# Policy Support for Heating and Cooling Decarbonisation

Roadmap

Written by Frank Gerard, Liliana Guevara Opinska, Tycho Smit, Koen Rademaekers (Trinomics),

Sibylle Braungardt (Oeko-Institut), Maria E. Monejar Montagud (DTU)
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*Contact:* *Eva Hoos*

*E-mail:* *Eva.Hoos@ec.europa.eu*

*European Commission*
*B-1049 Brussels*

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# ACRONYMS

| | |
|---|---|
| 4GDH | 4th Generation District Heating |
| BACS | Building Automation and Control Systems |
| CCGT | Combined Cycle Gas Turbine |
| CCS | Carbon Capture and Storage |
| CCUS | Carbon Capture Utilisation and/or Storage |
| CHP | Combined Heat and Power |
| CSP | Concentrated solar power |
| DHC | District Heating and Cooling |
| DHW | Domestic Hot Water |
| DSO | Distribution System Operator |
| EE | Energy Efficiency |
| EED | Energy Efficiency Directive |
| EEF | Energy Efficiency First (principle) |
| EII | Energy Intensive Industry |
| EEOS | Energy Efficiency Obligation Schemes |
| EPBD | Energy Performance of the Building Directive |
| ESCO | Energy Service Company |
| EU | European Union |
| GHG | Greenhouse Gas |
| H&C | Heating and Cooling |
| HP | Heat Pump |
| HPA | Heat Purchase Agreement |
| IEA | International Energy Agency |
| LNG | Liquified Natural Gas |
| LTRS | Long Term Renovation Strategy |
| LTS | Long Term Strategy |
| MS | Member State |
| NCA | National Comprehensive Assessment |
| NECP | National Energy & Climate Plan |
| nZEB | Nearly Zero-Energy Building |
| PV | Photovoltaic |
| PPA | Power Purchase Agreement |
| RAC | Refrigeration and Air Conditioning |
| RED | Renewable Energy Directive |
| RES | Renewable Energy Sources |
| RES-H | Renewable Heating |

| | |
|---|---|
| RFNBO | Renewable Fuel of Non-Biological Origin, e.g. hydrogen and e-fuels |
| SME | Small Medium Enterprises |
| SMR | Steam Methane Reforming |
| TCO | Total Cost of Ownership |
| TEN-E | Trans-European Networks in Energy |
| TES | Thermal Energy Storage |
| TSO | Transmission System Operator |
| TWh | TeraWatt-hour = 1 billion kiloWatt-hour |
| TYNDP | 10-Year Network Development Plans |

# 1. Executive summary

## 1.1. The Heating and Cooling landscape

The heating and cooling (H&C) sector is responsible for a central part of the EU's energy demand, representing roughly half of the final energy consumption. As such, **the decarbonisation of the H&C sector is crucial for a successful transition to a carbon-neutral energy system by 2050**. Most of the energy demand for H&C is related to heating purposes, although the demand for cooling is increasing. Space and water heating needs in buildings represent over 60% of the demand for heating, followed by industry, which represents a further 32% of heating needs, the remainder is related to agriculture and both building and industry related cooling applications. The decarbonisation rate and uptake of renewables in the H&C sector has been relatively slow, as more progress is needed in the adjustments to heating equipment, heat delivery systems, building envelopes/industrial processes, required infrastructure and energy supply, and paying attention to vulnerable consumers.

In Europe, there is a significant stock of old buildings with poor energy performance, combined with a strong reliance on fossil-based heating systems. In many cases, stand-alone dwellings are heated through their own individual heating equipment, mostly gas-fired and to a lesser extent oil-fired, combined with high temperature heat delivery systems. Full decarbonisation of the building stock by 2050 requires to quickly stop the installation of heating systems fuelled by fossil fuels. Switching the energy carriers from fossil fuels to the similarly combustible renewable fuels (e.g. from natural gas to biogas), while maintaining the existing heating equipment and delivery systems should be considered only for a limited share of the building stock, as the resource will remain limited. The supply of renewable gases and liquids (e.g. biomethane, biopropane), which can directly replace fossil fuels in the existing equipment will be insufficient if the demand increases significantly, and/or too expensive compared to other alternatives. On top of their limited availability, bio-energies should be produced and used in a sustainable manner, further limiting the supply potential and viable applications. Although, renewable fuels of non-biological origin (RFNBOs), such as renewable hydrogen, will have a place in the transition to a carbon-neutral energy system, the extent to which these would play a role in the decarbonisation of H&C and especially in the building sector is still subject to debate. Electrification with heat pumps as well as the connection to existing and the development of new district heating grids using renewable and other carbon-neutral heat sources should be increasingly considered. In both cases, changes to and investments in energy infrastructure are required.

The number of H&C solutions that can be applied for decarbonising a specific building, is intricately linked to the energy performance of the building(s) concerned. By applying the energy efficiency first principle, the overall energy need is reduced, thereby reducing the demands on the infrastructure required and the required volume of renewable energy resources. Consequently, the investment needs are also lowered. Improvements in building energy performance are important to reach cost-efficient decarbonisation of the built environment and to reach the energy efficiency targets. However, it should be integrated and balanced with supply-side decarbonisation measures to seek for the cost-optimum between energy efficiency and renewable supply. This means that deep renovations make sense for some buildings, whereas in other buildings more modest energy efficiency improvements may be more cost efficient or may be limited by other considerations like the cultural and patrimonial character of buildings.

Adequate **planning** will be key to ensure that resources are utilized in an optimal way while keeping costs to a minimum. Infrastructure planning should facilitate the integration of various renewable and carbon-neutral energy sources and arbitrate between the development of new infrastructure or re-purposing of existing ones. It should consider alternatives to investment in energy network (e.g. electricity, gas) expansion, including demand-side solutions and storage. The required changes to the heating and cooling system will be challenging but they also represent a **unique opportunity to promote energy system integration, increase flexibility and maximise energy efficiency across the entire energy system** including, for example, making use of 'waste heat'. Heat pumps allow for efficient integration of renewable electricity into the heat sector at high efficiency, while helping utilise geothermal and ambient energy or waste heat. In addition, heat pumps, district heating grids or thermal energy storage can increase the flexibility to the entire energy system. Thermal energy storage is one of the key instruments to integrate the electricity and H&C sectors in a smart, integrated approach that benefits power as well as thermal systems.

Changes to the heating and cooling system in the built environment can be disruptive as they often require modifications to dwellings and construction works in cities' roads and streets. This is one of the main reasons why the decarbonisation process in this sector must be accomplished with **citizen participation to ensure social legitimacy of the transformation process**. While transitioning to a renewable and carbon-neutral H&C sector will represent a cost, tackling energy poverty and ensuring that the cost of this transition is not passed-on to the most vulnerable must be a priority. Consumers should be informed and empowered to take appropriate decisions, and a level-playing field in terms of prices between different technology options should be ensured through adequate policy and economic measures.

Fuel price structures, including taxes and levies, have a large role to play in incentivizing the use of renewable and carbon-neutral H&C solutions. Furthermore, the barrier stemming from the high upfront costs associated with building renovations and investment in renewable H&C systems needs to be tackled. This applies especially to low-income households, living in buildings with low energy performance and fossil-based H&C systems. In the context of decarbonising the built environment, knowledge acquisition and coordination are important at all levels, from the design to the operation, to ensure the appropriate level of quality and the most adequate technological solutions are implemented.

Lastly, the decarbonisation of industrial heat demand is also challenging. Industry is hard to decarbonise due to conversion costs, temperature levels, competitiveness risks, and long facility life among other elements. Here, demand for high-temperature processes, which can currently be supplied by a limited number of technologies and carriers, is an additional constraint. Solutions to decarbonise industrial heat are dependent on the local context and parameters, so the most optimal solutions need to be determined on a case-by-case basis.

Renewable H&C development should be mainstreamed in the broader framework of industrial decarbonisation. A holistic perspective is essential to identify the most suitable zero-emission solutions. In some cases, existing processes can remain as they are but switched to renewable fuels or electricity, while in other cases the switch to renewable energy sources will require far-reaching changes in the production process by switching to innovative breakthrough processes.

## 1.2. Decarbonising the H&C sector – the way forward

Decarbonising the H&C sector will necessarily imply considering a number of different variables including the availability of renewable energy sources, the presence of the required infrastructure, the availability of financial instruments, a high energy performance, cost efficient heating/cooling solutions, consumer awareness, skilled professionals and access to and affordability of renewable-based alternatives. These variables will be specific for each locality, thus requiring local planning and expertise. Thus, transforming the H&C sector will require strong action and adequate coordination, addressing simultaneously the reduction of energy use and the deployment of renewable based H&C solutions. Integrated and coordinated planning is essential for a successful transition. Coordination, to ensure that different elements of relevant policies and legislations are comprehensively assessed and reinforce one another is important. Given the wide set of elements that require consideration and diversity of options, a central aspect of H&C decarbonisation is setting clear goals and objectives, and having clear plans at national, regional and local level.

The large set of variables to consider and the fact that heating and cooling, especially in the built environment, has a direct impact on the citizens, means that the **involvement of a wide variety of stakeholders in the decision-making process is of paramount importance**. In order to ensure that the views, interests and needs of different stakeholders are accounted for innovative participatory models and structures for multi-level governance should be considered. **Capacity building** is another essential element to ensure a successful and cost-optimal decarbonisation process. Providing local authorities with the right tools and levers and empowering them, including through capacity building and trainings, to be able to make informed decisions about their local H&C systems will ensure that the best decisions are taken. Furthermore, training and upskilling of construction workers, architects, engineers, planners, installers and other relevant professionals is required to drive the transition of the sector forward.

All the above elements require adequate financial support. Although several financial instruments are available at the EU level to finance the decarbonisation of the building and industry sectors, there is still a **need for establishing a comprehensive and integrated financial & fiscal strategy for the H&C sector** and for creating a stable and long-term favourable investment environment. A variety of financial instruments (including grants/ loans, rebates, subsidies, etc.) should be considered and, in particular, ones that address high upfront costs for building renovation and renewable heating equipment are important. Support to development of heat markets, is equally important. Currently, one of the difficulties is that even though the final users need heat, different types of H&C supply systems operate in completely

different markets due to the different energy carriers used. Provision of heat as a service, could address the need to simplify procedures and information on choices for consumers.
As immediate next steps, furthermore, policy measures and instruments to promote the transition in the H&C sector should be urgently implemented, where possible by reinforcing current policies. The roadmap identifies a number of no-regret options, which can be implemented regardless of location-specific considerations and with low risk of lock-ins. Finally, the urgency of decarbonising the H&C sector by mid-century at the latest, means that while setting up a comprehensive approach tackling all the elements at once, could be a great important instrument, actions should not wait until the end of a possibly longer process of exhaustive policy development. Instead of waiting for more time to set up a perfect approach – **we must start acting now, while tackling the most important elements with diligence and based on best-available knowledge**.

## 1.3. Aim and structure of the project

The project 'Policy Support for Heating and Cooling Decarbonisation' commissioned by the European Commission – Directorate General for Energy, was aimed at providing policy support for policy makers and stakeholders to explore pathways and agree on solutions to decarbonise the European H&C sector. To do this, the study endeavoured to increase and systematise the knowledge base of decarbonisation solutions through the elaboration of a **meta-study**, promoting the cooperation of stakeholders through a series of workshops and identify a number of key determining factors (building blocks) in order to produce a decarbonisation roadmap.

**This roadmap aims to bring these elements together illustrating all the complexity to decarbonise the H&C sector.** Since there is no silver bullet solution for decarbonizing this sector, this roadmap will touch upon the various elements that need to be considered when developing a H&C decarbonisation strategy and how these are interlinked.

The development of the roadmap is supported by an extensive review of recent literature on the decarbonisation of H&C sector, catalogued in an accompanying meta-study. The meta-study consists of three parts:

- **Part I: Strategies for the decarbonisation of H&C in building**s: The first part of the meta-study covers studies providing modelling pathways at EU level, contributions assessing policies and financing strategies as well as national strategies for the decarbonisation of heating and cooling. Across the studies covered in the review, the reduction of the energy demand in buildings is seen as key for achieving the long-term greenhouse gas (GHG) reduction goals. Reducing the energy demand by enhancing energy efficiency also prepares the ground for a large-scale application of renewables in the heating sector by reducing the needed temperatures in the heating systems of buildings. The use of heat pumps plays an important role in most of the scenarios, and electricity demand for heating is expected to increase considerably. The assessed studies differ considerably in the rating of different renewable energy sources, especially regarding the use of biomass in the (building) heating sector. The role of district heating also differs between the studies, with most studies highlighting the importance of district heating for the decarbonisation of the heating sector especially in urban areas. The studies included in the meta-study identify a multitude of barriers for the decarbonisation of H&C, including economic barriers (high investment costs, low prices for fossil fuels, lack of economies of scale resulting in higher prices), structural barriers (split incentives, lack of supply chains), technical barriers (suitability of the building stock and process heat technologies), psychological barriers (lack of awareness, hassle factor) and a lack of data at various levels. These multiple barriers need to be addressed by multiple policy instruments, working together in a consistent policy set. Several studies included in the meta-study identify the need for an integrated policy mix including regulatory, economic and other complementary policies.

