savings.

6.13.2. Thermal networks

According to HRE 2050, the thermal networks in Sweden reached a suitable level. However, the further decarbonisation targets can by fulfilled by refurbishment of the existing heat networks, utilisation of the excess heat from the industrial sites and most importantly, by integration of large-capacity heat pumps which could cover more than a third of the district heating demand. Thermal storages can prove crucial to link the heating, cooling and electricity sector thereby facilitating the balance of the electricity grid as well as to handle fluctuating local heat sources.

6.13.3. Low-carbon heat supply

Sweden still has a high potential for incorporating heat pumps (68% of total heat production) which could contribute to the overall energy efficiency and decarbonisation of heating and cooling systems. In particular, they are the more efficient alternative for gas boilers and electric heating in rural areas where district heating is not a financially viable solution.

Another important aspect for efficient heat pumps deployment is an accurate estimate of future energy supply needs. A range of future economic, political and social changes factors should be carefully considered by energy companies and planning authorities in performing the energy demand projection.

The carbon emission reduction target set in HRE 2050 compared to 1990 annual emissions was estimated at more than 100%. The reason for this ambiguous ambition lies in the calculation methodology of CO_2 which includes carbon sinks in non-energy sectors i.e. reductions related to land use, land-use change and forestry (LULUCF) as well as emissions from international maritime transport. The total RE share of primary energy supply in HRE 2050 for Sweden is 84%.

Details on the results of the Swedish H&C scenarios are described in the report:
Heat Roadmap Sweden [38]

6.14. United Kingdom

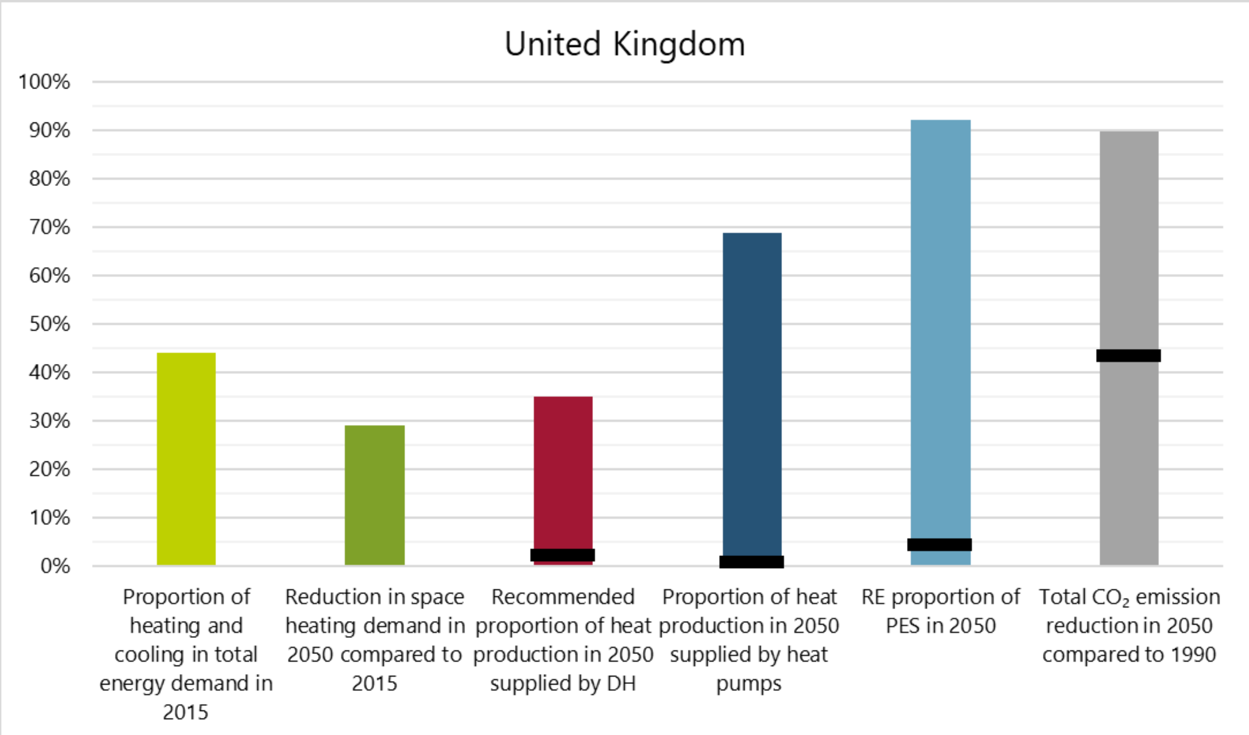

Figure 18. Overview of the heating and cooling sector in the United Kingdom and its anticipated changes according to the energy decarbonisation scenario modelled in Heat Roadmap Europe 2050. Where relevant, the 2015 reference value is indicated with a black horizontal line.

6.14.1. Energy savings

Nearly a 45% of United Kingdom's final energy needs is comprised by heat and cooling consumption. In HRE 2050 this is reduced significantly until 2050 with a drop of almost 30% in space heating demand.

National policymakers should maintain a balance between promoting a decarbonised energy *supply* and an integrated approach in maximising energy *savings*. Achieving an efficient infrastructure for heating and cooling is one of the major goals for the 2050 horizon and this should be supported by the government by building a coherent and integrated system methodology towards sustainable heating and cooling solutions.

6.14.2. Thermal networks

With the current only 2% share of district heating in the country’s heating market, the decarbonisation targets can be achieved by focusing specifically on thermal network investments. Though it has been seen [13] that more than half of the demand is located in not very dense areas indicating typically individual detached single-family houses, still more than a third of the heat demand could be covered by district heating. A high investment cost of the district heating infrastructure can be mitigated by variety of identified low-cost heat sources[25] which can (only) be used in district heating networks. The optimisation of network sizes, accurate estimation of energy demand and an in-depth understanding of the built environment and industries. A stronger emphasis on the energy efficiency improvement of buildings could shave heat demand peaks which requires a spatial analyses and comprehensive investigation of existing energy systems.

6.14.3. Low-carbon heat supply

Recommended extensive investments in RE should be coupled with a thermal storage and electric heat pumps to provide a system flexibility in the face of variable operation of renewables. Heat pumps could be controlled preferably to operate in times of excess electricity which could then store heat in thermal storages. This applies both at individual level and in large scale for district heating though the latter holds an even bigger potential for cost-effectively supplying the required flexibility services needed in the electricity grid when integrating large shares of fluctuating renewables. United Kingdom has a great potential for heat pumps development as up to 69% of overall heat production on 2050 can be supplied by this low-carbon technology. The total RE share of primary energy supply in HRE 2050 for United Kingdom is 92%.

Details on the results of the British H&C scenarios are described in the report:
Heat Roadmap United Kingdom [39]

[25] See *Peta*.

7. Conclusion

When planning for a low-carbon future, it is evident, that the entire energy system must be taken into account to ensure that a decarbonisation focus in one place does not simply increase emissions somewhere else. The same level of consistency should be applied across all national policies – and possibly even sub-nationally, which should then be considered jointly with national targets – to ensure that these are in line with the Paris Agreement.

It is critical that various efforts are made simultaneously to remove the barriers hindering the energy transition in order to ensure that stakeholders successfully overcoming one barrier are not immediately thereafter blocked by others. Periodical reviews and – if necessary – changes should be formalised accordingly in those policies, administrative processes, etc. which either cause a particular barrier or could facilitate overcoming it. Carbon taxation and other direct or indirect incentives should be ensured to encourage the realisation of energy savings, the implementation of renewables and the use of efficient energy system infrastructure applications.

Investments in infrastructure to decrease fuel demand such as district H&C networks, heat pumps and energy savings should be promoted in terms of the following combined and complementary efforts:

- Raising awareness about relevant H&C solutions among policymakers, businesses and individuals and formulating a common narrative for all Europeans that the decarbonisation of our society is not only possible, but cost-effective and affordable with existing technologies available on the market today and can prove profitalbe for our local economies.
- Setting up frameworks to improve qualifications and the number of skilled professionals supporting decarbonisation solutions.
- Ensuring certainty (predictability) for investors, avoiding "stop-and-go" measures.
- Removing administrative barriers for stakeholders to establish district heating and cooling and use an increased share of renewables in H&C as well as recover excess heat[26].
- Requiring integrated energy planning and regular evaluation of status across all energy sectors and at all governmental levels.
- Improving feasibility of a sustainable energy system directly and indirectly by means of CO_2 taxation.
- All fossil fuel subsidies should be stopped immediately including also indirect support such as incentive schemes for gas and oil combustion boilers.
- Fossil fuel boilers should be phased out. Expiry dates should be set combined with banning the installation of fossil fuel boilers in new buildings. This should go hand in hand with

[26] The administrative process of selling low-grade excess heat in some cases require that the industry is approved to be considered an energy production company similar to a company owning a power plant.

stronger support for alternatives (e.g. renewables and sustainable excess heat) and thus potentially avoiding increased costs for end-consumers.

- Expiry dates for fossil fuel power production should be set to avoid investments in new (long-lasting) fossil-based capacity and provide certainty for the power industry to invest in sustainable solutions into the long-term.

If the HRE 2050 scenario would be implemented, it would result in the following short- to long-term benefits covering all levels of society:

- Lowered uncertainty of future fuel prices, thereby ensuring a more stable framework for energy-producing companies, consumers on different levels (households, services and industry) and (public) investors.
- Opening of the market for locally-based heat sources, thereby increasing the security of supply and local economic growth, while also making the countries more resilient to geopolitical changes.
- Creation of local jobs – both on a (sub-)country level and in terms of strengthening the competitiveness of European industries nationally and internationally.
- Reduction of the overall energy system cost compared to alternative decarbonisation scenarios.
- Improvement of living standards by ensuring better air quality (locally), while also reducing emissions (globally).

16	**HRE4 shows how an energy system transition can facilitate the integration of at least 87% renewables in total. The HRE 2050 scenario does not hinder but rather enables the possibility of further RE implementation. Contributions from all energy sectors must support the implementation of such a cost-effective and socially acceptable pathway.**

The responsibility of creating the framework which will facilitate the decarbonisation of the energy sector as a whole lies first and foremost with the decision- and policymakers at a national level. By achieving this, a country can better ready itself to embrace also increased demands caused by improved living standards and ensure a sustainable future for all inhabitants. However, this requires a stronger commitment and bolder actions in terms of truly ambitious energy and emission targets, and an intelligent choice of pathways accounting for all the demands of tomorrow – for this reason, HRE's national scenario Heat Roadmaps are key tools to facilitate more viable predictions and suitable solutions to address them.