- **Part II: Decarbonising industrial heating and cooling:** The second part of the meta-study covers studies addressing decarbonisation strategies for process heat. The opportunities for the decarbonisation of industrial process heating and cooling are essentially based on the substitution of fossil energy sources with renewable electricity, green hydrogen and, to a certain extent, biomass, solar thermal and geothermal energy. For heat demand up to a temperature level of 200°C, there are several technology options, such as industrial heat pumps in combination with waste heat, environmental heat (ambient energy) or solar thermal energy. The analysed studies agree that main barriers for energy-intensive industry decarbonisation are the high capital investments needed for the transition as well as low energy prices for fossil fuels. Some studies point out the lack of market-ready alternative technologies for high-temperature process heat. Regarding suggested policies for the promotion of decarbonisation in industry, there is an agreement on the need for stronger support of research and development (R&D) activities, innovation, and commercialisation, promoting pilot projects and product development. Moreover, the necessity of decarbonising energy-intensive industry is emphasised, since the main energy-intensive sectors (e.g., production of cement, steel, petrochemicals, glass) account for nearly 21 % of global $CO_2$ emissions.

- **Part III: Energy carriers and infrastructure:** The third part of the meta-study covers an overview of the different decarbonisation options including heat pumps, biomass, solar thermal, geothermal, hydrogen and e-fuels as well as the studies addressing sector coupling and infrastructures. For heat pumps, key elements discussed in the studies are the efficient use in existing buildings, the impact of heat pumps on the electricity grid as well as the flexibility potentials. For district heating, where several successful examples for positive energy districts based on efficient district heating and cooling systems have been implemented, key priorities for research and development to support large-scale deployment remain. This includes novel approaches for low-temperature district heating, the integration of renewable energies, and waste heat in district heating and cooling, scaling up the use of large-scale heat pumps for district heating and cooling, the development and deployment of digital technologies as well as the introduction of local planning. The role of new gaseous fuels for heating are discussed controversially in the studies covered in the review. There are numerous studies addressing potential pathways for the future use of gas for heating, however the projected use of gas differs largely in the different scenarios. While the demand for gas is expected to decrease due to improvements of the efficiency of buildings and the use of renewable heating, the technological, economic, and regulatory implications for the future of the gas grid are discussed controversially.

The roadmap contains a section on ‘building blocks’, which refer to the essential underlying elements that must be taken into consideration in the planning of the practical steps for the decarbonisation of the H&C sector. The building block components are: options for H&C decarbonisation, fossil fuel phase out, energy efficiency, industrial H&C decarbonisation, energy storage, cooling, resource availability, coordinated planning, cost and financing, energy markets, consumer choice, direct electrification, renewable fuels of biological origin and renewable fuels of non-biological origin. The approach emphasises flexibility and acknowledges that there are no “fit-for-all” solutions when it comes to decarbonising the H&C sector across Europe. The roadmap lists different types of barriers as identified in the analysis of the building blocks and corresponding policy measures to address them. Finally, the roadmap addresses different aspects pertinent to the development of national H&C decarbonisation strategies including the involvement of different stakeholders in the process, the evaluation of existing progress and gaps, an assessment of the potential for domestic renewable production and suggestions for developing scenarios based on existing policies and plans.

# 2. Background

## 2.1. Introducing the challenges to decarbonise the H&C sector

The heating and cooling (H&C) sector is one of the key drivers of the EU's energy demand, representing roughly half of the final energy consumption. As such, the decarbonisation of the H&C sector is crucial for a successful transition to a carbon-neutral energy system by 2050. The lion's share of the energy demand for H&C is related to heating purposes, although the demand for cooling is increasing. Space and water heating needs in buildings accounts for over 62% of the EU energy consumption for heating and cooling, followed by industry, which represents a further 32% of heating and cooling needs.[1] The remaining demand comes from agriculture and from both building- and industry-related cooling applications. The decarbonisation rate and uptake of renewables in the H&C sector has been relatively slow, as more progress is needed in optimisation of heating equipment, heat delivery systems, building envelopes/industrial processes, required infrastructure and energy supply, and addressing energy poor consumers.

In the built environment, there is a significant stock of relatively old buildings with rather poor energy performance, combined with a strong reliance on fossil-based heating systems. In many cases, individual dwellings are heated with their own individual heating units, mostly gas-fired and, to a lesser extent, oil- or coal-fired, combined with high temperature heat delivery systems (radiators). Switching the energy carriers from fossil fuels to the same renewable fuels (e.g. from natural gas to biogas), while maintaining the existing heating equipment and delivery systems should be considered only for a limited share of the building stock, as the resource will remain limited. The supply of renewable gases and liquids (e.g. biomethane, biopropane), which can directly replace fossil fuels in the existing equipment will be insufficient if the demand increases significantly, and/or too expensive compared to other alternatives. On top of their limited availability, like all resources, bio-energies should be produced and used in a sustainable manner, further limiting the supply potential and viable applications. Diversification of renewable heating sources (e.g. solar, geothermal, ambient energy, etc), electrification with heat pumps as well as district heating grids using a wide range of renewable or carbon-neutral heat sources should be increasingly considered. In these cases, changes to and investments in energy infrastructure are needed in addition to changes in the heating equipment, e.g. when an entire housing block switches to heat pumps, this may have repercussions on the required capacity of the local electricity distribution grid (to be addressed via adequate integrated infrastructure planning). The deployment of renewable H&C equipment should also consider creating the link between electricity and heating and cooling systems in order to promote energy system integration. Heat pumps, district heating grids or heat storage can increase the flexibility to the entire energy system. Furthermore, building renovations to make buildings fit for renewables by increasing their energy efficiency and replace fossil-based heating systems with renewables need to be considered in a coordinated way when planning the decarbonisation of the H&C system. The long planning cycle and implementation time of these infrastructural changes (e.g. when new district heating grids need to be built) highlights the need for clear choices with regard to the selection of the preferred H&C solution (on a local level) in the short term.

The number of H&C solutions that can be applied for decarbonizing a specific building/neighbourhood, is also intricately linked to the energy performance of the building(s) concerned. By applying the energy efficiency first principle, the overall energy need is reduced, thereby reducing demands on the infrastructure required as well as the required volume of renewable energy resources. As a consequence, the investment needs are also lowered. This happens, for instance, when switching from an individual, gas-fired boiler to a heat pump and

[1] HeatRoadMapEurope (2018) Profile of heating and cooling demand in 2015.

simultaneously improving the building envelope, and switching from a high-temperature to a low-temperature heat delivery system. Building renovations improve energy performance and reduce overall energy demand and hence also the extent to which electricity grids need to be reinforced, considering the deployment of decentralized electricity production, and the increasing flexibility of the system elements. Also, to become fully renewable, auxiliary energy driving the heat pumps (mostly electricity) need to be supplied from green energy. Generally, the more the energy demand in the built environment is reduced, the lower the additional required renewable electricity generation. Improvements in buildings' energy efficiency performance are important for reaching cost-efficient decarbonisation of the built environment and for achieving energy efficiency targets. However, measures for the reduction of energy demand should be integrated and balanced with supply-side decarbonisation measures to achieve cost-optimality between energy efficiency and renewable energy supply. This means that deep renovations make sense for some buildings, whereas in other buildings more modest energy efficiency improvements may be more cost efficient or the level of renovation may be limited by other considerations, such as preservingthe cultural and historical character of buildings. Daily and seasonal variations of heat demand in the building sector is also an important and critical aspect to consider when addressing the decarbonisation of H&C supply.

Greenhouse gas (GHG) abatement in the built environment is challenging not because the lack of technologies and solutions, but because the various actors and components of the value chain should be addressed in an integrated and coordinated way. Solutions based on renewable energy carriers are proven and available today. The challenge is due to the complexities involved and the need for a high level of integration of the various factors, requiring that infrastructures and energy carriers, the range of technology options and the characteristic of the building stock are considered simultaneously to arrive to the most cost-effective options. This should be done while also addressing energy efficiency in a coherent way. Another challenge is the relatively low price of fossil fuels compared to renewable heating alternatives. Fuel price structures, including taxes and levies, have a large role to play in incentivizing the use of zero- or low-emission H&C solutions. Furthermore, the barrier of high upfront costs associated with building renovations and investment in renewable H&C systems needs to be tackled. This applies especially to low-income households, living in buildings with low energy performance and fossil-based H&C systems. In the context of decarbonizing the built environment, knowledge acquisition and coordination are important at all levels, from the design to the operation, to ensure that the appropriate level of quality and the most adequate technological solutions are implemented. These options should cover all available technologies and energy carriers, being produced on-site, nearby or remotely.[2]

Lastly, the decarbonisation of industrial heat demand is very challenging, although some renewable solutions are already available. Industry is hard to decarbonise due to conversion costs, temperature levels, competitiveness risks, and long facility life among other elements. For many energy-intensive industries, energy (including heating) costs can represent a significant share of their overall production costs, meaning that the switch to renewable energy would face drastic competitiveness constraints. . Demand for high-temperature processes, which can only be supplied by certain technologies and carriers, is an important constraint, while on the other hand, a more constant demand for heat from industry can be considered an advantage compared to the variable seasonal demand of the built environment. Solutions to decarbonise industrial heat are dependent on the specific sector, context and parameters, so

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[2] Following the terminology proposed under the Energy Performance of Buildings Directive, 'on-site' refers to the premises and the land on which the building is located and the building itself; 'nearby' means produced within a local or district level perimeter of the building assessed, which fulfils all the following conditions:

(a) it can only be distributed and used within that local and district level perimeter through a dedicated distribution network;

(b) it allows for the calculation of a specific primary energy factor valid only for the energy from renewable sources produced within that local or district level perimeter; and

(c) it can be used on-site of the building assessed through a dedicated connection to the energy production source, that dedicated connection requiring specific equipment for the safe supply and metering of energy for self-use of the building assessed;Remote refers to premises which do not fall under the above two definitions.

the most optimal solutions need to be determined on a case-by-case basis. Renewable H&C development should be mainstreamed in the broader framework of industrial decarbonisation. A holistic perspective is essential to identify the most suitable carbon-neutral solutions. In some cases, existing processes can remain as they are but switched to renewable fuels or electricity, while in other cases the switch to renewable energy sources will require far-reaching changes in the production process by changing to innovative breakthrough processes.

Thus, decarbonizing the H&C sector necessitates considering a number of different variables including the availability of renewable heat/energy sources, existing infrastructure and the specific characteristics and distribution of buildings, industry structure, the availability of financial instruments, cost efficiency, consumer awareness, administrative capacities, the availability of skills and trained professionals, and access to and affordability of renewable-based alternatives. These variables will be specific for each city, each rural area or island, to each region and geography to a large extent, thus requiring local planning and expertise; however, goal setting and planning at national levels are important for ensuring the sufficient development of infrastructure, energy sources, technologies, financing and investment, skills and institutional capacities.

This roadmap aims to bring these elements together and illustrate the complexity of decarbonizing the heating and cooling sector, and provides guidance for this decarbonisation process. Since there is no silver bullet solution for decarbonizing the H&C sector, this roadmap will touch upon the various elements that need to be considered when developing a H&C decarbonisation strategy and how these are interlinked. Given the urgency in decarbonising the sector by mid-century, trying to set up an exhaustive approach tackling all the elements at once, is no longer an option. There is no more time to set up a perfect approach – but we can start acting while tackling the most important elements with diligence!

## 2.2. Progress made so far and ways to reach H&C decarbonisation

The heating and cooling (H&C) sector plays a crucial role in the EU's ambition to transition to a clean and carbon-neutral economy by 2050. Thus, efforts at the EU and Member State (MS) levels have been made over the last two decades to decarbonise the sector. Figure 1-1 shows the progress in increasing the share of renewable energy in the electricity, H&C and transport sectors. In 2019, the overall share of renewable energy consumption was 19.7% thus putting the EU on track to reach its 2020 overall target of 20% renewables share in its total energy mix. Overall, the renewable energy share in the H&C sector in 2019 was estimated to be 22.1%.