A common understanding of national roadmaps to show the determination, providing effective incentives and ensuring stable framework conditions will no doubt boost energy infrastructure investments and speed up the energy transition process, thereby benefitting both businesses and private citizens. National policymakers are therefore strongly urged to fully consider all the proven opportunities, tools and recommendations offered by HRE4 and act accordingly to make sure that each country contribute positively to European and global initiatives.

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9. Abbreviations

BL:	Baseline (scenario)
CAPEX:	Capital expendidures
CHP	Combined heat and power
CO_2	Carbon dioxide
COP:	Coefficient of performance
DC:	District cooling
DH:	District heating
DSO:	Distribution system operator
EE:	Energy efficiency
EED:	Energy Efficiency Directive
EPBD:	Energy Performance of Buildings Directive
EU:	European Union
EU ETS:	European Union Emissions Trading System
GWP:	Global warming potential (factor)
H&C:	Heating and cooling
HP:	Heat pump(s)
HRE:	Heat Roadmap Europe project series starting in 2012
HRE 2050:	Heat Roadmap Scenario for 2050
HRE4	Heat Roadmap Europe 4 (H2020-EE-2015-3-MarketUptake)
ICT:	Information and communications technology
MEP:	Member of the European Parliament
MS:	Member State(s) of the European Union
MSR:	Market Stability Reserve (of the EU ETS)
OPEX:	Operational expendidures
Peta:	Pan-European Thermal Atlas
PEF:	Primary energy factor
PES:	Primary energy supply
PV:	Photovoltaics
RE:	Renewable energy
RES:	Renewable energy sources
RED:	Renewable Energy Directive
UK:	United Kingdom
VRE:	Variable renewable energy

2050

Heat Roadmap Europe

A low-carbon heating and cooling strategy

Guidelines for the Energy System Transition

The Energy Union Perspective

Deliverable 7.17-E

Project Number:	695989
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Preface

The findings of Heat Roadmap Europe 4 (HRE4) proves that a common and coordinated effort of all Europeans for the transition to a low-carbon future in accordance with the Paris Agreement is not only possible, but cost-effective and affordable with existing technologies available on the market today. Therefore it would be an ethical, political and organisational failure, if the European Commission, its Member States as well as regional and local governments together won't be able to ensure the change required to keep global warming significantly below 2 °C compared to the pre-industrial area.

In particular, current and planned policies should be aligned with the vision of a carbon emission free heating and cooling sector by 2050, as the sector corresponds to about 50% of the final energy demand in Europe and has a crucial role to play in the connectivity and affordability of the entire sustainable energy system of the future. This includes energy, environmental, economic, tax and educational policies, while ensuring that the impact of any legislation on all levels does not hinder the development towards this goal, but instead encourages and accelerates the transition.

There is no sustainable alternative for the future of Europe than a decarbonised, integrated energy system. Postponing the challenges will only make the transition organisationally more difficult and unnecessarily expensive, but will not make the challenge itself become obsolete. The emission targets required to meet the Paris Agreement must be reached sooner, rather than later in order for society to benefit from the improvements created. The scientific and technolocially neutral research initative Heat Roadmap Europe verifies how choosing the path of decarbonisation in an integrated manner will be beneficial for all governmental levels, wether if the main priorities are economic, social or environmental.

Based on the outcomes of Heat Roadmap Europe, the authors call for action from all politicians in Europe to accept their responsibility to take on their necessary role as leaders towards a fossil fuel free energy system by setting up the decisive framework which will have guided Europe to an economically feasible, socially accepted and environmentally needed low-carbon future.

Executive summary

The aim of the HRE4 project is to create the scientific evidence to support short-to long-term energy strategies and decision-making at local, regional, national and EU levels to accelerate and empower the transition to a low-carbon energy system by quantifying the impact of various options, particulary in the heating and cooling (H&C) sector. Specifically, the results are presented in terms of roadmaps and recommendations towards 2050 for the H&C sector of the 14 EU countries[1] that correspond up to 90% of the EU's thermal demand, but are also still applicable to other Member States.

These *Heat Roadmaps* [1] should not be considered as the exclusively definited and only viable future sustainable energy mix, but rather as solid, cost-effective and affordable pathway presenting how the benefits and synergetic opportunities – ready to be exploited today by taking an integrated approach in a redesign of the entire energy system – can lead to a feasible, decarbonised future in accordance with the Paris Agreement [2].

Key messages – requested actions from EU policymakers

1	**Europe can already reduce its CO_2 emissions by 4,340 Mton or 86% compared to 1990 by using existing, mature technologies in the heating and cooling sector. HRE4 verifies that decarbonisation in line with the European commitments under the Paris Agreement is possible and that the coupling of sectors is essential for the most cost-efficient, and therefore economically and socially feasible low-carbon energy system.**

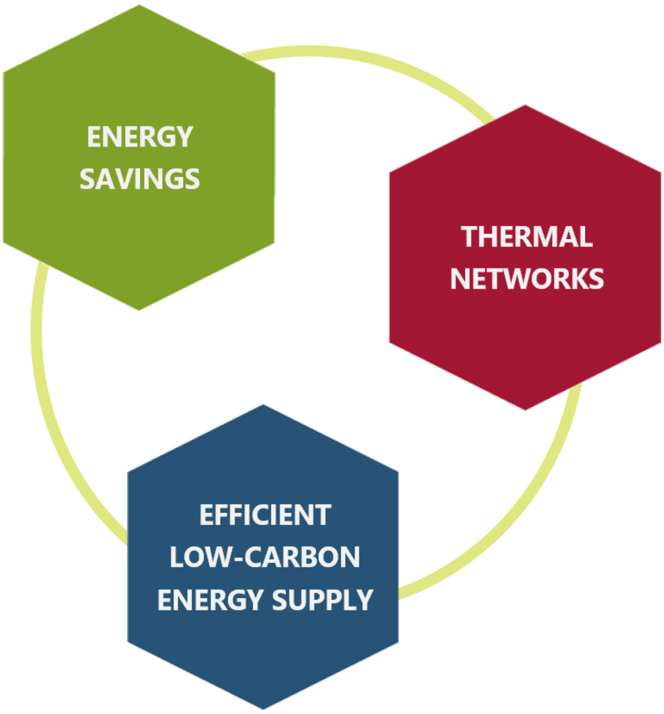
- By redesigning the heating and cooling sector the total costs of decarbonisation can be reduced by 6% annually compared to conventional methods of decarbonisation. In all future scenarios less financial resources are spent on fossil fuels and more on the infrastructure that delivers sustainable energy. This requires clear sectorial targets and policies that facilitate and foster a fossil fuel phase-out by 2050 and a strategic redesign of the framework conditions to enable investments for an integrated, efficient and renewables-based energy system on a local, regional, national and European level.

- H&C should be politically and technically recognised as an essential component and the most cost-effective solution that allows the integration of shares of renewable energy of up to

[1] Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Netherlands, Poland, Romania, Spain, Sweden and United Kingdom.

87% and more, while supplying flexibility and ensuring the stability and security of an overall integrated sustainable energy system.

The three main "pillars" or focus areas – energy savings, thermal networks and efficient low-carbon energy supply to enable electrification of the energy system – are especially important for policy-makers to steer the transition holistically towards a low-carbon energy system. HRE4 shows that a mix of energy savings, establishing and expanding district H&C areas, integration of low-carbon renewable and excess heat sources together with a significant electrification of the H&C sector can create synergies which are not as exploitable if one (or more) of these components is overlooked. The cross-sectoral energy planning approach of HRE reveals further points covering all three pillars, as revealed in the subsequent key messages.



2	**Energy savings are required on both the demand and supply side to cost-effectively reach the decarbonisation goals. HRE4 shows that the majority of recommended savings in primary energy demand can be achieved by more efficient supply options. EU policies, directives and the EU financial framework need to coherently support both sides.**

- Substantial amounts of cost-effective energy savings are ready to be exploited and these are key for the decarbonisation of the energy system. Related EU directives, like the Energy Efficiency Directive and the Energy Performance of Buildings Directive, need to reflect the higher, but feasible energy saving targets of at least 30% for space heating in buildings for instance. Consequently, also the EU financial framework including financial incentives should support this higher ambition and enable the exploitation of the potential in the residential, industry and service sector alike.

- Despite common misconceptions, introducing energy efficiency measures does not necessarily make district heating unfeasible, neither for existing nor new networks. In fact, energy efficient buildings can effectively shave expensive peaks and improve the performance and feasibility of the entire (new or existing) district energy network. Respectively, policies and financial programmes should support the efficiency for district heating systems and the integration of small- to large-scale excess heat sources, as HRE4 has identified an excess heat potential in the electricity production alone corresponding to more than the heat demand of Europe's entire building stock today.

ENERGY SAVINGS

- Where district heating is not the most cost-effective solution, mainly in rural areas, energy retrofitting of buildings should consider combining such measures with the replacement of boilers by individual heat pumps. The most efficient heat pump systems are those found in new buildings and in those that have undergone deep renovation. On top of the added value in energetic savings, such efforts will also improve the comfort level for the buildings' inhabitants. Respectively, policies and financial programmes should support the massive roll-out of heat pumps in rural areas.

3	**HRE4 identifies suggested balances between decentralised heating and cooling systems being the most cost-effective decarbonisation option in rural areas, and thermal networks in dense urban areas. Those individual supplies should mainly be based on heat pumps as they can enable the flexible integration of renewables without using scarce bioenergy resources.**

- Electrical heat pumps should be implemented to a much greater extent and up to an overall market share of about half, specifically:
    - in rural areas, where individual heat pumps should replace fossil fuel boilers;
    - in urban areas, where large-scale heat pumps should make the use of low-temperature renewable and excess heat sources and replace a fossil-based district heating supply relying on boilers and/or CHP.

EFFICIENT LOW-CARBON ENERGY SUPPLY

- Increasing the share of district heating in combination with cheap thermal storages, heat pumps and CHP can stabilise the electricity grid and thus facilitating the integration of renewables, when introducing more fluctuating sources such as wind and solar.

- Several renewable energy technologies benefit – or even require – large-scale installations in order to be economically viable. To exploit the full potential of large-scale and capital-intensive technologies like deep geothermal energy and solar heating, a district heating system needs to be present since for these technologies, economy of scale is key. The future energy mix will be much more diverse than in the past. A thermal grid in place will be able to integrate small- to large-scale renewable and excess heat sources in the most cost-effective way.

- By means of detailed spatial analysis HRE shows that approximately half of the total building heat demand in the residential and service sectors is located in high density areas. Some countries have higher or lower shares, depending largely on their level of urbanisation. Combining cost calculations with the overall system modelling reveals the scientific evidence supporting the conclusion that more than half of European countries' heat demand can cost-effectively be supplied with district heating in 2050. Furthermore, the spatial components of HRE and in particular its Pan-European Thermal Atlas (*Peta*) online mapping tool can even pinpoint where these new or expanded networks can feasibly be located.

THERMAL NETWORKS

4	**Excess heat recovery is key to an efficient and resilient thermal sector, and has the potential to support local industries, economies and employment. The identified quantities of excess heat across Europe are with 2.4 PWh/y (8.7 EJ/y) immense and thus need to be addressed through policies, regulations and finance that enable integration into the energy system.**

Small to large-scale excess heat 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 HRE 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.

Administrative and financial barriers to use (low-temperature) waste heat should be suitably removed, but of course giving priority to sustainable excess heat sources free of fossil fuels or other negative environmental impacts.

5	**District heating and cooling in cities and towns is the least-cost and most-efficient solutions for reducing emissions and primary energy use. Through a thermal grid H&C can be completely decarbonised using renewables, large heat pumps, excess heat and CHP. Therefore, investments in the establishment and expansion of thermal grids in urban areas need to have high priority in public funding and support programmes.**

The HRE recommendations correspond and support all aspects of the EU Energy Union including energy security, strengthening the internal energy market, prioritizing energy efficiency, identifying viable options for the decarbonisation of the economy, and enhancing research, innovation and competitiveness.

- The presented solutions of the HRE scenarios recommend the shift towards a more capital-intensive heat supply, however, with much lower operational costs due to a heat supply mainly based on renewables and excess heat. With this shift fossil fuel imports which currently amount to a value of about € 50-65 billion for natural gas alone, could be phased out and economically be replaced by local added value chains of energy efficiency and renewable energy throughout Europe.

- With the comprehensive energy system modelling approach of HRE4 it was analysed how a reduced consumption of fossil fuels can be achieved in order potentially to eliminate the dependence on imported oil and natural gas for heating purposes in Europe and the uncertainty related to future fuel prices.

- The decarbonisation of the H&C sector will open the market for locally based heat sources and thereby increase the security of supply and making the countries more resilient to geopolitical changes, while enabling the implementation of increased amounts of fluctuating renewables.

- The restructuring of the thermal energy system will create and maintain local jobs related to energy efficiency and renewable energy products and services. Moreover, the redesign would significantly strengthen the competitiveness of industries, nationally as well as internationally.

6	**HRE4 shows how an energy system transition can facilitate the integration of at least 87% renewables in total. The HRE 2050 scenario does not hinder but rather enables the possibility of further RE implementation by decarbonising also the remaining fossil fuel use which primarily is allocated to transport, industry and flexible CHP.**

The ambitious long-term climate and energy targets of the EU must be translated into adequately ambitious short-term actions through policies that facilitate the energy transition in the electricity, thermal and transport sector. Cross-sectorial, complementary efficiency and renewable targets applied at all governmental levels will be essential for realising a sustainable low-carbon society. Integrated management, knowledge transfer, holistic energy planning tools, open business models with broader forms of collaborations and incentives are some of the most important aspects that need to be carefully addressed, since in most cases the barriers faced are political, regulatory and organisational rather than technical. Among the key recommendations can be mentioned several action points:

- A horizontal integration of energy/climate targets (into all sectors such as electricity, heating and cooling, transport etc. incl. their subsectors) combined with vertical integration of targets (throughout governmental levels) should be applied. Besides this, it is important to ensure not only targets, but actual policy implementation and realisation, with regular reporting and evaluation cycles on progress and impact.

- It is recommended to increase the target to at least 30% savings for space heating in buildings by 2050 compared to 2015 which requires higher annual refurbishment rate at 1.5% to 2%, and deeper renovation of existing buildings that anyway undergo a renovation. The EPBD should reflect these ecomically feasible findings.

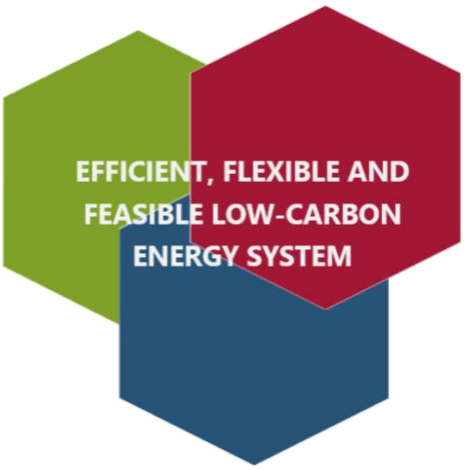
- Policies such as the RED should incentivise flexible interaction for prosumers to help balance electricity grids and not maximise self-consumption which in some cases will be counterproductive for the overall energy system.

- An investment initiative – both at EU level and at national level – for comprehensively and fast expansion and establishment of systematically new district thermal infrastructures in urban areas and roll-out heat pumps in rural areas should be initiated. This financial framework has to be aligned with policies reflecting the reduced role and appliance of natural gas and an increased importance of electricity grids.

- More support is also needed to ensure implementation and higher energy saving targets and higher energy saving targets for both deeper renovation of the existing building stock and investments in industry. Stronger price signals (e.g. energy obligation schemes or taxes), together with information-availability (e.g. smart meters), communication (e.g. “nudging”), as well as the proper education of craftsmen and citizens, will be crucial drivers.

7	**HRE recommends a complete decarbonisation of H&C by 2050 and shows how this can be done. Contributions from all energy sectors have to support the implementation of such decarbonisation targets to ensure the most cost-effective and socially acceptable pathway. The targets should also be reflected in directives such as the EED, RED, EPBD and EU ETS[2].**

- To remove barriers the following complementary measures for the recommended key actions have been identified:
    - Raising awareness and formulating a common narrative for all Europeans that the decarbonisation of our society is not only possible, but cost-effective and affordable with existing technologies available on the market today and much more profitable for our local economies.
    - Setting up frameworks to improve qualifications and the number of skilled professionals.
    - Removing administrative barriers for stakeholders to establish district heating and cooling and excess heat recovery[3].
    - Requiring integrated energy planning, implementation and regular evaluation of status across all energy sectors and at all governmental levels.
    - Improving feasibility of a sustainable energy system directly and indirectly by means of CO_2 taxation.
    - All fossil fuel subsidies should be stopped immediately including also indirect support such as incentive schemes for gas and oil combustion boilers.
    - Fossil fuel boilers should be phased out. Expiry dates should be set combined with banning the installation of fossil fuel boilers in new buildings. This should go hand in hand with stronger support for alternatives (e.g. renewables and sustainable excess heat) and thus potentially avoiding increased costs for end-consumers.
    - Expiry dates for fossil fuel power production should be set to avoid investments in new (long-lasting) fossil-based capacity and provide certainty for the power industry to invest in sustainable solutions.



[2] Referring to the Energy Efficiency Directive [3], Renewable Energy Directive [4], Energy Performance of Buildings Directive [5] and EU Emissions Trading System [6] respectively.
[3] In some cases, even small industries would need the same level of approval as an electricity production utility if they are to enter an agreement on selling their low-temperature excess heat.

- The EU Emission Trading Scheme (ETS) today does not reflect actual costs of emissions. A decision to ensure a minimum price level (increasing over the years) would serve as a safety net to make investments in RE solutions and energy efficiency more certain. Increasing the amount of allowances put in the Market Stability Reserve (MSR) until a certain lower price level is reached could be combined with the present MSR and ETS cap reduction plans. This additional MSR action will only come into force, if the cost of allowances becomes too low.
- In general, all public financing should be cross-checked, if they counteract or support the short- to long-term energy efficiency, renewable energy and emission reduction targets and activities of the EU and its Member States.

HRE resources available to support the energy transition

The HRE provides a range of new information to empower the decision processes and improve the foundation for political and technical choices on the most cost-effective and affordable pathways towards a decarbonised energy system. These include among others, detailed profiling of the present H&C demands by subsector, cost-curves for reducing the H&C demand in buildings and industries[4], and complete energy system model datasets which users can modify to investigate for themselves the likely impacts of alternative scenarios. HRE has the aim provide a transparent approach to democratise the debate on how future energy systems can and should be structured.

Guidelines for the energy system transition with a *local/regional* and *national* approach respectively are also available, and may be useful to get an insight into variations of these recommendations from either perspective. All project reports are available on the HRE website. Two outcomes stand out in particular as major results building upon the knowledge gathered from the other HRE analyses: The Pan-European Thermal Atlas and the energy system scenarios of the 14 HRE countries.

- The Pan-European Thermal Atlas (*Peta*) represents a publicly available interactive online portal to support planners, investors and policymakers by presenting and quantifying H&C possibilities (geo)graphically for all 14 HRE countries. The following features are included amongst others:
  - Heating and cooling demands, each on a hectare level.
  - Renewable heat resource potentials such as geothermal, solar thermal and biomass.
  - Pinpointed potential excess heat sources e.g. from waste incineration, power plants, data centres and industrial processes.
  - Existing and prospective district heating areas including the cost of establishing network infrastructure and indications of the recommended shares of district heating.

[4] The cost-curves shows the cost of reducing the demand depending on how ambitious the target is, i.e. what are the cost of measures, when “low-hanging fruits” have been exploited and further savings are required.

- Heat Synergy Regions highlighting the overlap of demands and identified excess heat – indicated as an "excess heat ratio", i.e. the ratio between excess heat and heat demand within a given region.

- The development and findings of the modelled HRE 2050 decarbonisation scenarios including methodologies used, different energy demands, different energy supply technologies, their role within the wider energy system and how these compare with alternatives [1]. Country-specific results such as the recommended balance between energy savings and district heating are included in the 14 individual country reports. Collectively, these 1+14 reports hold the title: *Heat Roadmap Europe – Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps.*

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1. Introduction

In Europe, there is a clear, long-term objective to decarbonise the energy system. The Heat Roadmap Europe 4 (HRE4) project, co-funded by the European Union, seeks to enable new policies and prepare the ground for new investments by creating more certainty in relation to the changes that are required.

HRE4 provides new capacity and skills for lead-users in the heating and cooling (H&C) sector, including policymakers, industry, and researchers at local, national, and EU levels. This is done by developing the data, tools, methodologies, and results necessary to quantify the impact of implementing more energy efficient measures on both the demand and supply side of the sector.

The results of HRE4 show how a complete decarbonisation of the European heating and cooling sector is technically feasible and economically viable, and can be achieved with proven technologies already used today. The "Heat Roadmaps" representing decarbonisation pathways for 14 EU countries[5] towards 2050 (covering approx. 90% of the EU heat demand) show how this can be done, and all the available HRE outcomes such as guidelines and interactive tools can help stakeholders facilitate this transition. This report emcompasses *key messages and recommendations* based on the overall HRE4 project targeting policymakers at European level such as DG ENER, DG CLIMA, DG REGIO, MEPs etc.