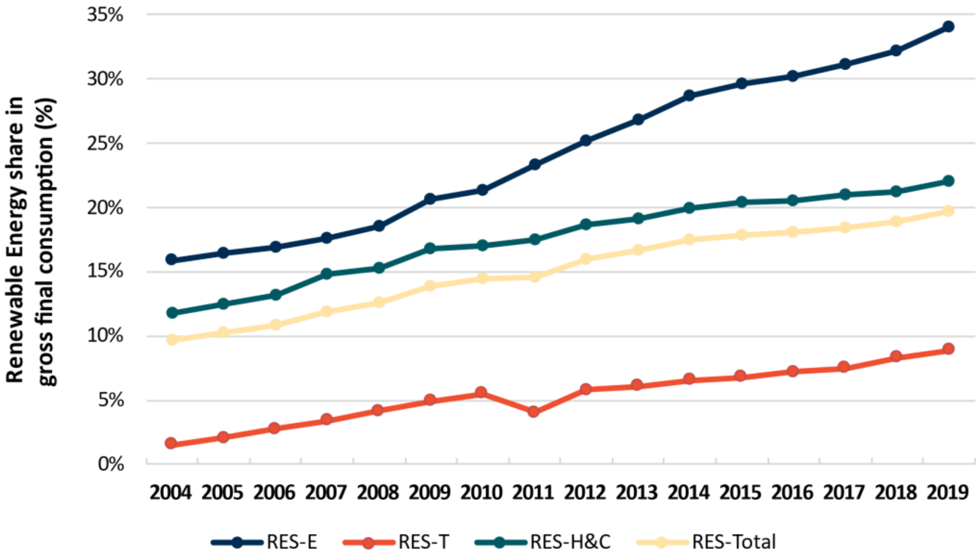


*Figure 1.2. Share of RES in final energy consumption per sector in the period 2004-2019*

*Source: own elaboration based on EUROSTAT[3]*

The final National Energy and Climate Plans (NECPs) of EU MSs anticipate a share of renewable energy in the H&C sector of 23% in 2020 and 33% in 2030. All countries show an increase in this period; however, as shown in Figure 3-2, the level of ambition varies significantly among countries. Only nine countries (EE, IE, EL, ES, FR, LT, LU, FI, SE) meet the target of a 1.3% annual increase of renewables in the H&C sector set in the Renewable Energy Directive (RED).

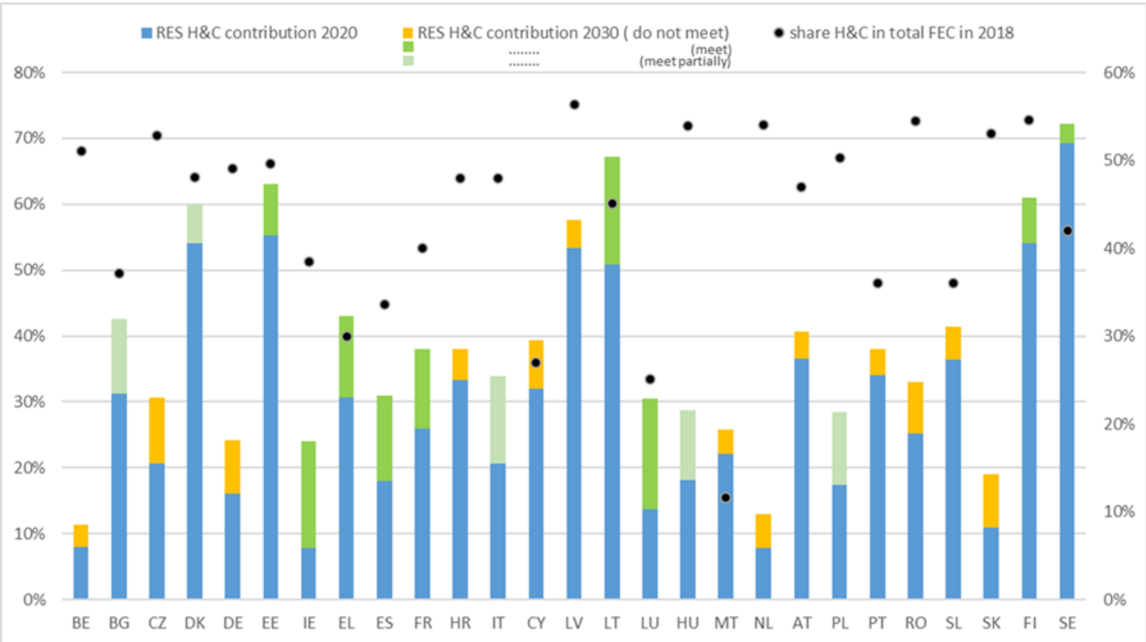


*Figure* ***Error! No text of specified style in document.****-4 Shares of RES in H&C in all MS in 2020 and in 2030 including share of H&C in final energy consumption[4]*

*Source: own elaboration based on JRC (2020)*

In Figure 1-2, the blue bars show large variations between MSs regarding their share of renewable energy as projected for 2020. In 2020, six MSs were expected to have a share of

[3] Eurostat – SHARES Tool. Available at: https://ec.europa.eu/eurostat/web/energy/data/shares
[4] JRC. (2020). Assessment of heating and cooling related chapters of the National Energy and Climate Plans.

Renewable Energy Sources (RES) in H&C above 50% (mainly driven by bioenergy), while three MSs would have a share below 10%. In 2030, only nine MSs are expected to meet the target of 1.3%-point annual increase of renewables in the H&C sector established in article 23(4) of RED II (dark green). Four additional MSs partially meet the target (light green), in either the 2021-2025 or the 2026-2030 period, and the 14 remaining MSs do not meet the target (orange bars). Only a few countries provided details about the constraints responsible for not meeting the objectives in their NECPs. [5]

The black dots (Y-axis on the right side in Figure 1-2), illustrate the differences between MSs regarding the level of H&C in the total final energy consumption in 2018. For 21 MSs, this share is above 40% (with an average of 46%), emphasizing the importance of the H&C sector in the total energy system (and its impact on carbon emissions), the decarbonisation of which should be a priority.

[5] According to JRC. (2020). Assessment of heating and cooling related chapters of the National Energy and Climate Plans

## 1.3 Main components: energy sources & carriers, infrastructure and technologies

The decarbonisation of the H&C sector is a complex task given that, as seen in Figure 1-3, it requires taking into consideration and linking together energy sources, energy carriers, infrastructure, the characteristics and patterns of demand and technologies.

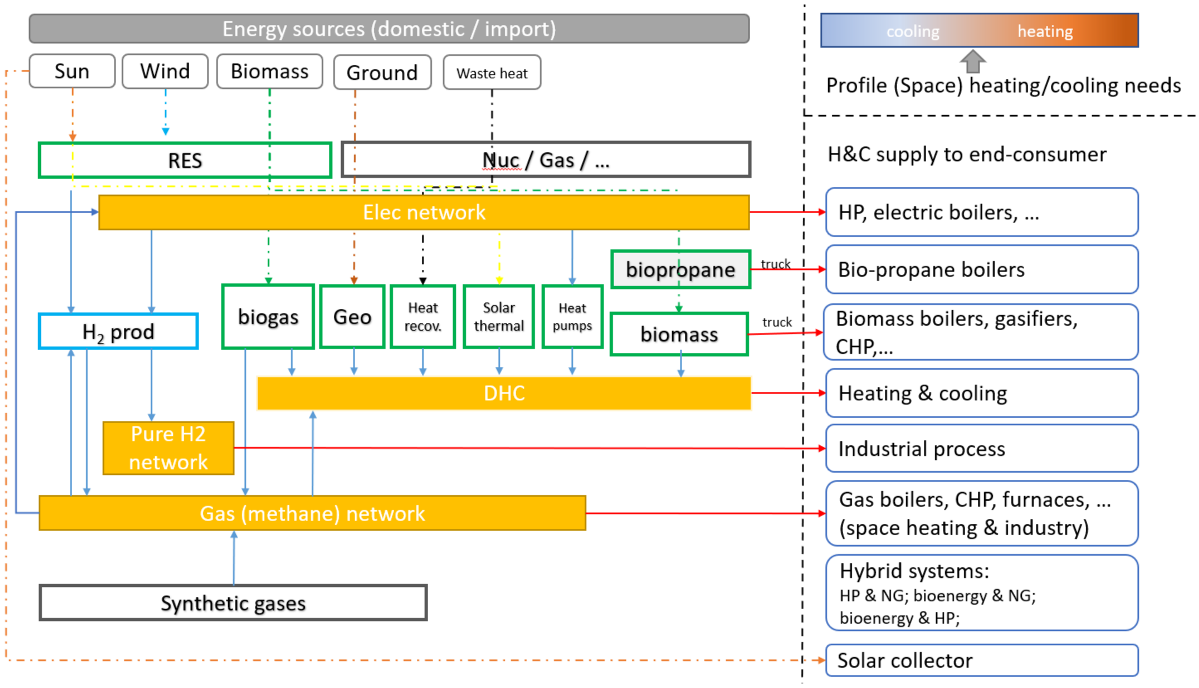


*Figure* ***Error! No text of specified style in document.****-5 Illustration of the complex interplay between energy sources, energy carriers, infrastructure and H&C technologies (non-exhaustive)*

*Source: own elaboration*

The decarbonisation of the heating sector will require a myriad of changes in the energy system, across the different parts of the value chain from the supply to the transportation, transmission and distribution, and inside buildings or industrial plants to end-user applications. An overview of the energy carriers available for heating and cooling purposes is given in Table Error**! No text of specified style in document.**-1, covering both the conventional sources and renewables.

**Table** Error! No text of specified style in document.**-1**

*Overview of energy carriers and energy sources available for H&C*

| Energy carrier | | Fossil | Renewable | Other |
|---|---|---|---|---|
| Gaseous fuels | Methane | Natural gas | Sustainable biogas and biomethane, synthetic methane produced from renewable hydrogen | N.A. |
| | Hydrogen | Hydrogen produced from natural gas using SMR (potentially with Carbon Capture and Storage (CCS) | Hydrogen produced using renewable electricity or from biogenic sources | N.A. |
| | Other gases | Propane and butane | Biopropane, biobutane | N.A. |
| Electricity | | Coal, gas or oil-based thermal power generation | Hydropower, wind, solar PV, concentrated solar power (CSP) and geothermal power generation. Thermal power generation from liquid, gaseous or solid biofuels or biomass | Nuclear power generation |
| Liquid fuels | | Fuel oil/heating oil (petroleum based) | Sustainable liquid biofuels or renewable fuels of non-biological origin (synthetic fuels) | N.A. |
| Direct heat | | District Heating and Cooling (DHC) supply (heat produced from fossil systems) | Ambient heat, solar heat, geothermal heat | Waste heat from cooling or industrial processes (high-temperature or low-temperature), and from nuclear |
| Solid fuels | | Coal, lignite, peat | Solid sustainable biomass (wood pellets and chips, wood waste, energy crops) | Waste incineration heat |

*Source: own elaboration*

Several energy carriers need dedicated infrastructure to be transported, sometimes stored, and delivered to the end-user. Renewable and carbon-neutral gases (incl. hydrogen blends to a certain extent) can be carried through the existing gas (methane) infrastructure, through the extension of the existing network or via new, small scale grids (supplied by local producers of biogas or by Liquefied Natural Gas - LNG trucks). For the transport of high concentrations of hydrogen, dedicated hydrogen pipelines are needed. These can be made through conversion of existing methane grids or development of new dedicated hydrogen grids. Electricity is transported via the electricity network, consisting of high-voltage transmission grids and lower voltage regional distribution grids. The growing electrification of the H&C sector carried out to benefit from renewable electricity, where available cost-effectively, will increase electricity demand, especially at decentralised levels. This is an aspect that needs to be considered when planning. Finally, district heating and cooling networks (DHC) are used to transport energy in the form of thermal energy (heat & cold) to final users.

Table Error**! No text of specified style in document.**-2 shows the different H&C technologies/technology groups that can be used to produce renewable and carbon-neutral heat and cold and link them to the energy source they use.

**Table** Error! No text of specified style in document.**-2**

*Renewable heating technologies including the energy sources and carriers they consume*

| Technology groups (carrier-based) | Technologies for Heating and Cooling |
|---|---|
| **Direct heat technologies** | • Deep & shallow geothermal heating & cooling (e.g. heat pumps, DHC)<br>• Solar panels (incl. heat collectors and PV)<br>• Ambient H&C (e.g. heat pumps, …)<br>• *Waste H&C recovery** |
| **Gas-based heating technologies** | • Propane boilers, fuelled with bio-propane<br>• Conventional gas ($CH_4$), $H_2$ converted boilers (incl. Combined Heat and Power - CHP) fuelled with renewable fuels<br>• $H_2$ boilers / turbines (incl. CHP)<br>• $H_2$ Fuel cells (CHP)<br>• Industrial gas boilers and furnaces (incl. CHP and micro-CHP)<br>• Gas or thermally driven heat pumps[6] |
| **Solid-based technologies** | • Bio-based products (wood chips, split logs, agricultural bioenergy) gasifiers & gasification boilers (incl. CHP)<br>• Bio-based products (wood chips, agricultural bioenergy) boilers & stoves (incl. CHP)<br>• Wood stoves (incl. coupling to central heating)<br>• Industrial solid fuel boilers and furnaces (incl. CHP) |
| **Liquid-based technologies** | • Liquid fuel boilers (incl. CHP) |
| **Electricity-based technologies** | • Electric heat pumps (all sources, building & industry) & air conditioners (cf. annex 6.2)<br>• Electric heaters<br>• Electric boilers<br>• Industrial process |
| **Hybrid technologies[7]** | • Combination of two or more energy carriers and heat generators (e.g. gas, liquid, electricity-based, solar thermal, pellet boiler). For some heat generator combinations, the carriers can be renewable-based<br>• |

*Source: own elaboration*

**Waste heat is not renewable energy, however it can be used to fulfil the renewable heating and cooling target up to 40%, and the renewable district heating and cooling target up to 100% under Directive (EU) 2018/2001 (Article 23 and 24, respectively).*

To arrive at a sustainable and decarbonised H&C sector, it is important that all energy carriers used are produced in an emissions-free and sustainable way. For electricity-based H&C technologies (i.e. heat pumps) to become fully decarbonised this means that the electricity supply needs to be decarbonised, mainly through the switch to renewable electricity generation (e.g. PV and wind), potentially in combination with conventional, fossil-based, generation technology combined with Carbon Capture and Storage (CCS). For technologies using gaseous fuels, such as gas boilers or several types of Combined Heat and Power (CHP)

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[6] Thermally driven heat pumps can be used with renewable gases like biomethane or biopropane. Developments are ongoing to ensure they can work with hydrogen blends or pure hydrogen as well. There are several types of thermally driven heat pumps, including thermally driven compression heat pumps, adsorption and absorption heat pumps. Thermally driven heat pumps can also run in waste heat.

[7] Hybrid systems build on the strengths of different technologies – i.e. they combine a traditional gas or oil boiler (possibly operating with biomethane or bio-propane, or even hydrogen) with a renewable heating system such as a heat pump. Hybrid heating systems can monitor the temperature outside and automatically choose the most efficient option. Hybrid systems combining fossil and renewable energy sources and technologies can provide a cost-effective solution to reduce GHGs in the building sector on the short and medium term and prepare a ground for full decarbonisation. Hybrid systems consisting of a gas/oil boiler and an electric heat pump support the idea of sector coupling with the possibility to switch between different energy sources to alleviate stress on the electricity grid and to reduce extension cost for the infrastructure of the electricity grid. They provide flexibility and support resource adequacy in an integrated gas-electricity system. They can gradually become fully decarbonised by replacing fossil gas and oil with decarbonised gas and liquid fuels. Hybrid systems consisting of a combination of renewable technologies can make it easier to provide 100% renewable heating and cooling for a building, in particular in combination with thermal storage,

plants, it is important that the gas supply is decarbonised. Carbon-neutral gases include biogas or biomethane (biogas with upgraded methane concentration and lower levels of $CO_2$ and contaminants), but also renewable and carbon-neutral hydrogen, and synthetic gases (such as e-methane). Lastly, liquid biofuels and synthetic liquid heating fuels produced from hydrogen can theoretically be used for heating purposes. For biomass-based applications (bio-liquids, biogas and bio-solids), it is important that the biomass is sourced in a sustainable manner, avoiding negative impacts on the environment, biodiversity and additional GHG emissions through (in)direct land use change, while also considering the emerging bio-economy and increasing demand for the resource. Air quality and health impacts are an increasing concern due to the combustion of solid fuels, and to a more limited extent, of liquid fuels.

## 1.4 Methodological approach for the roadmap

The objective of this roadmap is to provide policy makers at different levels of government (e.g. regional, national and EU) with guidance on how to develop strategies for the decarbonisation of heating and cooling. At EU-level the roadmap aims to provide information on elements where further guidance and support at EU-level could support Member States in their efforts to decarbonise their H&C systems) with a practical tool to design a tailored approach to fully decarbonising the H&C sector by 2050. Given the central place of the H&C sector in the whole energy system, and the complexity to find the right approach for its decarbonisation, the roadmap is based on a description of essential elements to consider for the decarbonisation of the H&C sector, both in buildings and industry. The approach is based on presenting a series of key 'building blocks' which refer to these essential underlying elements that must be taken into consideration in the planning of the practical steps for the decarbonisation of the H&C sector. The 'building blocks' should be adaptable to the needs of each Member State. The approach emphasises flexibility and acknowledges that there are no "fit-for-all" solutions when it comes to decarbonising the H&C sector across Europe.

In addition to the proposed 'building blocks' for decarbonising the H&C sector at the national level, the roadmap contains a set of recommendations at EU, national and local-levels to address the barriers and gaps identified throughout the study that can be implemented without additional delays. These recommendations are a list of examples of policy measures that can be taken-up at different levels, but they do not constitute a fully-fledged set of complementary measures. They illustrate what the policy measures could look like.

This roadmap should be considered as a guidance to develop individualised national, regional or local roadmaps.

# 3. H&C building blocks

## 3.1. Structural building blocks

### 3.1.1. Options for H&C decarbonisation

The starting point in planning a decarbonised heating system (be it a district, city or country-wide) is understanding the existing (legacy) heat supply structure: fuels/energy sources, technologies and infrastructure. An important element of planning is opting between individual or collective (district heating and cooling (DHC)) decarbonised H&C systems. Currently, most residential and commercial buildings in Europe are individual H&C systems (91%) and only 9% is connected to a DHC network[8]. Today, these buildings are often equipped with fossil fuel boilers (mainly natural gas, heating oil), although renewable H&C solutions are already available and cost-competitive, such as modern biomass boilers/stoves, solar thermal collectors, and geothermal and ambient heat-based heat pumps. Given the recent electrification trend, scenarios for the decarbonisation of heating and cooling in buildings foresee an increasing importance of electricity-driven heat pumps (air-source and geothermal) as the most important technology for individual heating.

Other views advocate renewable-based gases and liquids, as alternative solutions to electrification, as they would require less changes at the consumer sites. Benefits sited include better fitting the lack of available space, neighbourhood or aesthetic constraints, lower adaptation costs[9] and capacity to provide high operation temperature (if a building is not sufficiently insulated). Depending on the resource availability, and whether they are cost-competitive in comparison with other solutions in terms of total cost of ownership, gas solutions could be considered in decarbonisation pathways, keeping in mind both their advantages and disadvantages. Gas technology may also be used in combination with heat pumps (in buildings with less insulation) in hybrid systems and provide a form of demand flexibility to help manage the electricity system and increase system resilience[10]. Gas infrastructure (transport, storage and distribution) partially exists, meaning that coupling gas, e-gas, e-liquid and electricity, via various[11] appliances, could be one of the options for energy transition, where the availability of gas infrastructure and the future costs of decarbonised gases make it cost-effective and affordable.

While some believe there is  vast potential to produce biomethane and e-gases (e.g. renewable hydrogen and e-methane), these solutions should be promoted only if there is strong evidence and certainty that the potential can be utilised in practice and these alternative fuels can be produced sustainably and at an acceptable cost. As regards biogases, sustainability constraints need to be also taken into account. In the case of e-gases, note that their production requires renewable electricity, and since their primary energy efficiency is below that of a heat pump, an e-gas pathway will require more electricty production and possibly more electric grid expansion or adaptation compared to the direct heat electrification pathway using heat pumps. Both the sustainability constraints for biogases and the additional electricity production need for e-gases may increase the cost of these fuels and risk making them unaffordable, unavailable or uneconomic for ordinary consumers. The potentially very high costs and other constraints lead to a significant risk that gas decarbonisation will be hard to achieve, therefore resulting in lock-in with continued use of fossil gases. Stranded gas assets, both in heating systems and infrastructure, are therefore a significant risk. Thus, bio and electricity-based fuels may best be used in specific and limited situations for individual heating. Stand-alone systems often are the only options when the heat consumption density is low and

[8] According to the EU Reference Scenario 2020 – Energy, transport and GHG emissions : trends to 2050, available at https://op.europa.eu/en/publication-detail/-/publication/96c2ca82-e85e-11eb-93a8-01aa75ed71a1/language-en/format-PDF/source-219903975

[9] heating technologies (e.g. boilers) using gas are easy to retrofit (natural gas and e-gas produced with renewable electricity are chemically the same)

[10] e.g. combining an electric heat pump and a high-performance condensing boiler can make an efficient use of renewable gas

[11] E.g. power-to-gases, power-to-liquids, micro CHP, fossil-renewable hybrid systems

when other site conditions negatively affect the economic feasibility and efficiency of new heat grids. Last but not least, options for the development of gas, bio-based and electricity solutions and infrastructure have to consider local parameters like resource availability and technical and economical constraints.

Off-grid households or buildings, currently supplied by heating oil and other fossil-based fuels, will not always have the possibly to install heat pumps, and could therefore have no affordable, sustainable or practical alternatives than using liquid fuel for heating. An effective approach to decarbonise off-grid households and buildings could consider the use of hybrid systems (to optimise the use of different resources), and the replacement of fossil-based liquid fuels by 100% renewable liquids by 2050. The sector currently runs multiple field tests to verify and proof the compatibility of existing heating devices.

On the other hand, DHC can deliver sustainable H&C by connecting multiple local resources to local needs. DHC is a proven solution for delivering heating, hot water, and cooling services through a network of insulated pipes, from one or several central points of generation to the end users. DHC is already widely deployed in Nordern and Eastern European countries, where they allow aggregating heat sources to progressively optimise the energy supply and switch to more sustainable fuels. The availability of district heating infrastructure can improve the competitiveness of renewable heating and cooling technologies, for example within the solar-thermal and geothermal segments. Some RES H&C technologies such as solar-thermal can be much cheaper at scale but require a district heating grid for the distribution. Geothermal energy often is much more economic to develop if there is a district heating network that can serve many customers. However, the refurbishment, construction, and expansion of modern, highly efficient DHC networks (4th and even 5th generation DHC systems ), operating at lower temperature levels and equiped with large thermal storage and smart control systems, are prerequisites for deploying many renewable and sustainable energy sources. Studies differ considerably in estimates of potential to expand district heating and cooling, with the more ambitious ones suggesting that DHC could supply up to 50%[12] of the heat demand in the EU, predominantly in urban areas. DHC is a cost-efficient enabler for the development of carbon-neutral and resilient local energy systems. It has the potential to improve energy efficiency (e.g. large heat pumps, efficient piping) and support the uptake of multiple sources of local renewable energy (e.g. biogas, biomass energy through high efficiency cogeneration) even at very low temperature levels (e.g. solar thermal energy, or geothermal energy in many areas), as well as recycled waste heat.

Several elements need to be considered when choosing between individual and DHC-focused decarbonisation approaches. District heating is financially feasible for communities with heat densities that are comparable to inner and outer cities areas, especially if local waste heat[13] from industry or a power plant is available. The roadmap concerns both increasing the share of renewables in existing infrastructure and the deployment of new renewable-based district heating (DH). A recent analysis[14] of the cost-effectiveness of district heating compared to individual heating solutions under conditions based on the Danish system (e.g. taxes and tariffs) shows that new district heating can be competitive vis-à-vis individual heating technologies. Looking at a heat demand of 13.800 kWh/year corresponding to an energy renovated building and considering DH produced with a wood chip boiler or electrical compression heat pump, the results shows that the annual costs of DH are ~ 19% (EUR 430 cheaper) lower compared to an individual natural gas boiler and ~ 30-31% cheaper (EUR 805) than an individual biomass boiler or individual air-to-water heat pump. The study assumed no

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[12] Paardekooper et al. (2018), Heat Roadmap Europe 4: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps, available at https://vbn.aau.dk/ws/portalfiles/portal/288075507/Heat_Roadmap_Europe_4_Quantifying_the_Impact_of_Low_Carbon_Heating_and_Cooling_Roadmaps..pdf

[13] Waste heat does not qualify as renewable energy but can fulfil the renewable heating and cooling target partially (up to 40%) and the renewable district heating and cooling target fully (100%) under Directive 2018/2001/EU on renewable energy (See Article 23 and 24 of that Directive).

[14] Green Energy Association. (2018). The competitiveness of district heating compared to individual heating: When is district heating the cheapest source of heating?

pre-existing heating systems in the area (neither DH nor individual heating). Interestingly the results show that heat demand and district network length are important variables. It is also essential to recall DHC can utilise many different local resources that could not be valued via individual systems. On the other hand it should be noted that many people today prefer an individual system, even if competitive DHC solutions are available for them.