The overarching "pillars" of HRE (see section 2) identified to be the main focus areas each represent one section headline. These sections include key messages related to the topic including explanations of the context regarding why this is important as well as how the raised points apply to policymakers, how the HRE outputs can be used, and how to apply the outputs to policies.

> The development and findings of the HRE scenarios including methodologies used, different energy demands, different energy supply technologies, their role within the wider energy system and how these compare with alternatives are described in the report
> *Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps* [1]
>
> Guidelines similar to this report only aimed at national and local/regional policymakers respectively may also be of interest to the readers of this report to get an insight in the country-specific recommendations and the ones suggested for other governmental levels.
> *Guidelines for the Energy System Transition – The National Aspects of the HRE 2050 Scenario and Associated Policy Recommendations* [7]
> *Guidelines for the Energy System Transition – Recommendations for Local and Regional Policymakers* [8]

[5] The HRE4 project especially focuses on those fourteen EU countries with the highest H&C demands (around 90% of the EU's total demand): Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Spain, Sweden and the UK.

2. Three main pillars to decarbonise the H&C sector

The HRE4 project identifies three main pillars, which are especially critical to address in order to facilitate the transition towards a future low-carbon H&C system. These are closely linked. Hence, in many cases the recommendations cover more than one of them. Figure 1 below sketches the pillars as well as interconnections between them. Examples for each of these pillars (hexagons in Figure 1) district heating (DH) or district cooling (DC) in urban areas – fed by renewable energy (RE) or excess energy, building renovations to improve energy efficiency (EE) and heat pumps (HP) for space heating and domestic hot water in rural areas.

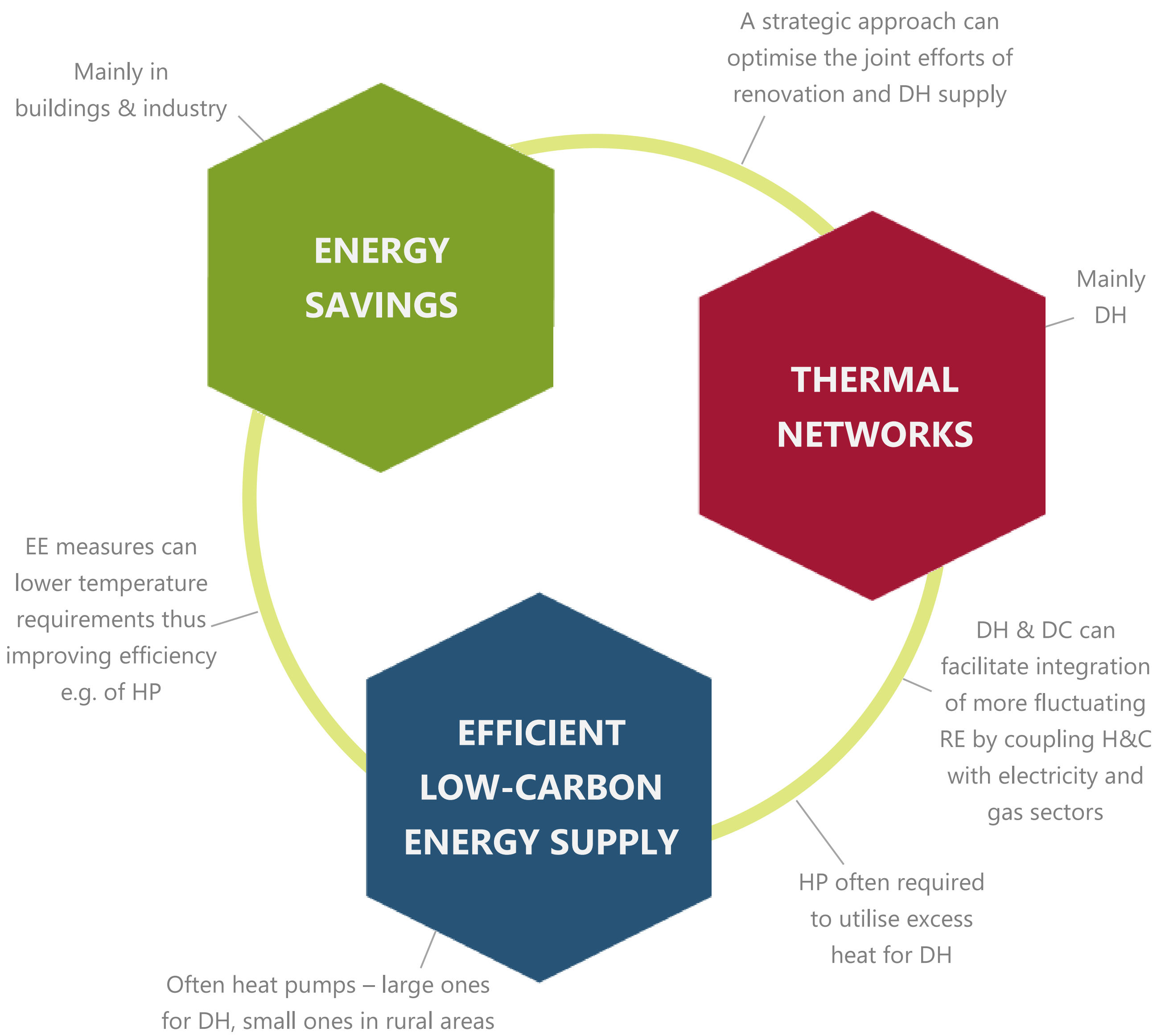

Figure 1. The three HRE "pillars", including examples of linkages between them.

The “Heat Roadmaps” of each of the 14 countries are commonly referred to as the HRE 2050 scenario. They should not be considered as the exclusively definited and only viable future sustainable energy roadmap, but rather as solid, cost-effective and affordable pathway presenting how the benefits and synergetic opportunities can lead to a feasible, decarbonised future in accordance with the Paris Agreement. One aim is to democratise the debate on how future energy systems can and should be structured.

Detailed energy system modelling has been used to take into account short-term hourly interactions of demand and (renewable) supply and including both challenges such as balancing requirements, and opportunities such as cross-sector links, while also looking at the long-term developments of the overall energy system and its demands towards 2050. This makes it possible to consider the connections between demands and supplies for heating, cooling, electricity and transport to optimise the overall system. HRE 2050 shows 86% decrease in CO_2 levels compared to 1990. The remaining fossil fuels are primarily in transport, industry and flexible CHP. In this context it should be mentioned that HRE 2050 does not hinder but rather *enables* the possibility of further implementation of renewables[6].

1	**The holistic HRE approach – which jointly considers electricity, heating, cooling and transport – reveals synergies between (and within) these different sectors and shows that decarbonisation is indeed possible and affordable with existing, mature technologies.**

The cross-sectoral energy planning approach of HRE reveals the following:

- Increasing the share of district heating and cooling, including cheap thermal storages, helps to stabilise the electricity grid when introducing more (non-dispatchable) variable renewable energy (VRE).
- Substantial energy savings in different sub-sectors are possible, feasible and recommendable for each of the targeted countries.
- An integrated approach considering the energy demands for transport, electricity, heating and cooling as a whole can release larger savings as a result of synergies.
- Even without including the significant health-related and climate change-related costs [9, 10], decarbonisation can be achieved at lower costs than “conventional decarbonisation”[7]

[6] See section 4.4.

[7] The HRE 2050 scenario (one per country) can be compared with the 2015 situation, a baseline development towards 2050 and the ”Conventionally Decarbonised scenario” (CD 2050). CD 2050 represents an energy system targeting 80% reduction in EU CO_2 levels compared to 1990 levels and assumes encouragement of RE but without the same focus on savings and a redesigned H&C sector as in HRE 2050, cf. [1].

only, while reaching even greater CO_2 reductions. However, it requires a massive changeover of the current system design and framework conditions to support it.

These results should subsequently encourage policymakers to choose their own prioritisation – economic feasibility, environmental impact, quality of life, etc. – but nonetheless it is expected to reach the same conclusion regardless of priorities: that remains no reason to delay pushing this development forward.

> The results of the baseline scenario showing the path towards 2050 with current policies is included in the report below. Furthermore, it contains a description of the energy modelling tools that can be further used – even beyond the HRE4 project. This provides a basis for understanding how markets will likely develop under current policy, and which markets need further development of their framework conditions in order to contribute to full decarbonisation.
>
> *Baseline scenario of the total energy system up to 2050* [11]
>
> For users who want to evaluate, elaborate or adjust these models themselves, the freeware and baseline scenario input files are publicly available, presenting hourly energy system models for each of the 14 countries for both 2015 and 2050.
>
> *Hourly energy system models for each of the 14 MSs for the business-as-usual scenario* [12]

The following sections represent the main findings and associated policy recommendations covering these three complementary pillars based on the complete energy system modelling of each of HRE's 14 target countries.

Just like the integrated energy system approach covers the challenges and opportunities in a holistic manner, the points raised in the following text should not be considered applicable only to a single pillar, but rather something that builds upon each of them, reinforced by the interconnections.

A key point derived from the results of HRE is that the presented decarbonisation roadmaps require *combined* efforts of energy efficiency measures, an efficient low-carbon H&C supply with increased electrification and a significant deployment of more district H&C. These synergetic effects will not be realised to the full extent possible if policymakers fail to take the potentials of all pillars and their linkages into account.

While national governments may wish to push for a sustainable development they will often be concerned with risking (short-term) reduced competitiveness for the country's industries if hard taxation and/or sustainability criteria are applied without corresponding support to facilitate the transition towards sustainability. Even with the aim to balance support and taxation for the involved stakeholders to steer the energy transition, some stakeholders will in most cases be affected more than others and thus oppose the change. Long-term political goals and corresponding stable frameworks ("raising the bar" continuously), can let stakeholders plan ahead and make wise (transition) decisions to avoid a cost increase. Collaboration and agreements on supranational level – for various sustainability topics – can encourage a common understanding of necessary changes and avoid that Member States (MSs) apply protectionist legislation.

2	**The reluctance of some national governments for pursuing ambitious energy and climate targets – setting nation-centric interests first – calls upon EU policymakers to show leadership by pushing for a common EU ambition level for 2050 matching the globally-required targets of the Paris Agreement [2].**

Stricter efficiency requirements applied to products related to buildings and industrial processes, can prove to be an advantage for Europe's exports[8] since sustainability requirements across *all* sectors will create improved technologies and products thus increasing the competitiveness globally in the long run where sustainable technologies and production chains are indeed the only viable option.

[8] In accordance with one of the objectives of the Energy Union – to make the EU the global leader in renewable energy and lead the fight against global warming.