The energy performance of buildings is also an important factor in the selection of a supply technology. When DHC is deployed in existing building stocks, the energy performance of all connected buildings must be considered during the design phase, as it will have an influence on the volume of energy consumption (energy density is an important parameter for the economic viability of a DHC).The technical viability of low temperature DH must also be evaluated because 4th[15] or 5th[16] Generation DH requires buildings or any other user to operate at low temperatures. The heat demand profile and especially peak demand also determines what supply (baseload, peak and back up) and infrastructure capacities are needed. A complete green retrofit may be required of older building stocks for the installation or conversion to efficient DH (4th or 5th Generation). In the case of heat pumps, the smaller the temperature difference between the source and the heat output, the smaller and more efficient the heat pump is. A complete deep energy renovation remains needed in older buildings for the installation of heat pumps, although it appears that heat pumps may also satisfy heat demand in buildings not fully retrofitted either via high-temperature heat pumps or hybrid heat pumps[17], which are complemented with gas condensing boilers to cover peak demand. The modernisation of windows and roofs can achieve much in this regard. Better insulation of building envelopes allows installing low-temperature floor heating, or low-temperature radiators. As shown with the example of modern low-temperature efficient district heating and heat pumps, it is essential to combine the deployment of renewable and carbon-neutral heating technologies with building retrofits, especially in regions or countries with low energy building performance (this is further developed in the section on the “planning building block”).

### 3.1.2. Fossil fuels phasing out

The transition from fossil fuel-based energy sources to low carbon H&C must be carefully managed as it requires extensive planning and high-level expertise, along with significant investments in building retrofits, in developing new renewable and carbon-neutral energy sources for heating and cooling, in renewable and zero/carbon-neutral gases and renewable electricity generation, in end-user technologies, in industrial technology development, in energy transmission and distribution infrastructures, and in storage capacities. The future energy mix should focus on both ready-to-adopt and quickly deployable renewable and carbon-neutral H&C technologies (in the short-term) and innovative renewable and carbon-neutral H&C technologies and systems (in the medium-term), while phasing out fossil fuels. Full decarbonisation of the building stock by 2050 requires to quickly stop (ideally by 2025) the installation of heating systems fuelled by fossil fuels[18], unless their installation is connected to spatial planning, clearly identifying areas where the gas grid should remain[19]. Several National

[15] 4th generation District Heating (4GDH or 4th DH), as defined in Lund H, et al. (2014) refers to “coherent technological and institutional concept, which by means of smart thermal grids assists the appropriate development of sustainable energy systems”.

[16] 5th generation District Heating (5GDG or 5th DH) is defined by Abugabbara et al. (2020) as a system that “harnesses the shared energy concept which is realized in a network that connects ‘prosumers’”.

For an overview of differences between 4th DH and 5th DH see: Lund H. et al. (2021) Perspectives on fourth and fifth generation district heating. Available at: https://www.sciencedirect.com/science/article/pii/S0360544221007696

[17] A hybrid heat pump is a system that uses a heat pump alongside another heat source, typically, a fossil fuel (gas, oil or LPG) boiler.

[18] Heating systems can run with either fossil fuels, low-carbon fuels or renewables. Note that heating systems such as boilers can use either fossil fuels or the same renewable-based fuel (e.g. replacing natural gas by biomethane or synthetic natural gas). Therefore, stopping the installation of systems currently using fossil-based fuels could prevent the development of alternative renewable or low-carbon fuels, which should probably not be rejected in all cases (especially when there are limited alternatives, and the existing equipment can be easily run on renewable or low-carbon based fuels).
[19] https://www.oeko.de/fileadmin/oekodoc/Phase-out_fossil_heating.pdf

Energy and Climate Plans (NECPs)[20] and Long Term Renovation Strategies[21] already include measures for the phase out of fossil fuels for heating, such as quickly stopping the installation of heating systems fuelled by fossil fuels. Three EU countries already have plans to phase out oil-fired and gas-fired boilers in all buildings and five more have plans or implemented policies to ban the installation of fossil-based heating equipment in new buildings.[22]

Policies to phase out fossil fuels must put citizens at the center allowing them to plan for the required changes, by keeping the market open and improving consumer information so that everyone has fair conditions to choose the most appropriate heating system for their specific situation. In the building sector, the new EU energy label (providing information on energy savings of products, like heaters[23]) should be useful for end-users and investors to inform them how to faster and deeper modernise or completely replace their heating appliances according to their individual needs, as there is evidence[24] that the energy label in its current form is considered by consumers as not effective (people are aware of the label, but it does not trigger a switch to another heating technology). The main reason is that purchasing decisions depend on the building characteristics (e.g. insulation level, size of radiators, …) and financial capabilities. The revised label for space heaters could also integrate information on the origin of the energy carrier (i.e. to indicate if the origin is renewable or not), except for electricity (e.g. via a pictogram), and add information regarding smartness and digitalization.

A progressive phase-out of fossil fuel boilers could be accelerated with the early rescaling of energy labels to downgrade inadequate appliances to the lowest grades (F and G)[25]. These appliances could then be progressively phased out by banning the installation of the worst performing appliances (G) in the first phase (e.g. by 2023) and then of F-grade appliances in a second phase (e.g. by 2025). Ending the installation of new boilers fired by gas, oil and coal as of 2025 could bring about 110 million tonnes of annual $CO_2$ savings by 2050, while a more gradual approach would allow consumers and manufacturers to plan ahead. Such a progressive ban would not necessarily depend on an EU level decision; it could be implemented at national level by Member States wishing to do so, depending on specific local characteristics[26], e.g. under the Energy Performance of Buildings Directive transposition[27].

In the transition to a fully decarbonised H&C sector, the role of natural gas is somewhat controversial. The H&C sector accounted for 64% of the overall natural gas demand in Europe in 2015 and thus decarbonising the sector will have important implications for future demand of gas.[28]

Natural gas has a lower carbon footprint than oil or coal; however, it is not compatible with climate neutrality. On average, switching from coal to gas cuts emissions by 50% when producing electricity and by 33% when used for heating.[29] In addition, fuel switching from more

[20] Introduced under the Regulation on the governance of the energy union and climate action (EU/2018/1999), the NECPs are 10-year integrated plans for energy and climate for the period 2021-2030. Areas covered adress energy efficiency, renewables, GHG emission reductions, interconnections and R&I.

[21] Under the 2018 Energy Performance of Buildings Directive, all MS are required to submit to the Commission a long-term renovation strategy outlining plans to support the renovation of their national building stock into a highly energy-efficient and decarbonised one by 2050.

[22] ECOS (2021) Member States' ambition to phase out fossil-fuel heating – an analysis, available at https://www.coolproducts.eu/wp-content/uploads/2021/07/ECOS-Coolproducts-Background-Briefing-MS-ambition-to-phase-out-fossil-fuel-heating.pdf

[23] As example, local space heaters with a nominal heat output of 50 kW or less are sold with energy labels as of 2018, https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products_en

[24] *Consumer study on purchase decisions regarding heating appliances*, CentERdata (2021).

[25] https://ec.europa.eu/transparency/expert-groups-register/screen/meetings/consult?lang=en&meetingId=28735&fromExpertGroups=true

[26] Among the local characteristics, are the presence of gas infrastructure, the ability to effectively move to renewable-based fuels, the ability to conduct rapid and effective local H&C planning, …

[27] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings

[28] The Oxford institute for energy studies (2018) Decarbonisation of heat in Europe: implications for natural gas demand

[29] IEA (2019), The Role of Gas in Today's Energy Transitions. Available at: https://webstore.iea.org/the-role-of-gas-in-todays-energy-transitions

polluting fuels to gas contributes to the improvement of air quality. On the other hand, natural gas is not compatible with a fully decarbonised system and if carbon neutrality is to be achieved by 2050, any lock-ins and investment in stranded assets must be avoided. Thus, investments in gas infrastructure should consider whether the projects and infrastructure are future-proofed, whether such infrastructure could be adapted to transporting decarbonised and/or carbon-neutral gases[30], and should ensure that renewable gas will be injected in the concerned infrastructure (given the limit of resource availability). As such, although several studies suggest that keeping the gas infrastructure and greening the gas is a viable and cost-effective solution[31] to quickly decarbonise the H&C sector, this should not be seen as a general rule applicable to all gas network segments and should be assessed on a case by case basis, taking into account the availability of renewable gases.

In addition to investments in infrastructure, government support for gas-based heating appliances is important to re-examine. A recent study finds that many Member States use ‘green’ energy schemes to finance the installation of new gas boilers, which are already about three times cheaper than heat pumps.[32] This support is incompatible with the results of an earlier study reporting that a total phase-out of gas and oil boilers would be needed by 2025, if Europe is to achieve carbon neutrality by 2050.[33] This support is also not in line with the framework Energy labelling regulation 1369/2017, which stipulates that “Member States provide incentives for a product specified in a delegated act, those incentives shall aim at the highest two significantly populated classes of energy efficiency, or at higher classes as laid down in that delegated act.” With the proposed rescaled label, gas boilers are included in the space heating energy label (Commission Delegated Regulation (EU) No 811/2013[34]) and are not included in the highest efficiency classes (classes reserved to more efficient heating products, such as heat pumps); hence they should not be supported by national incentives. Additional aspects related to decarbonised and/or low carbon gas and its role in decarbonising the H&C sector are discussed under various building blocks below.

Given that most decarbonised heat solutions will require changes to the customers’ heating systems in their homes, offices or factories, an important consideration in planning fossil fuel phase-outs is the distributional, economic and social effects that moving towards a decarbonised H&C sector will have, especially on energy poor households (for further discussion on this topic see **Error! Reference source not found. Error! Reference source not found.**).

### 3.1.3. Energy efficiency

The EU’s energy efficiency first principle, enshrined in the Governance Regulation, emphasises the importance of measures to reduce energy demand. Energy savings are the easiest way to reduce GHG emissions while at the same time saving money for consumers. However, currently much of the building stock in the EU is not energy efficient, and 85% to 95% of these buildings will still be in use in 2050. Hence, defining pathways leading to a highly efficient and decarbonised building stock by 2050 is fundamental to achieving the objective of climate neutrality.

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[30] European Commission (2020) Impact on the use of the biomethane and hydrogen potential on trans-European infrastructure. Available at: https://op.europa.eu/en/publication-detail/-/publication/10e93b15-8b56-11ea-812f-01aa75ed71a1/language-en

[31] Gas for Climate & Guidehouse (2020) Gas Decarbonisation Pathways 2020-2050. Available at: https://gasforclimate2050.eu/sdm_downloads/2020-gas-decarbonisation-pathways-study/
E.ON (accessed on 08/09/2021) Energy transition with green gas benefits low-income households. Available at: https://www.eon.com/en/about-us/politics/energy-transition-with-green-gas.html

[32] European Environmental Bureau on behalf of Coolproducts campaign (2021) Clean heat grants are failing to green our homes – New analysis. Available at: https://www.coolproducts.eu/failing-rules/green-heat-grants-are-failing-to-clean-up-the-sector-new-analysis/

[33] ECOS and Coolproducts campaign (2021) Five Years Left: How ecodesign and energy labelling can decarbonise heating. Available at: https://www.coolproducts.eu/wp-content/uploads/2020/12/Five-Years-Left-How-ecodesign-and-energy-labelling-Coolproducts-report.pdf

[34] Commission Delegated Regulation (EU) No 811/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device Text with EEA relevance

Improving the energy performance of buildings is a key element of decarbonising space H&C. Ambitious renovation of the building stock can lead to substantial energy savings, resulting in reduced investments in renewable energy generation technologies and energy infrastructure, but also providing the opportunity to broaden the number of renewable options (e.g. better performing building can operate at lower temperature levels expanding the options of suitable technologies such as solar heating or heat pumps, while reduced consumption decreases the required capacity of production and storage, e.g. storage tank for hot water or for pellets). To that end, energy management solutions that guarantee energy/$CO_2$ savings and performance over time, such as Energy Performance Contracts, are key tools to support decarbonising the building sector. The current renovation rate and depth need to be substantially increased across the EU Member States . The annual renovation rate at EU level is currently around 1%, while the annual rate of one-off, deep renovations is only around 0.2% - 0.3%, translating into low replacement rates of fossil-based heating equipment and low development and modernisation of DHC.

Viable strategies to abate emissions from buildings needs to consider the heterogeneity of the building stock, the varying local conditions and social impacts. The decarbonisation of buildings will likely require a wide range of solutions and energy carriers. Different heating technologies are available for different building needs and for different renovation stages (deep renovation would favor technologies taking care of the residual heat load and domestic hot water; while in staged renovation, modularity of modern heating technologies could be preferred, e.g. hybrid systems).