3. Realising essential and feasible energy savings

3.1. Energy savings is not a single-player game

HRE identifies substantial amounts of cost-effective energy savings ready to be exploited and highlights that these are key for the decarbonisation of the energy system. It is recommended to target at least 30% savings for space heating in buildings by 2050 (compared to 2015) which requires a higher refurbishment rate of 1.5% to 2%, and deeper renovations when they occur. As a precaution, such a target could be set somewhat higher since the results of HRE show only little difference in socio-economic costs while there is an inherent risk that whatever targets are set, the savings realised may fall short of reaching these. However, when targeting energy savings objectives, it should be remembered that the goal should not be the savings per se, but rather emission reductions. Hence, the extent of savings should be balanced with alternatives such as RE-based supply as illustrated in Figure 2.

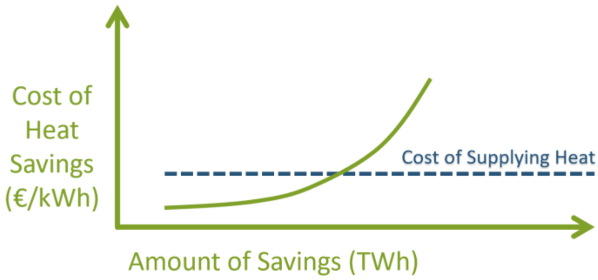

Figure 2. Illustration of the principle that savings should be realised to a certain extent, until it becomes more relevant to apply a decarbonised heat supply.

3	**Energy efficiency is required on both the demand and supply side to cost-effectively reach decarbonisation goals. To meet its greenhouse gas emission reduction target by 2050, the EU needs to combine energy efficiency measures with the decarbonisation of the energy supply.**

Decarbonising Europe's building stock is not an "either/or" decision between energy efficiency and the deployment of renewables, but needs a system focus on both. The balancing of necessary investments to achieve demand reductions vs. a decarbonised energy supply should be optimised.

Cost of savings should be balanced with cost of decarbonised supply. It is important not to promote one over the other in an unbalanced way, among others in relation to EPBD. Building performance assessments and similar sets of rules as well as the EU framework on cost-optimality calculations for nearly-zero energy buildings must consider systemic measures and individual measures, efficiency and renewables, and onsite and offsite energy solutions equally. This means for example that primary savings through using waste heat and through a more efficient building need to be compared on a non-discriminatory basis while taking into account more than just one individual building. Similarly, individual RES solutions like PV panels should not be considered as energy savings as it is the case, when using a purchased energy approach. On the contrary, RES onsite and offsite must be treated in a non-discriminatory way that reflects the actual contribution to a better performing building.

When considering the contribution of sustainable energy sources, be it RES or excess, the use of primary energy factors (PEFs) has a key influence on the way this happens. They are crucial in policies implemented in relation to both the EED and to EPBD. It must be ensured that methodologies in general reflect the real energy mix and it is worthwhile to consider seasonal variations in the use and supply of energy.

Similar to the case of PEFs, also other indicators must treat all options in a fair manner. The smartness readiness indicator[9] should consider heat and electricity equally e.g. in a way that *demand side management* and *demand response* solutions are included[10].

> By investigating the energy savings potentials – including their sub-sectors, type of savings and associated costs – HRE4 has evaluated how the costs increase as the energy efficiency ambition-level rises. This is graphically represented as "cost-curves" which naturally vary from country to country. The information can be used when developing national scenarios targeting a certain savings potential. The same methodology is applied across all countries, which makes the cost-curves of different countries directly comparable. This can be used to identify suitable policymaking and other solutions from third countries which may have a potential for replication. The report below describes how to relate investments to delivered energy savings.
> *Cost-curve Guide for Lead-Users* [13]

3.2. Ensuring the implementation of savings

By investigating the potential and corresponding cost of a wide range of concrete energy savings measures (sub-groups within residential, tertiary and industry) it has been analysed to which extent these can be implemented economically including a comparison with alternative means of covering demands (e.g. supplying more RE instead of implementing some of the savings). The results show that in some countries the ambitious policies passed on since the 2010 EPBD[11] are already enforced

[9] Article 8 of the 2018 EPBD states the following: "The [smart readiness] rating shall be based on an assessment of the capabilities of a building or building unit to adapt its operation to the needs of the occupant and the grid and to improve its energy efficiency and overall performance."
[10] See also section 4.5 regarding consumer flexibility.
[11] Directive 2010/31/EU on the energy performance of buildings.

in national laws meaning that the baseline scenario includes roughly the same level of savings as in the Heat Roadmaps. To achieve these savings the focus needs to shift from encouraging ambitious policy targets towards ensuring *implementation* to the extent of complete achievement of these goals. It is vital that defining the goals does not become a pretext for inaction.

4	**While Belgium, the Czech Republic, Hungary, the Netherlands, Poland and Romania need to significantly enhance their current legislation on energy efficiency, other countries already-passed policies that would lead to a substantial, cost-effective reduction in residential heating demand. Therefore, the latter group should focus on the effective implementation of these policies.**

HRE4 finds that in Belgium, the Czech Republic, Hungary, the Netherlands, Poland and Romania there is a need to significantly improve/upgrade current legislation to increase their energy savings efforts, while (as in all countries) keeping a focus on supporting policies to ensure that the expected savings are reached in practice. Regular follow-up evaluation on the progress and impact on legislation and support schemes is important to ensure that expected targets are met.

Considering the lifetime of buildings compared to other investments, planning is needed for 2050 in which the development of built area quantities including types of demand, renovation rates, and uncertainty of compliance should be taken into account. Once investments have already been made for "low-hanging fruit" in energy efficiency renovations, the remaining savings potentials will have higher investment costs, and therefore need to be made attractive for end-users to invest in them. It is relevant to distinguish between refurbishment *rates* of 1.5%-2% per year and refurbishment *depth*.

5	**Supporting deeper thermal renovation of buildings that will anyway undergo a renovation could avoid an important missed opportunity. Financial incentives should be combined with increased awareness and education of related companies and craftsmen.**

Stronger price signals (e.g. energy obligation schemes or taxes), together with low-cost financing schemes for decarbonisation investments, information-availability (e.g. smart meters), communication (e.g. "nudging"), as well as the proper education of craftsmen and citizens, will be crucial drivers to ensure realisation of the necessary savings to reach the decarbonisation goals across Europe. These are not technical barriers but can all be addressed if the political will and required efforts are put into the processes.

The Heat Roadmaps use the abovementioned cost-curves for each of the 14 countries highlighting to which extent energy savings should be applied in the context of various energy system configuration alternatives. The report below can support policymakers by presenting the costs and benefits of targeting various (sub-)sector-specific efforts relevant to establish suitable frameworks to steer a development towards recommended savings levels.
Cost-curves for heating and cooling demand reduction in the built environment and industry [14]

3.3. Feasible heat savings potential in industry

By assessing the cost of heat savings depending on penetration level and sectors, HRE4 finds that energy savings in industry are highly cost-effective from a socio-economic perspective, and since industries often benefit from economies of scale (e.g. larger equipment, greater demands and/or higher annual full-load hours than in the residential or tertiary sector) the result is smaller investment costs for industrial heat savings than in residential buildings.

The extent of heat savings in industry tends to be more limited than in buildings because the temperature levels of many industrial processes cannot easily be lowered (and some savings have already been implemented). However, energy efficiency measures with small investment costs compared to the reference technology have been identified e.g. increased paper recycling and a shift from blast furnace steel to electric arc steel. Efficiency standards and financial incentives for process heat savings should be ensured to realise this potential.

Specific industrial savings categories, including the potentials and cost levels per kWh saved, is described in section 3.4 of the report mentioned above:
Cost-curves for heating and cooling demand reduction in the built environment and industry [14]

Working towards a circular economy approach to the energy sector, could result in an even larger share of savings by recycling resources, both in materials and energy.

6	**Efficiency standards and financial incentives should better reflect the highly cost-effective potential for energy savings in industry and the service sector from a socio-economic perspective. Excess heat should be regulated, as the quantities of energy losses are contradicting not only the climate targets, but also enable the affordability of the decarbonisation of the economy in Europe.**

3.4. Energy savings and district energy combined

Introducing energy efficiency measures does not necessarily make district heating and cooling unfeasible, whether for existing or new networks. In fact, energy efficient buildings can effectively shave peaks and improve the performance and feasibility of the entire (new or existing) district energy network. With new or renovated energy efficient buildings, a new network can be designed for low temperatures whereas an existing network peak demand can be reduced, while/or additional consumers can be connected to the same grid. In district heating, the relatively small number of hours per year with peak demand are often the most expensive – in terms of OPEX and/or CAPEX (since the capacity required may have few full-load hours per year).

7	**Energy efficiency measures in buildings and district energy can be seen as complementary solutions, not in opposition to each other as commonly thought.**

Not only are low-temperature district heating networks in general more efficient, but they are also better equipped to take advantage of a wider variety of heat source input options – e.g. low-temperature excess heat with or without the need of applying heat pumps.

3.5. Energy savings and individual heat supplies

Similar to the synergy effects highlighted in 3.4 above, the combination of energy efficiency in buildings and an energy efficient individual supply can contribute to the overall efficiency and decarbonisation of the heating/cooling systems more than either one on its own. One example is the replacement of a boiler by a heat pump. Heat pumps run very efficiently in new buildings and in those that have undergone deep renovation. In all other cases, a proper assessment of the energy demand is necessary for a proper heat pump system design. If the operation temperatures of the heating system are low enough, the necessary energy can be provided by a heat pump. If not, energy efficiency measures should be applied to the building envelope and the heat distribution system before installing the heat pump. In general, heat pumps run most efficient (expressed as the COP/SCOP[12]), if the difference between energy source and the needed supply temperature of the building is as small as possible. Optimising the building envelope and/or the heat distribution system can in some cases be a requisite to make the building "heat pump ready" and thus enhance the technologies application area – on top, it will improve the comfort level of inhabitants.

[12] The coefficient of performance (COP) represents the efficiency of a heat pump – as an annual average also referred to as seasonal coefficient of performance (SCOP).

4. Ensuring an efficient, low-carbon energy supply

4.1. Electrification of H&C is a key piece of the puzzle

Electrical heat pumps should be implemented to a much greater extent – both individual ones in rural areas where thermal networks are not feasible and in urban areas where they can make the use of low-temperature renewable and excess heat sources possible.

8	**Where decentralised H&C systems are more feasible than centralised thermal networks, individual heat pumps should be promoted, since they can simultaneously contribute both to direct decarbonisation and to the flexible integration of renewables.**

The results of the Heat Roadmaps show that a too uniform energy transition focusing only on few solutions (such as full electrification without integrating district heating) would not result in the most cost-efficient future energy system configuration. All the "players on the field" should be considered as possible contributors of the (optimum) energy mix, and energy system modelling should fully take into account specificities of the H&C sector – only then can potential synergies be obtained. Revealing these opportunities requires knowledge on the various demands, available sources and costs of infrastructure – all in high spatial resolution – as well as detailed energy modelling in a short timewise resolution combined with a long-term horizon. Such a combination of mapping and modelling is essential to analyse the heating and cooling sectors but should be expanded to other parts of the energy system in the future.

The Pan-European Thermal Atlas (*Peta*) is a public online interactive portal to support planners, investors and policymakers by presenting and quantifying the possibilities in a (geo)graphical manner for all 14 HRE countries in terms of, among other features: a) H&C demand densities on a hectare level and b) various heat sources to decarbonise the H&C sector, such as geothermal sources, solar district heating potentials, residual biomass resources and excess heat from waste incineration plants, power plants and industrial processes respectively. More information on *Peta* can be found directly in the online map or in the report *Maps Manual for Lead-Users* [15]

The details regarding the underlying methodology which the maps are based on is described in *Methodology and assumptions used in the mapping* [16]

4.2. A sustainable supply is required for all future demands

Not only a conversion of the existing energy demands is required. Targets and corresponding planning should reflect the future supply needs taking into account the increasing demands following economic growth and increased electrification for heating, cooling, transportation – e.g. electric vehicles (EVs) and industries such as datacentres. A renewable electricity capacity to cover 100% of the existing electricity demands would therefore not be enough.

By profiling the energy demands it is shown how important H&C is when aiming for a decarbonised energy system. With a final energy demand (FED) of 6,350 TWh in 2015 (22.9 EJ), H&C accounts for around 50% of the EU28 FED.

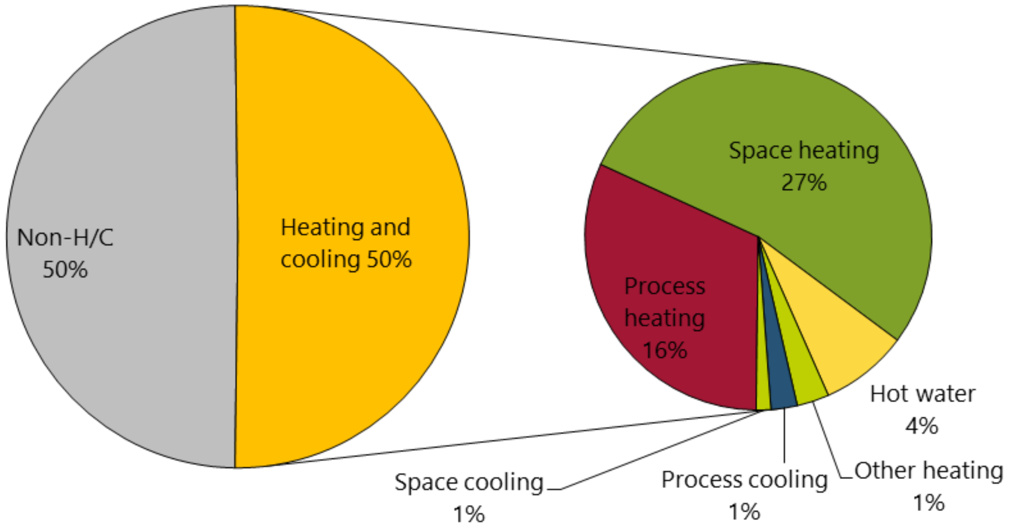

Figure 3. H&C demand in 2015 in the EU28, by end-use, compared to total final energy demand [17].

HRE4 presents a wide extent of freeware data for anyone to use for further analyses. This includes the descriptions of profiling the 2015 energy demand for H&C developed by calculating energy balances for all 28 EU countries. Besides the report including a methodology and summary of main results, the 2015 H&C profiles for all EU28 member states are freely available for download as interactive spreadsheets.

Profile of heating and cooling demand in 2015 [17]

Besides this, the scenarios of current policies are presented towards 2050 (i.e. targets and measures concerning RE H&C and energy efficiency, which have already been agreed or implemented at the latest by the end of 2016). These are described in:

Baseline scenario of the H&C demand in buildings and industry in the 14 MSs until 2050 [18]

A guide for how lead-users can utilise the demand data for 2015 and 2050, technology datasheet, and FORECAST tool is described in the report
FORECAST Guide for Lead-Users [19]

The use of biomass in boilers and CHP plants should not be considered an "easy-fix" solution to cover all the decarbonisation demand. In the future there will be an increased demand for biomass as it will have to cover several fossil-based demands of today such as bioplastics and biofuels for transport. For any biomass demand purpose, strict national and European sustainability rules will be crucial to ensure that it is sourced in a sustainable and effective manner, preventing deforestation and other harmful effects.

4.3. Carbon taxes and investor security

Across all pillars a consistent and reoccurring argument from various stakeholders is that an adequate carbon tax is needed to make the recommended decarbonisation solutions economically feasible and to accelerate their deployment in the medium to long run. If state revenues from such increased carbon taxation is fed back to the same stakeholder groups in the form of support for decarbonisation solutions, it can minimise the overall negative economic impact on the affected companies/end-users. This way the focus can be on the support scheme(s) and common goal(s) rather than what may be a (general) negative impression of increased taxation.

As a simultaneous and important step, all fossil fuel subsidies should be stopped immediately since these are directly counterproductive to the agreed climate targets.

For all the additional capacity needed as explained above (section 0) what is needed for investors is *certainty*. Feed-in tariffs could prove efficient to ensure stakeholder engagement (i.e. continuous RE capacity deployment) even when the RE shares are increased and electricity prices become harder to predict. The price of EU ETS allowances does not in itself provide the certainty for investors to promote new RE capacity. The dilemma of applying feed-in tariffs (to ensure that investors get a minimum price) or not can be boiled down to who should cope with the uncertainty of future energy prices – investors or MSs. Allocating the entire risk to investors may result in additional overall cost of the energy transition (included by investors to cover the risks) and/or to prolong the required changes.

In many cases the feasibility of converting from the fossil-based status quo to a low-/non-carbon alternative is simply not incentivising enough (if even positive) to realise the transition in practice. One example is the widespread use of natural gas boilers used for space heating which is recommended to be phased out (along with inefficient direct electric heating). Though taxation is a strong mean to encourage sustainable choices for the industry, residential and service sector, it cannot stand alone as the only mean promote the energy transition but should rather be considered as one part of a complete package towards decarbonisation.

A starting point for the abovementioned example is to ban the installation of fossil-based heat supplies in new buildings and phase out the ones in existing buildings. This measure – together with increased fossil fuel taxation – could go hand in hand with support for the shift to alternatives (e.g. subsidies or tax discounts). In order to minimise the impact of those who are used to their fossil fuel demand (e.g. natural gas) and associated costs, the economic incentives to shift to alternatives could be implemented simultaneously in order to keep a similar level of expenditures for the consumers.

On a European level, the EU ETS[13] today does not reflect actual costs of the damaging effect of emissions (and obviously distinguish between those polluters covered by the ETS and those who are not). At the same time industries are granted with free quotas allowing for continuous fossil fuel-based production. There is a need to plan for the phase-out of this fossil fuel demand already now. Defining long-term plans including a continuous increase in emission taxes could be a signal to investors showing what is considered a sustainable path forward and what is not, thus providing a more solid foundation for decision makers.

Though the ETS can play a key role in the energy transition, it is important to avoid the shift of CO_2 emissions from ETS to non-ETS sectors. Whereas the (typically centralised) electricity production required for these heat pumps are covered by the ETS, the residential use of fossil fuels (e.g. gas boilers) are not. This represent an unfair advantage favouring fossil fuel-based heat supply. Taxation should cover also emissions beyond ETS to promote decarbonisation outside urban areas.

Due to the following two points, carbon taxation and pure market mechanisms cannot be entrusted with the task of ensuring the energy transition alone:

- Other barriers must be overcome, e.g.:
  - removing unnecessary administrative burdens
  - educating skilled professionals e.g. in terms of renovation measures as well as HP installations and service checks of these
  - raising awareness about relevant H&C solutions among policymakers, businesses and individuals
  - facilitating access to financing schemes
- Broad market mechanisms will have a smaller impact as the RE share is increased. As the RE share increases in some countries/regions while others will lag behind, the price of ETS allowances will not be enough ensure an appropriate continuous push towards decarbonisation. To reach ambitious targets, milestones should push the threshold

[13] In short also referred to simply as "ETS".

continuously. Emission taxation therefore needs to follow this development by having a local aspect.

Though the ETS cannot stand alone, it may prove to be one of several effective tools if the price of emission allowances is high enough. A decision to ensure a minimum price level (increasing over the years) would serve as a safety net to ensure a minimum price threshold, thus making investments in RE solutions and energy efficiency a more certain venture – a critical point to engage investors and convince them to contribute.

9	**Increasing the amount of allowances put into the Market Stability Reserve (MSR) until a certain lower price level is reached could be combined with the present MSR and ETS cap reduction plans[14]. Thereby, this additional MSR action would only come into force if the cost of allowances becomes low enough.**

4.4. Renewable energy requires and offers flexibility

With the increasing integration of VRE, the positive role which the heating and cooling sector can play to augment grid flexibility becomes increasingly important and apparent. The use of renewable electricity in the heating and cooling sector can help balance the electricity grid when more VRE is introduced. Individual heat pumps in rural areas in combination with smart controls and large-scale heat pumps in district heating networks can play an important role in this connection when operated at times of surplus electricity thus providing a demand response potential to stabilise the grid and to allow more renewable electricity in to the energy mix.

Thermal storages – being several times cheaper than electrical ones – can increase the flexibility potential. In fact, storages for district heating represent a key role to provide the flexibility required in future energy systems with an increased amount of non-controllable energy production.

10	**To provide the flexibility required when increasing the share of wind and PV power, thermal storage is important in combination with individual heat pumps. However, the potential for grid flexibility and cost-effectiveness to integrate fluctuating RE becomes even greater by using district energy together with large-scale thermal storage, heat pumps and CHP.**

[14] See the EU Directive 2018/410 of 14 March 2018.

Avoiding the release of harmful refrigerants with high global warming potential factors (GWP) to the ambient is critical to realise the positive climate effect of heat pumps. In the HRE 2050 only low-GWP refrigerant heat pumps are used.