New homes often represent a ‘low hanging fruit’ for building efficiency and for installing renewable heating, as new buildings are usually constructed with higher performance standards and newer technology. High perfomance levels are harder to reach in buildings that have been poorly designed and built. Under the Energy Performance of Buildings Directive (EPBD), all new buildings constructed after 31 December 2020 should be nearly zero-energy buildings (NZEB). Nearly zero-energy buildings need to have very high energy performance under the EPBD, with their low energy needs being covered largely by renewable sources generated on-site or nearby. Such buildings are often based on common characteristics including a well-insulated thermal envelope, built without any thermal bridges and ensuring high level of airtightness. Furthermore, windows in NZEBs require thermally insulated frames and high quality glazing. Shading is another important factor that can reduce the need for cooling in the building. In many cases, NZEBs have a mechanical ventilation system with heat recovery and incorporate building automation and control systems and other smart solutions. Specificities of NZEBs need to consider the buildings’ location, climatic conditions, availability of local renewable resources and needs of the inhabitants. District heating systems either with a high share of renewables and/or high energy performance characteristics are a promising solution for NZEBs in urban areas.

With regards to building renovation, given the current low energy performance of the building stock in the EU, it is essential to address the replacement of old and inefficient heating equipment and the improvement of the building envelope in a holistic manner. Improvements of the building energy performance increase the number of options for renewable H&C systems that are available and decrease the overall investment and operational costs. Ideally, energy renovations are planned before the expected end-of-life of the existing H&C systems, so that urgent replacement with new fossil-based systems can be prevented. Approaches such as Building Renovation Passports (at building level), urban heat planning and zoning approaches (at community level), staged renovations and trigger points may support coordinated and long-term action. Planning in advance would allow end users to explore different renewable options and chose the most suitable for the application and local conditions.

In cases where options for improving the energy performance of a building are limited (e.g. due to excessive cost of the works or for the case for historical buildings), suitable renewable heating (RES-H) technologies need to be identified. The technical feasibility of installing heat pumps in existing buildings is a key question to be addressed.

As highlighted by the Energy Efficiency First Principle, building demand-side flexibility must also be recognised and valorised as an essential dimension of the building’s energy performance. Doing so will capture the benefits of sector coupling and contribute to a more cost efficient energy transition (cf. section 2.3). The focus should be placed not only on average annual efficiency but also on a dynamic systemic approach considering the evolution of the energy mix. Buildings can play an important role by bringing affordable flexibility and resilience to the energy system, during the transition but also in fully decarbonised H&C systems.

Ideally, the design of dynamic electricity tariffs (time of use, dynamic) should stimulate the dynamic use of energy by allowing final energy users (building occupiers) to provide load flexibility, and thus allowing better integration of intermittent renewables. This would ensure a more efficient use of electricity infrastructure, and help reduce or avoide electric grid reinforcement (by reducing peak demand). Preferably this is done through the use of systems that automatically adapt to fluctuations in energy availability (by means of price signals) so that consumers can provide system flexibility in a convenient and accessible manner. Such developments would require the possibility for new types of energy contracts with more dynamic pricing.

Inside buildings, hot water preparation accounts for 495 TWh final energy per year in EU. It is the main source of energy consumption for highly energy efficient new housing, and yet 80% of this heat ends up in sewers and is wasted. Considering up to 80% of hot water is used in showers, harvesting heat from shower drains in buildings could be a simple way to save wasted energy and $CO_2$ emissions.

### 3.1.4. Industrial decarbonisation H&C technologies

Industry is an important and challenging sector to decarbonise. In the EU, heavy industrial processes such as the production of cement, steel, petrochemicals, glass, ceramics, petroleum refining, and others contributed for at least 34% of total $CO_2$ emissions in 2019.[35] In the EU, the final energy consumption of the industrial sectors (e.g. manufacturing, construction) was 2.780 TWh in 2019, representing a share of 26% of the total final energy consumption.[36] Within the demand for H&C, industrial process heat accounted for roughly one third of the total demand in 2015.[37] Heat use under 200°C (process and space heating) represents 44% of the overall EU28[38] final energy consumption for industrial H&C, while the final energy consumption for process and space cooling accounts for around 4% of overall final H&C energy consumption in industry. The remaining 51% of final energy consumption in EU's industries is used to generate heat above 200°C.

Industrial decarbonisation constitutes a particular challenge due to several characteristics associated with this sector. Industry is hard to decarbonise due to conversion costs, temperature levels, competitiveness risks, and long facility life. For many energy-intensive industries (EIIs), energy costs make up a significant share of their overall production costs and hence increases in energy costs can have a significant impact on industrial competitiveness. Energy costs in manufacturing accounted for between 1% and 10% of production costs in the period 2010 to 2017 in the EU.[39] For energy-intensive sectors such as paper, building material, iron and steel and cement these costs are on the high end of the spectrum and can even exceed 10% share of production costs. Even with the increased cost competitiveness of renewables observed in recent years, uptake of renewables will have an impact on the overall production costs, which in turn will translate into considerations of competitiveness. While processes/sectors using low temperature heat (< 150°C) have several efficient renewable heating and cooling technologies available, the higher the temperature of the heating demand is, the more limited the options are for decarbonisation with renewable-based fuels and sources. In addition, since the average economic lifetime of industrial facilities is long (~ 20

[35] https://ec.europa.eu/energy/sites/default/files/energy_statistical_countrydatasheets.xlsx
[36] Eurostat (2021) Complete Energy Balances.
[37] HeatRoadMapEurope (2018) Profile of heating and cooling demand in 2015.
[38] Industrial data on heat uses differentiated according to temperature ranges are not available at EU level. Such data were collected specifically for the purposes of this study and do not provide disaggregation by Member States. The data relate to the year 2015 and EU28. The quoted data provide an order of magnitude as regards the approximate share of low temperature process heat in overall industrial heat consumption.
[39] EC (2021) Study on energy prices, costs and their impact on industry and households. https://www.euneighbours.eu/sites/default/files/publications/2020-10/MJ0220370ENN.en_.pdf

years or more), any intervention must be immediate and investments in new facilities should be based on low or zero carbon technologies.

Figure 2 3 illustrates the decarbonisation strategies available for the industry, based on three approaches:

- Dematerialize or recycle/reuse – mainstreaming circular economy, depending on the sector;
- Keep the core existing process and either capture the carbon (for usage or storage) and/or make fundamental changes to shift to low carbon fuels; or
- Change the existing process.

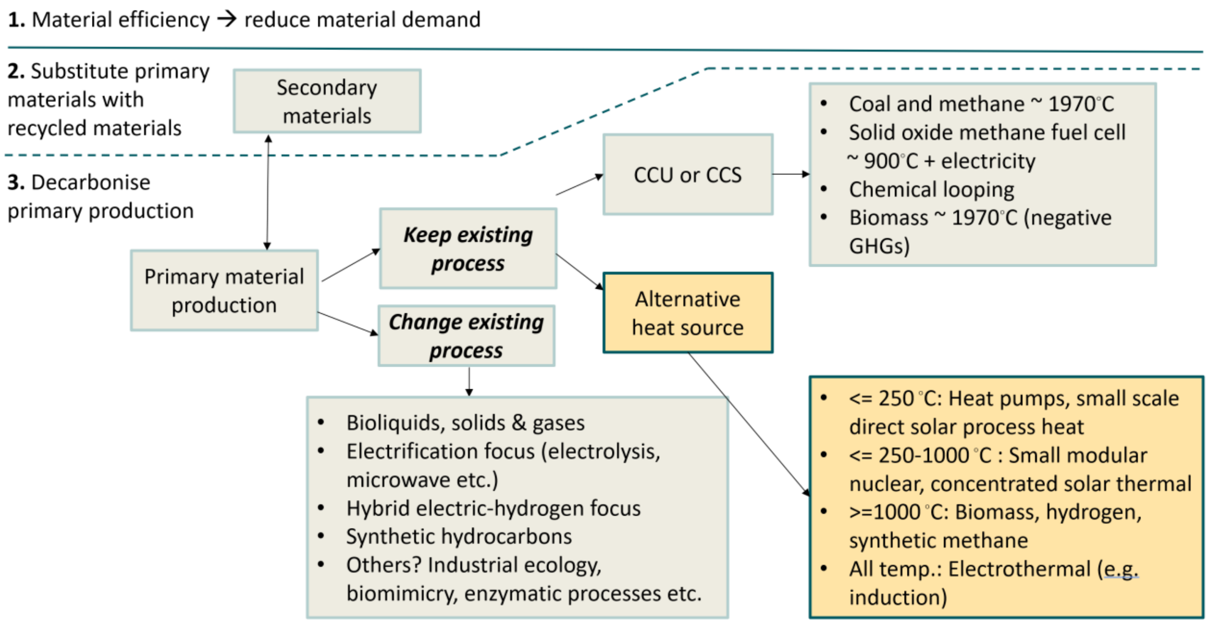


*Figure **Error! No text of specified style in document.**-3 Flow chart for choosing the most suitable industrial decarbonisation options*

*Source: Own elaboration inspired by: A review of technology and policy deep decarbonisation pathway options for making energy-intensive industry production consistent with the Paris agreement*

A selection of main decarbonisation pathways applicable to most industries using high temperature processes, and especially the EIIs, could include the following options :

- Further energy efficiency improvements and energy savings
- Process integration
- Further electrification of heat
- Further electrification of processes
- Use of low-$CO_2$ hydrogen
- Valorisation of $CO_2$ (Carbon Capture and Utilisation)
- Use of biomass
- Carbon Capture and Storage
- Higher valorisation of waste streams and materials efficiency

Although many of the technology options are already well-developed, there is still need for public support to steer demonstration of emerging technologies, to promote industrial investments and to ensure the appropriate market conditions are in place. Thus, to accelerate the decarbonisation of industrial processes, emerging technologies are still needed, such as more efficient electrolysis; solid oxide fuel cells ; producing renewable hydrogen-derived ammonia, methane and methanol; $CO_2$ capture & storage and/or use (e.g. through methanation); biomass (ideally waste) gasification; high-temperature heat pumps; electric virgin steel production; new cement chemistries; electrothermal technologies, and; electrolytic smelting. Finally, for low-$CO_2$ technologies reaching maturity, their market uptake will depend on operational costs. Cost reductions can be achieved by having multiple technologies to be tested in demonstration projects to allow for experimentations with design improvements on an industrial scale.

There is need for investments in infrastructure to support an industrial carbon-neutral transition. Mapping infrastructure needs should take into account existing connections between industrial clusters across borders (e.g. existing pipeline infrastructure connection regions) and how economic or other synergies between regions can be realised. The risk of industrial clusters becoming isolated from new low-$CO_2$ infrastructure must be identified together with options to mitigate this. Furthermore, it is important to consider that for most energy-intensive industries, the current production location has significant strategic value (e.g. connections to infrastructure and logistics, proximity to raw materials supply chains and/or customers). Most investments in low-$CO_2$ processes will therefore likely happen at the same location. This implies that major brownfield conversions will have to be part of an industrial low-$CO_2$ transition.

A final aspect that is important to take into account when decarbonising industry is that decarbonisation strategies should not focus only on decarbonising existing processes and energy demand, but alternative processes and solutions for subprocesses need to be considered too. Traditionally, it was common to produce a large volume of heat at the highest temperature needed in one of the subprocesses in an industrial plant and then cascade for lower-temperature processes. In a fossil-based system, this is an efficient practice, but in a system based on renewables where energy carriers with a high energy density are scarce it is more efficient to break up the demand in components with different temperature levels and find a solution for each. In some cases, the minimum temperature required for a process can be lowered by adjusting the production process or shifting to a new process, which increases the number of available renewable heat supply technologies.

### 3.1.5. Energy storage

Thermal energy storage refers to the temporary storage of energy in the form of heat so that the stored energy can be used at a later time in H&C applications or for power generation. The technology takes advantage of materials that gain energy when increasing their temperature, and lose enrgy when decreasing it.Thermal energy storage is one of the key instruments to integrate the electricity and H&C sectors in a smart integrated approach that benefits power as well as thermal systems.

Figure 2-1 shows some of the key applications of thermal energy storage  in an energy system with high renewables penetration.

Thermal energy storage is already broadly used in many different end-uses and applications. However, many aspects still require further development or improvement, including: liner materials for high temperature thermal energy storage that have long lifetime and acceptable costs; construction techniques for large volumes, deep pit or tank storage, in different geological settings; thermal insulation materials and techniques to cost-effectively lower the heat loss and improve storage performance; floating or self-carrying lid constructions to enable the use of the storage top area; optimised system integration and hydraulics and controls to optimise system performance. Generally, further improvement towards cost-effectiveness of such systems is dependent on the parallel development of novel materials, improved components, and further development and demonstration of system-based applications.