4.5. Flexibility from decentralised consumers and prosumers must be valued

In order to create new business models, which facilitate connections between the thermal and electricity sectors, the provision of demand side flexibility must become more interesting in an economic sense. This may be achieved by offering variable electricity tariffs to end-users or aggregators, among other solutions. Heat pumps can shift electricity consumption by absorbing its surplus in times of low demand through storage in a hot water tank, or in some cases within the building envelope itself. Giving this grid-flexibility service a true economic value would accelerate the technology deployment as more individuals and enterprises seek to profit from heat pumps and/or thermal storage.

Introducing many more consumers/prosumers[15] will result in a more decentralised and diverse energy system interacting across both sectors and the traditional stakeholder groups. New ICT solutions make market interactions with smaller consumers manageable. One example could be the use of local storage options (thermal or electric) to act as buffers to reduce peak demands for the electricity grid and the inherent dimensioning or capacity upgrade criteria to cope with this, when introducing large quantities of electric heat pumps (besides EVs etc.) The financial benefits for the prosumers should be structured to reflect the needs of the overall system. In some cases, the feasibility of electrical storages for individuals lies only in the avoidance of taxes. Household batteries should for example be able to respond to signals from the DSO instead of only maximise self-consumption. The use of RE should not be the end goal, but a mean to reach energy system emission targets – not single household targets.

11	**Policies such as the RED should incentivise flexible interaction for prosumers to help balance electricity grids and not just maximise their own self-consumption, which in some cases would end up being counterproductive for the overall energy system.**

[15] The term "prosumer" is a contraction of the words "producer" and "consumer". It reflects a consumer who sometimes produce more energy than what is consumed.

Flexible prices could reflect the strain on network and the balancing needs besides the production costs e.g. by introducing a tariff differentiation depending on periods or the user's maximum power peak. However, it is important *not* to structure cost schemes in a way that repels the interest of building owners to install a heat pump in the first place (where this is recommended). One option is to include an electricity tax discount on some of the bills (approximately the share for heating) for residential owners where their building is registered as supplied by a heat pump.

4.6. Excess heat is often politically neglected

HRE4 identifies an excess heat amount theoretically available that could supply heat for more than the entire building stock in Europe. Therefore, the avoidance as well as usage of excess heat – when not able to avoid – should receive high(er) priority and immediate attention in local to European decision-making processes, energy planning instruments and funding lines. However, the "CO_2 free" excess heat which could be gained from polluting power plants should not prolong their lifetime. What is shown by HRE4 is the massive potential to utilise current excess heat *and* renewable heat sources which planners and decision makers can evaluate in more detail to consider where the use is relevant and where not. Tapping into the excess heat potential can in many cases only be realised by applying district heating networks, which – once established – will have numerous supply opportunities – even if one excess heat source should terminate. HRE shows that at least 25% of the district heating production could be covered by excess heat considering the location of the sources.

Large-scale (cheap) thermal storages can act as buffers to maximise the use of excess heat when the supply and demand profiles do not match. Large scale heat pumps can make it possible to utilise excess heat sources at lower temperature in district heating networks where it is not possible to apply it directly.

HRE's *Peta* mapping platform includes geographically pinpointed and categorised excess heat sources such as power production, industrial processes, waste incineration, metro stations and urban waste water treatment plants. By clicking on the specific excess heat source, more information on the selected source is presented for the user. This can be used to illustrate not only *how much* excess heat potential is present, but also *where* this potential is located, thereby assisting the decision process of where decision-makers should investigate its utilisation further. More info on excess heat sources is found in the *Peta* itself, and in the following reports representing a user guide and a methodological description respectively.

Maps Manual for Lead-Users (section 5.3.3) [15]

Methodology and assumptions used in the mapping (section 2.2.1) [16]

4.7. CHP plays a key role, but is not a "one-size-fits-all" solution

In the Heat Roadmaps, it is shown how CHP could cover around a third of the district heat generation in 2050 operating only in response to the needs of the electricity markets. The differentiation between the type of CHP as well as its timeline is important. In terms of utilisation of excess heat from electricity-only power plants and possibly comparing with alternative industrial excess heat options it is relevant to consider the following questions for all options: When is the excess heat source expected to be decommissioned? Is it worthwhile to utilise the heat until then even if it requires a follow-up plan from the beginning? What is required of both technical and administrative measures to realise the utilisation of this source? What are my alternatives?

When it comes to replacing electricity-only power plants with new CHP plants, one has to keep in mind if the demands of the future energy system match the properties of such plants (in terms of flexibility, fuel import/costs e.g. gas or biomass etc.) Experience has shown that with increased VRE capacity in the electricity network, the non-controllable electricity production will consequently cover a larger share of the electricity demand thus leaving fewer hours for feasible CHP operation. Introducing large scale heat pumps for district heating can significantly reduce the need for other heat production capacity. In many decentralised CHP plants in Denmark (with both gas engine and gas boiler installed) long periods with low electricity prices have in most hours made it unfeasible to run in CHP mode thus resulting in an increased share of boiler operation in these plants. Hence, careful planning is required to assess the need for the future CHP capacity – including the services it should supply (e.g. mainly baseload heat/electricity production or balancing power). Any energy system investment – supply units or infrastructure – should be considered together with the remaining system, which it will inevitably interact with throughout its lifetime – directly or indirectly.

It should be noted that future power-to-gas (P2G) such as hydrogen production could be established as combined heat and gas solutions where a district heating connection ensures a higher efficiency of the P2G energy conversion. District heating can prove even more relevant in case of targeting a complete decarbonisation of EU by means of 100% RE using the Smart Energy Systems approach [20] where the production of electro-fuels for transport sector plays an important role. Hence, the HRE scenarios can serve as a step towards such a goal.

4.8. Cooling demand should not be overlooked

There is a demand for cooling throughout Europe including Scandinavia. Across Europe the demand is expected to increase significantly towards 2050 and this has to be strategically addressed today. However, even in the most southern of the 14 HRE countries heat demand continue to dominate the

H&C sector. The cooling demand differ from heating by being more balanced between space cooling and process cooling and dominated by services and industry. District cooling (DC) can in some places be a cost-effective solution and has a high potential to reduce greenhouse gas emissions by replacing individual applications in households, commerce and industry. Cooling demands often offer a direct opportunity to use the extracted heat in other applications e.g. district heating thus representing yet another synergy opportunity. However, further research is needed in terms of data for cooling demands as well as the possibilities for combining cooling and heating in spatial analyses.

In general, sustainable technologies – for example using natural cooling, integrated systems such as district cooling and the integration of the cold chain – should be given far more attention and resources for data collection, research and the roll-out of sustainable solutions in order to address the growing demand well in advance.

> Datasheets for performance and cost data of space cooling technologies in the residential and service sectors, and district cooling networks is available from the report:
> *Space Cooling Technology in Europe* [21]

4.9. Inclusive transition leaving no one behind

With the energy transition comes the need to avoid that some countries, regions, sectors and/or citizens get "left behind", meaning that efforts must be made to ensure that those affected negatively (e.g. workers in fossil fuel industry) or more difficult access to modern energy technologies (e.g. poorer families/areas) are helped in contributing to *their own* transition, too (e.g. workers educated to take on jobs created in the RE sector instead or families/areas supported in installing more efficient H&C solutions). Such changes are needed, and it is critical to make sure that energy development is inclusive to avoid any growing discontent among European populations and politicians.

12	**Support to upgrading skills on different levels (energy/urban planners, craftsmen, etc.) will support a positive public opinion towards the energy transition. Labourers in the fossil fuel industry should not be neglected in the restructuring process.**

Some degree of local ownership can increase public acceptance of RE installations. One example is to include a precondition for the investor to offer a share (e.g. 20%) of the installed capacity to the municipality's inhabitants and/or the nearest neighbours. By owning a share (e.g. of a wind farm) the locals may see it as less "intrusive". An additional option is to somehow compensate the affected local environment (e.g. by financing non-related local activities, supporting cultural activities or homeless shelters, thus improving the local area).

4.10. Long-term benefits of capital-intensive transition

Following the energy transition is a general trend towards a more capital-intensive heat supply together with lowered operation expenses. Examples include solar heating and heat pumps – both in small scale units and large (DH) utility-scale – where the total cost of energy to a larger extent relates to the unit investment rather than the operation (compared to boilers). In relation to district heating, a shift from previous times' single fuel supply to many heat supply sources introduce a wide range of options for the operator to optimise the production and reduces the sensitivity associated with the fuel costs (and availability). Similarly, the use of heat pumps makes it possible to use (locally) produced electricity (from a wide range of RE sources) thus reducing the dependency (financially and geopolitically) on fuel import. This makes it possible to ensure more stable conditions for both consumers and investors in the long run thus also reducing the risk of energy poverty. The Heat Roadmaps could eliminate the dependence on imported natural gas for heating in Europe. With this in mind, establishing new natural gas-grids holds considerable lock-in risks of potentially lost investments in the future, once countries finally transition away from fossil fuels completely.

Thermal networks take the shift from operation-related expenses towards investment-related expenses further than what is possible with individual supply. Another result of a development towards a higher degree of energy infrastructure investments is the opportunity to create local jobs as a result of the need for installation and servicing the infrastructure. This applies both on sub-country level and in terms of improving competitiveness of European industries nationally and internationally. On top of this, the energy transition improves living standards by limiting emissions thus ensuring better air quality locally besides limiting the global warming.

However, in any project the administrative efforts required have to match the predicted benefits. This applies in small and large scale. Examples include the issue of a comprehensive administrative process which repels smaller industries from entering into agreements of supplying excess heat. Similarly, as a large-scale example, where establishing new district heating networks (and possibly companies) is a long-term process requiring significant financial and manpower resources. Such financial and administrative barriers could be overcome by removing unnecessary administrative burdens, by supplying access to cheap, long-term financing and by empowering local authorities to facilitate the processes required in any (small or big) project involving several different stakeholders.

13	**Frameworks for providing low-cost financing options and avoiding (unnecessary) administratively-heavy processes is an important precondition to effectively engage communities and industries. Furthermore, local authorities should be empowered to encourage and facilitate H&C decarbonisation projects.**

5. Thermal networks create synergies

5.1. District energy plays a key role in decarbonisation roadmaps

Introducing or expanding thermal networks means that numerous synergy options come into play e.g. balancing of electricity grids in a future with much more VRE, excess heat utilisation otherwise wasted and RE sources only feasible in large-scale. As a result of this, the HRE 2050 shows that district heating should be deployed to a much larger extent in most countries as it represents a feasible and effective way which can ensure the deployment of a low-carbon heat supply in large scales. By means of detailed spatial analysis HRE4 finds that approximately half of the total building heat demand in the residential and service sectors is located in high density areas which, combined with cost calculations and the overall system modelling, forms the scientific evidence leading to the conclusion that more than half of the European heat demand[16] can cost-effectively be supplied with district heating in 2050 – and showing where these networks can be located.