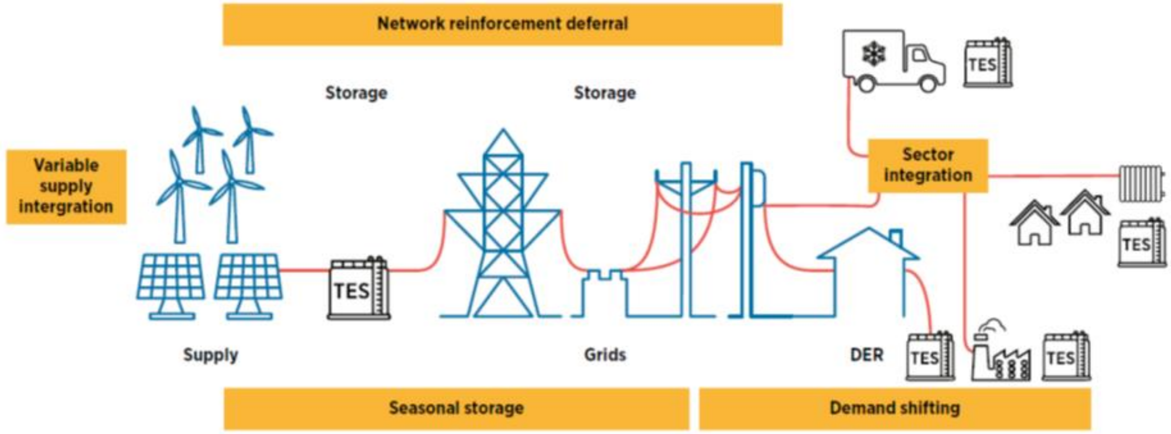


*Figure **Error! No text of specified style in document.**-6 Key applications of TES in the energy sector*[40]

*Source: IRENA 2020 Innovation outlook Thermal Energy Storage*

When it comes to heat pumps and their role in energy storage, the flexible operation of heat pumps in periods with low electricity prices can reduce the price of heat production and when the heat is needed in the short term, the heat capacity of the building itself can be used for temporary heat storage. To bridge longer time spans, dedicated thermal storage systems can be used. In the cases where reversible heat pumps are operating in the context of district heating and cooling, the best approaches include hot or cold water/brine storage or ice storage.

### 3.1.6. Cooling

Cooling accounts for around 4% of final energy demand in the EU, with 106 TWh for space cooling and about 110 TWh for process cooling complemented by 0,6 TWh for district cooling[41] Due to the increased temperatures experienced during the last years and changes in lifestyles and expectations with regard to thermal indoor comfort, the cooling needs of buildings have risen and are expected to further increase in the near future. Given the expected demand for cooling in the future, planning ahead is an important element to address future demand for cooling. Such planning should consider implementing integrated solutions that decrease the cooling needs of buildings without compromising comfort on the one hand; and matching the demand by best available and renewable space cooling technologies on the other. Renewable space cooling technologies well adapted to the different building types and needs.[42] Fortunately, currently 99% of cooling is electricity-driven; unlike heating, cooling typically does not involvthe direct use of fossil fuels.

The key drivers for the decarbonisation of space cooling are:

- Reduction of space cooling demand by increasing the thermal performance of buildings (passive cooling)
- Increasing the efficiency of cooling appliances (incl. the use of free cooling)
- Transformation of the electricity sector
- Increasing the share of cooling technologies using renewable heat or waste heat, and thermal energy storage

For process cooling, it is essential to consider cooling and heating in an integrated way, e.g. to recover the ‘waste’ heat from cooling in data centers, malls, hyper- and supermarkets, large

[40] IRENA 2020 Innovation outlook Thermal Energy Storage. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf

[41] Study ENER/C1/2018-493 “Renewable Cooling under the Revised Renewable”, by TU-Wien, Armines, EURAC Research, Viegand Maagøe, e-think, August 2021.

[42]

cooling and freezing rooms, and similar processes. Reversible heat pumps, which can produce both high and low temperatures, can be a good technology choice for buildings.

## 3.2. Transversal building blocks

### 3.2.1. Resource availability

Given that renewable energy for heating and cooling is derived from finite resources, resource availability plays a key role in the planning of a decarbonised H&C system. Resource availability plays a role for all renewable energy sources, but is especially key for bioenergy feedstock, although the deployment of solar, wind, geothermal may also face availability and spatial constraints, public acceptance issues, and critical raw material limitations. Technical wind energy potential can be constrained by competing land or water uses or can face public acceptance related constraints. High-temperature/enthalpy geothermal energy is another resource that is not available everywhere[43]. Low-temperature/enthalpy geothermal energy is available almost every where for heating and can be harnessed via heat pumps; its use can nevertheless be constrained, for examples by competeing uses of underground spaces or the need to protect the water tables. The sustainability impact of renewable energy sources should also be addressed in a comprehensive life-cycle assessment.

For bioenergy development, the key condition is the availability of reliable, affordable and sustainable biomass sources, considering its increasing use for biomaterials. Biomass production and use involves a chain of activities ranging from the growing and harvesting of feed stocks, processing, conversion, transport and distribution of bioenergy carriers up to the final energy use. Each step can pose different sustainability challenges that need to be addressed. The environmental performance of a bioenergy source depends on the specific characteristics of those steps in the value chain and need therefore to be assessed on a case-by-case basis. Competition is not only about competing raw material uses, but also about surface or land availability, including underground spaces, and potential conflicts among the various uses of space and land. Food production related cultures may create competition between food or biomass production; lignocellulosic resources and algae involve other challenges including indirect competition with food production due to competition for land. However, producing biofuels (like bioethanol) may be complementary to the extraction of food molecules (e.g. proteins ) when biorefinery processes are applied.

Recently, awareness has been growing about the importance of using biomass at the highest value possible. When competing biomass applications are present in a certain area, adhering to the biomass use hierarchy and cascading use, where material applications are prioritised, is a good principle for the optimal, economic, and sustainable use of biomass resources. In this regard, new circular economy ambitions, where substitution of non-renewable materials with biobased materials plays a significant role, combined with a continued increase in bioenergy use ambition, can lead to a situation where the claim on biomass resources for different applications exceeds the realistic sustainable supply. However, it should also be considered that (non-waste) solid bioenergy is mainly produced out of forest residues (woody by-products not fit for other purposes) and from industrial by-products (e.g. sawdust). Therefore, the increase of the use of biobased material (e.g. wood in construction) could lead to an increase in the availability of the streams required to produce solid bioenergy like pellets or chips. This could create an additional opportunity, although recent insights on the use of woody biomass for energy also suggest that the cascading use of forestry residues for energy purposes is often limited because direct competition with material applications, e.g. for production of wood panels and paper products, often exist. Still, in a specific local context, use of residues for energy might make economic sense as long-distance transport to a place where

[43] High enthalpy geothermal energy is generally used for electricity production, often together with heat production (cogeneration), and to supply process heat for industries.

it could be used for material purposes is not economically viable while good local bioenergy applications exist. This means that energy applications of biomass should not be ruled out beforehand, but should be evaluated on a case-by-case basis. Although biomass potential supply estimations significanlty vary between studies[44], it appears it is unlikely that there is enough potential for expanding biomass supply within sustainable boundaries, when also taking into account other emerging biomass applications.[45] Hence, biomass use should strictly proceed on a precautionary basis, while only considering sustainable biomass. Governments should ideally manage biomass resources in holistic way, considering the bio-economy as well as environmental and social impacts.

In the case of solar energy, solar irradiation increases when moving to lower latitudes and as such solar energy is most abundantly available in southern Europe. Average annual solar irradiation in southern countries is significantly higher than in northern countries, with Italy having the highest average solar irradiation and Finland having the lowest. One of the main challenges with solar is its temporal availability, including its short-term variability (day versus night) as well as the seasonal variability (summer versus winter). The latter is especially challenging from a heating point of view given that there is a mismatch between the solar energy availability and heating demand. This mismatch can be overcome with innovative thermal storage technologies, which highlights the importance of (affordable) energy storage solutions. However, there is a match for cooling demand, meaning that solar cooling technology could represent a promising solution.

Wind as a resource varies strongly across Europe, with the highest availability of wind energy in the coastal and mountainous areas, when it comes to onshore wind power; but even better wind energy resources can be found offshore. The largest onshore wind potential resides in north-western Europe and the largest offshore potential is located in the North Sea, Baltic Sea, Atlantic ocean as well as some locations in the Mediterranean and the Black Sea. There is a vast technical potential for wind energy generation in Europe of 75.000 TWh[46], which is more than 7 times the total EU final energy demand in 2030.[47] However, for onshore wind, environmental and social constraints mainly related to visual and sound impacts, stroboscopic effects and the impact on birds and bats reduce the overall potential. In offshore locations, the potential is restricted even more, due to competing uses of the offshore areas, for e.g., shipping, fisheries, protected areas and military purposes. Together, these constraints reduce the overall potential from an estimated potential of 30.000 TWh to around 3.500 TWh[48] by 2030 which still remains higher than the total anticipated electricity consumption in that year. According to the recent modelling exercise accompanying the Climate Target Plan of the European Commission[49], the total electricity consumption in 2030 will range between 2.726 TWh and 2.780 TWh, and 3.402 TWh and 3.446 TWh in 2050.

Geothermal energy for heat production can be split in two categories: shallow geothermal energy, and deep geothermal with depths reaching up to a few kilometres. Generally, the temperature in the earth's crust increases with depth and as such geothermal sources with relatively low temperatures are available virtually everywhere in Europe. For individual and small scale applications, the depths of geothermal heat exchange range from a few metres to more than 200 meters, depending on the technology, the geological situation, the demand profile, and on other design considerations.[50] At these depths the temperature of the heat is often not high enough to be used directly for space heating and is therefore mostly 'upgraded' using a geothermal heat pump. At higher reachable depths, there are only a few regions in

[44] According to the Policy report on Biomass in the EU Green Deal – Towards consensus on sustainable use of biomass for EU bioenergy, IEEP, November 2021, available at https://ieep.eu/uploads/articles/attachments/a14e272d-c8a7-48ab-89bc-31141693c4f6/Biomass%20in%20the%20EU%20Green%20Deal.pdf?v=63804370211

[45] Material Economics (2021) EU biomass use in a net-zero economy. https://www.climate-kic.org/wp-content/uploads/2021/06/MATERIAL-ECONOMICS-EU-BIOMASS-USE-IN-A-NET-ZERO-ECONOMY-ONLINE-VERSION.pdf

[46] EEA (2009) Europe's onshore and offshore wind energy potential, available at https://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential

[47] Based on the total final energy consumption of 840 Mtoe (9769 TWh) in 2030 projected in the EU Reference scenario 2020.

[48] Ibid.

[49] COM(2020) 562 final – Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0562&from=EN

[50] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC123160/jrc123160_online_1.pdf

Europe where the temperature gradient is steeper and high-temperature sources exist. Geothermal energy sources with higher temperatures, that allow for a combination of electricity and heat production also exist, but only in certain specific regions in Europe (Figure 2-2).

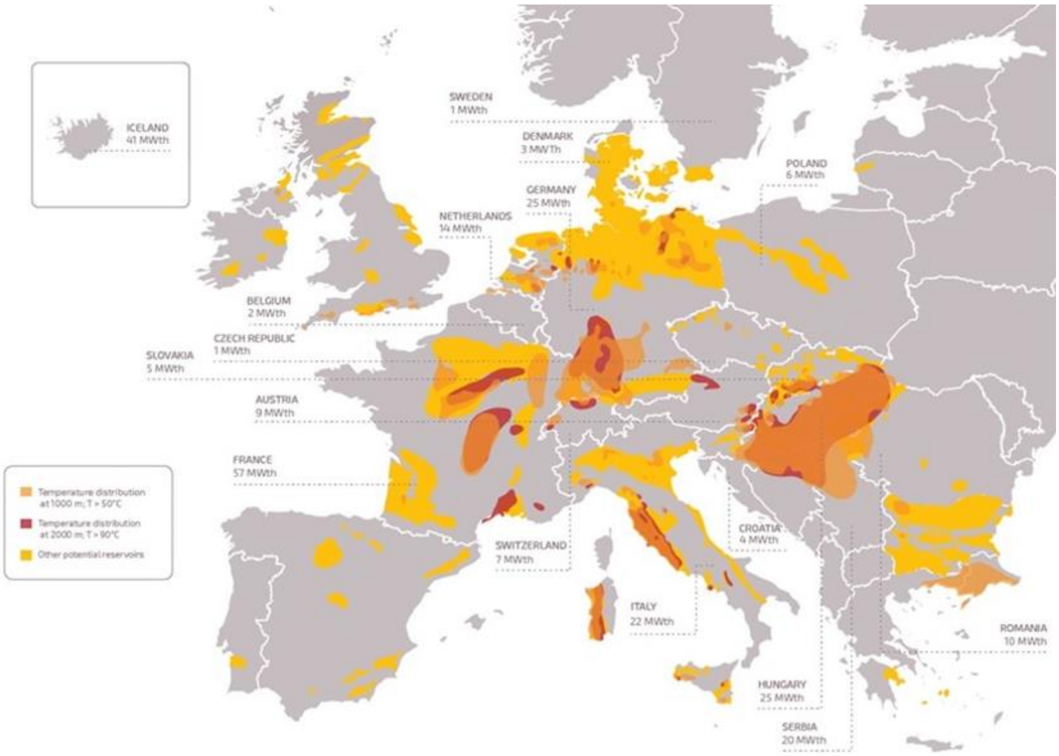


*Figure **Error! No text of specified style in document.**-7 Resource heat map for Geothermal Energy in Europe*[51]

As underlined in several works, such as in the EU project Heat Roadmap Europe or in the 2016 EU Heating and Cooling Strategy[52], the EU produces more waste heat than the demand of its entire building stock; despite this large potential, currently the number of small-scale examples of urban waste heat recovery across the EU is limited. The amount of waste heat produced by industries (hot water or flue gases) is sufficient to cover 100% of the EU's heating needs. However, given that industrial sites are often located far from urban areas, only a part of this waste heat is available at a reasonable distance from urban centres where it could be recovered in district heating. More easily accessible opportunities rely on the recovery and reuse of low temperature waste heat from different urban sources such as: the transport sector, services buildings, sewage water networks, data centres, harbours, rivers, lakes and seawaters, as was well as electrical substations. However, until now these have been largely unexploited. These heat sources are low enthalpy sources (around 20-40°C) and due to the proximity to a large number of end-users, they could effectively provide H&C services through individual systems as well as DHC networks. In addition, recovering waste heat also means a long-term relationship between heat providers and heat users, which should be considered in the frame of increasing efficiency and possibly switching to new industrial processes.