14	**Due to higher urban densities, district energy in cities is one of the least-cost and most-efficient solutions for reducing emissions and primary energy use. Almost all countries' Heat Roadmaps show a strong and viable potential to economically increase the current share of district energy.**

The list of benefits by increasing the share of district heating is long:

- Beyond its ability to use economies of scale to take advantage of renewables, district H&C systems can make it possible to utilise excess heat from industries and other sources, which is otherwise regarded as mere waste (and with possible negative impacts on ecosystems[17]).
- Often many different heat sources are available. Excess heat can be a cheap option with a short payback time, while other feasible alternatives can relatively easily "step in" in case this supply option is terminated.
- Because district energy is typically not strictly conditional on the availability of just excess heat or any single type of renewable source, the feasibility of establishing district energy systems is generally a solid venture and a safe investment.

[16] Based on the 14 countries included in HRE4 corresponding to 90% of the total EU heat demand.
[17] For instance, according to studies [22] of the Swiss Federal Institute for Technology the Rhine is one of the most heat-polluted rivers as a result of warm-water discharge from power plants.

- In case energy-savings targets are not met, district H&C can still supply this additional demand with renewable heat, thus increasing the certainty that overall decarbonisation goals can and will indeed be reached (i.e. representing a type of backup solution[18]).
- District energy and cheap thermal storages can represent an ideal bridge between the heating, cooling and electricity sectors, while providing flexibility for the overall energy system.
- District H&C can be completely decarbonised using renewables, large heat pumps, excess heat and CHP. In fact, several RE technologies benefit from – or even require – large-scale installations in order to be most feasible. For example, to exploit the full potential of deep geothermal and solar thermal, DH needs to be present due to the significant economy of scale for these solutions.

This leads to the recommendation that financing mechanisms, such as the Innovation Fund and the Modernisation Fund, should (more) effectively enable intelligent system integration, e.g. in the frame of district energy projects. In general, EU financing (of various kinds) could be more closely linked to those H&C options with the most emission reduction potentials.

EU market regulation should enable various ownership models, since the most suitable structure of H&C provision and distribution to achieve social, economic and environmental targets will depend on the national and local framework conditions, as well as the historical tradition and status of district energy.

Ways that identified barriers to the market uptake of recommended solutions can be addressed are described in:

Business cases and business strategies to encourage market uptake [23]

The *Peta* online mapping tool also includes a visualisation of both existing DH networks and the cost of establishing DH on a hectare level. This gives lead-users the ability to pinpoint where the most suitable areas to establish/expand DH are located. The costs are presented as annualised investment costs per unit of annual sold heat. The *Peta* platform also includes a layer showing *Heat Synergy Regions* highlighting those regions with high synergies between excess heat and heat demand (indicated by an "excess heat ratio", i.e. the ratio between excess heat and heat demand within a given territory). The purpose is to provide an overview of where these assets and demands are in balance with each other and/or could be "exported" to nearby regions. Other features of *Peta* include the cooling demand densities on a hectare level. More info on Heat Synergy Regions and cost of district H&C networks is found in:

Map of the heat synergy regions and the cost to expand district heating and cooling in all 14 MS [24]

Updated Peta atlas for each MS with the final level of district heating recommended in WP6 [25]

[18] Note that this should indeed be considered a back-up plan. It is highly recommended *not* to disregard the energy-savings perspective, as it holds the key to a cost-effective decarbonisation.

5.2. Increasing cooling demand

Cooling demands in general remain much lower than heating also in 2050 but becomes increasingly important. As opposed to heating, the cooling demands differ by being more balanced between space cooling and process cooling (around half each) and dominated by the service and industries rather than the residential sector.

Renewable cooling should be considered in long-term planning to take into account the obvious synergy options between heating and cooling (e.g. utilising excess heat from the cooling process for DH). A close collaboration e.g. with cooling equipment providers could be useful to tap into low temperature excess heat options.

5.3. A holistic planning approach optimising the energy system

As described in section 3.4 energy efficiency measures and DH should be coupled rather than seen as competitors. Energy efficient buildings with a lower demand per m^2 compared to non-renovated ones, make it possible to reach a larger number of consumers with the existing main DH network. This way a declining demand from the DH network *per building* may actually represent a business opportunity for the DH company – provided that DH is (made) attractive enough for new consumers. At the same time a more modern DH system with lower temperatures will also be better at utilising (cheap) excess heat i.e. potentially more excess heat sources available at low temperatures, and higher COP of large-scale heat pumps when they supply heat to a low-temperature DH grid.
To disregard thermal networks as a key player in the integrated energy system will result in costlier and/or insufficient decarbonisation while failing to take into account the opportunities of renewable sources and utilising excess heat from industries and power generation thus limiting the overall system efficiency.

15	**An investment initiative – both at EU level and at national level – for a comprehensive, fast and systematic expansion and establishment new district thermal infrastructures in urban areas should be initiated. This financial framework has to be aligned with policies reflecting the reduced role and appliance of natural gas and an increased importance of electricity grids.**

6. Conclusion

When planning for a low-carbon future, it is evident, that the entire energy system must be taken into account to ensure that a decarbonisation focus in one place does not simply increase emissions somewhere else. The same level of consistency should be applied across EU policies, which should be considered jointly so as to ensure that the targets are in line with the Paris Agreement.

It is critical that various efforts are made simultaneously to remove the barriers hindering the energy transition in order to ensure that stakeholders successfully overcoming one barrier are not immediately blocked by further ones. Periodical reviews and – if necessary – changes accordingly should be formalised. Carbon taxation in all countries and other direct or indirect incentives should be ensured to encourage the realisation of energy savings, the implementation of renewables and the use of efficient energy system infrastructure applications.

Investments in infrastructure to decrease fuel demand such as district H&C networks, heat pumps and energy savings should be promoted in terms of the following combined and complementary efforts:

- Raising awareness about relevant H&C solutions among policymakers, businesses and individuals and formulating a common narrative for all Europeans that the decarbonisation of our society is not only possible, but cost-effective and affordable with existing technologies available on the market today and can prove profitalbe for our local economies.
- Setting up frameworks to improve qualifications and the number of skilled professionals supporting decarbonisation solutions.
- Ensuring certainty (predictability) for investors, avoiding "stop-and-go" measures.
- Removing administrative barriers for stakeholders to establish district heating and cooling and use an increased share of renewables in H&C as well as recover excess heat[19].
- Requiring integrated energy planning and regular evaluation of status across all energy sectors and at all governmental levels.
- Improving feasibility of a sustainable energy system directly and indirectly by introducing a CO_2 taxation.
- All fossil fuel subsidies should be stopped immediately including also indirect support such as incentive schemes for gas and oil combustion boilers.
- Fossil fuel boilers should be phased out. Expiry dates should be set combined with banning the installation of fossil fuel boilers in new buildings. This should go hand in hand with stronger support for alternatives (e.g. renewables and sustainable excess heat) and thus potentially avoiding increased costs for end-consumers.

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[19] The administrative process of selling low-grade excess heat in some cases require that the industry is approved to be considered an energy production company similar to a company owning a power plant.

- Expiry dates for fossil fuel power production should be set to avoid investments in new (long-lasting) fossil-based capacity and provide certainty for the power industry to invest in sustainable solutions into the long-term.

If the HRE 2050 scenario would be implemented, it would result in the following short- to long-term benefits covering all levels of society:

- Lowered uncertainty of future fuel prices, thereby ensuring a more stable framework for energy-producing companies, consumers on different levels (households, services and industry) and (public) investors.
- Opening of the market for locally-based heat sources, thereby increasing the security of supply and local economic growth, while also making the countries more resilient to geopolitical changes.
- Creation of local jobs – both on a (sub-)country level and in terms of strengthening the competitiveness of European industries nationally and internationally.
- Reduction of the overall energy system cost compared to alternative decarbonisation scenarios.
- Improvement of living standards by ensuring better air quality (locally), while also reducing emissions (globally).

16	**HRE4 shows how an energy system transition can facilitate the integration of at least 87% renewables in total. The HRE 2050 scenario does not hinder but rather enables the possibility of further RE implementation. Contributions from all energy sectors have to support the implementation of such a cost-effective and socially acceptable pathway. The targets should be reflected in directives such as the EED, RED, EPBD and EU ETS.**

The ambitious long-term climate and energy targets of the EU must be translated into adequately ambitious short-term actions through policies that facilitate the energy transition in the electricity, thermal and transport sector. Cross-sectorial, complementary efficiency and renewable targets applied at all governmental levels will be essential for realising a sustainable low-carbon society. Integrated management, knowledge transfer, holistic energy planning tools, open business models with broader forms of collaborations and incentives are some of the most important aspects that need to be carefully addressed, since in most cases the barriers faced are political, regulatory and organisational rather than technical.

By decarbonising the energy sector as a whole, Europe can prepare to embrace the demand caused by improved living standards and ensure a sustainable future for all its inhabitants. However, this requires a strong commitment and bold actions in terms of ambitious energy and emission targets adequate to keep global warming significantly below 2 °C compared to the pre-industrial area.

A common understanding of a joint European roadmap to show the determination, providing effective incentives and ensuring stable framework conditions, would enable investments into the sustainable energy infrastructure needed to speed up the energy transition process, which will itself be beneficial for the public and private sector as well as the citizens of Europe.

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8. Abbreviations

CAPEX:	Capital expendidures
CHP	Combined heat and power
CO_2	Carbon dioxide
COP:	Coefficient of performance
DC:	District cooling
DG ENER	Directorate-General on Energy
DG CLIMA	Directorate-General on Climate Action
DG REGIO	Directorate-General on Regional and Urban Policy
DH:	District heating
DSO:	Distribution system operator
EE:	Energy efficiency
EED:	Energy Efficiency Directive
EPBD:	Energy Performance of Buildings Directive
EU ETS:	European Union Emissions Trading System
GWP:	Global warming potential (factor)
H&C:	Heating and cooling
HP:	Heat pump(s)
HRE:	Heat Roadmap Europe project series starting in 2012
HRE 2050:	Heat Roadmap Scenario for 2050
HRE4	Heat Roadmap Europe 4 (H2020-EE-2015-3-MarketUptake)
ICT:	Information and communications technology
MEP:	Member of the European Parliament
MSR:	Market Stability Reserve (of the EU ETS)
OPEX:	Operational expendidures
Peta:	Pan-European Thermal Atlas
PEF:	Primary energy factor
PV:	Photovoltaics
RE:	Renewable energy
RES:	Renewable energy sources
RED:	Renewable Energy Directive
VRE:	Variable renewable energy