Based on the above, it can be concluded that the technical potential for these resources will not be a constraint for expanding the use of H&C technologies that consume electricity (e.g. heat pumps) and/or directly use thermal energy. The challenge lies in a sufficiently swift deployment of the technologies to utilize the available potential as well as the creation of suitable business models.

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[51] ETIP Deep Geothermal (2018) A vision for Deep Geothermal.
[52] COM(2016) 51 final

### 3.2.2. Coordinated planning at the core of H&C decarbonization

A global framework for planning is already in place in the form of the National Comprehensive Assessment (NCA) to establish the technical and socially cost-effective potential for high-efficiency cogeneration (CHP) and efficient district heating and cooling (DHC) under Article 14 of the Energy Efficiency Directive (EED). An assessment of the potentials to use renewable energy as well as waste heat and cold for heating and cooling also exists under Article 15(7) of the Renewable Energy Directive (RED) II and this assessment should be art of the NCA under the EED. A better integration of these comprehensive assessments with NECPs under the Governance Framework has been proposed under the 'Fit for 55' package[53], including developing these assessments into national heat decarbonisation strategies. The importance of better coordinating the preparation of these comprehensive heating and cooling assessments for energy efficiency and renewable energy under the EED and REDII with the Long-term Building Renovation Strategies under the EPBD is more and more recognised and needs to be pursued further.

The coordinated preparation of Long Term Renovation Strategies (LTRS) and H&C assessments would ensure that the supply side of heating/cooling (energy production, capacities, technologies and infrastructures) and the demand side of heating/cooling (buildings technical H&C systems, building envelopes and enterprises/ factories equipment) are planned and developed together. Their integration into the Governance Process would ensure close coordination with financing, innovation, skills development, and market framework.

The expected growth in demand for cooling in the build environment should be carefully planned to ensure that the demand is met by supply based on renewable sources and while maximising system efficiencies. A better understanding of measures that can reduce cooling demand. Possibilities of passive cooling[54] should be exploited while improving the overall energy performance of the building, by making use of active building technologies (active shading, automation and control systems) should also be considered. Urban planning measures for climate adaptation at district level through, for example, the implementation of programs for heat reduction, or the reduction of glazing in buildings need to be considered.[55]

Infrastructure constitutes the backbone for the supply of carbon-neutral energy carriers in the H&C sector, except for some specific cases like biomass solids and liquids. Electricity, gas, DHC and hydrogen infrastructures are closely linked to the design of the decarbonisation pathway for the H&C sector and require integrated planning which should ensure the accessibility to infrastructure for all (see also the section on energy system integration).

Infrastructure planning should facilitate the integration of various energy carriers and arbitrate between the development of new infrastructure or re-purposing of existing ones. It should consider alternatives to network-based options, including demand-side solutions and storage.

The various components of the energy network will all need to evolve. Modern low-temperature district heating systems could be one of the key heat decarbonisation solutions, as they can connect local demand with often local renewable and waste energy sources, as well as the wider electric and gas grid, contributing to the optimisation of supply and demand across energy carriers.

The Regulation on Trans-European Networks in Energy (TEN-E) provides a framework for the selection of infrastructure projects of common interest in electricity, gas and $CO_2$ networks. In this context, currently, 10-Year Network Development Plans at national and EU levels are developed in parallel for gas and electricity by Transmission System Operators (TSO).

[53] A set of proposals and regulatory revisions proposed by the European Commission to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels..

[54] Passive cooling refers to using design choices to reduce heat gain and increase heat loss.

[55] Swiss Federal Laboratories for Materials Science and Technology (2021) Raisinf energy demand for cooling. Available at: https://www.sciencedaily.com/releases/2021/05/210518205457.htm

Future network planning will require a more integrated and cross-sectoral approach, notably considering infrastructure choices and complementarities between electricity, gas and DHC networks, and factoring in system integration benefits from connecting these networks. It will also require full consistency with climate and energy targets, including alignment with National Energy and Climate Plans, an adequate consideration of all relevant actors, and should be informed by local conditions.

Achieving full decarbonisation of the sector requires both clear goals and active policies to support the development of infrastructures for heating and cooling within the individual Member States' own contexts, on the EU level, as well as the local level. Policies for the decarbonisation of the H&C should be monitored periodically for compliance and changed or expanded if they do not have the desired level of results. A framework for expanding and establishing thermal infrastructure when this is the most cost-effective and viable option should be initiated by local governments in line with EU and national policies for gas and electricity grids.

It is key to involve local authorities and players in order to plan the distribution and delivery side. This planning should be carried out based on well-defined criteria to be tackled from a local perspective. Central coordination remains key in the process to ensure coherence and continuity.

### 3.2.3. Managing costs and financial challenges in the transition to decarbonised H&C systems

Higher costs, either related to higher upfront (capital) investment (for heating systems and higher energy performance buildings) or the higher variable costs related to new decarbonised energy carrier (e.g. renewable fuels of non-biological origins, such as e-methane) used are a key barrier for the deployment of renewable H&C solutions. In some cases, the variable costs of using carbon-neutral energy carriers such as renewable electricity are higher than those of fossil fuels like natural gas or heating oil, even when correcting for the fact that electric H&C solutions like heat pumps lower the overall energy consumption through their higher system efficiency. This highlights the need to align the prices of different energy carriers with climate objectives, which often involves changes in fiscal regimes and these should take into account the external (climate change related) costs that energy carriers incur.

In some cases, the total cost of ownership is already more favourable for renewable H&C solutions than their fossil-based counterparts due to high system efficiencies and relatively low variable costs, as illustrated in Figure 2-3. However, even in these cases high upfront costs and the split incentive[56] or 'landlord-tenant' problem can be a barrier for these renewable systems to be deployed. For households, this barrier can be addressed to a large extent through the provision of financial support, e.g. in the form of subsidies or cheap loans, while for the rental sector other policy instruments may be needed. A study by the United Kingdom's National Energy Agency[57], focused on the country estimates that depending on the chosen decarbonisation pathway, the average costs of heating per household could rise by between £200 and £800 per year. This, in turn, could accumulate to a difference in cost between £4.000 and £16.000 for the first and last households to convert to decarbonised heating over a 20-year period. Experience from different projects has shown that help to those unable to pay the high up-front costs of technology upgrades is more effective in the form of up-front capital support rather than ongoing payments.

[56] Split incentives describe a situation where the flow of investments and benefits associated with these investments are not properly distributed among the parties to a transaction, discouraging investment decisions.

[57] https://www.nea.org.uk/wp-content/uploads/2020/11/Heat-Decarbonisation-Report-2017.pdf

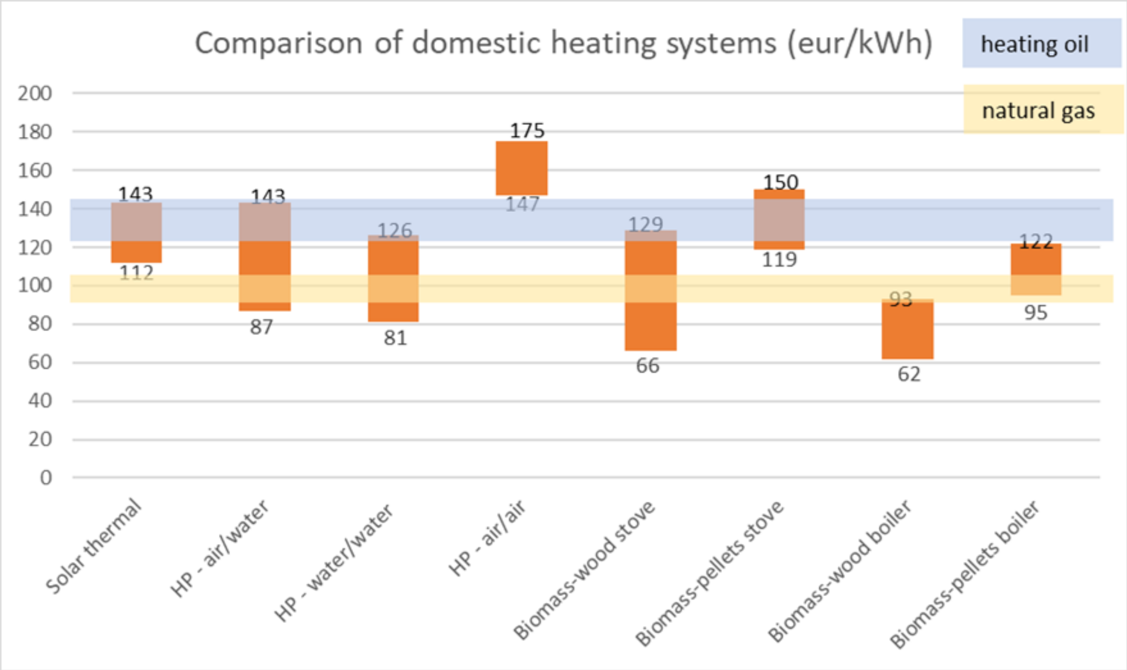


*Figure 2-3 Comparison of costs of individual heating systems in France. ADEME (2020)[58]*

Figure 2-3 provides a comparison of the cost of differenet heating systems in France. These costs may differ from one country to another, as they depend on local/national costs.

One of the other important aspects of addressing the costs involved with transitioning to renewable/carbon-neutral H&C systems in the built environment is the impact on low-income households. In many cases, such households use relatively old fossil-based H&C systems and those living in rented buildings are usually not in charge of the maintenance or replacement of the heating appliances because it is owned by the building owner. In such cases, increasing fossil fuel prices can increase the energy bills of these households, aggravating their financial situation, and increasing the risk of energy poverty; such households also have limited possibilities for shifting to renewable alternatives. Therefore, to ensure a just transition, it is important that specific policies are implemented to support the shift of these low-income households to sustainable H&C systems.

### 3.2.4. Energy Market frameworks

The progressive increase of renewable and carbon-neutral carriers in the energy system, including in the H&C sector, will require the re-design of electricity and gas markets. The penetration of these energy carriers also implies a higher share of variable renewable energy in the system and will require further energy system integration (discussed in the following section) to maximise efficiency and minimise energy losses. Technologies such as CHP link electricity and heat and fuel markets on the supply side whereas heat pumps and electrolysers can link the electricity and heat and fuel markets on the demand side. Thus, the increased integration across energy carriers should also imply the need for analysis of the energy markets based on a coherent understanding of the electricity market, gas and liquid markets and heat market. In this regard, recent studies have shown, through modelling, the price influence of electricity and heating markets on gas and liquid fuel markets and vice versa. Additional research underlines the benefits of a hybrid, multi-energy day-ahead market, which would eliminate the need for price forecasting in parallel markets, would allow for the use of flexibility from one carrier to balance another, and increase optimality of the market.

[58] Own elaboration based on ADEME (2020), Coûts des énergies renouvelables et de récupération (data 2019). https://www.geothermies.fr/sites/default/files/inline-files/ADEME_couts-energies-renouvelables-et-recuperation-donnees-2019-010895.pdf

Heat markets are currently not as developed as electricity markets. One of the difficulties is that even though the final users need heat as a final energy service, different types of H&C supply systems operate in completely different markets due to the different energy carriers used. Consequently, it is very complex for consumers to easily compare different H&C options with one another. Heat purchase agreements (HPAs) can be an important tool to support the creation of heat markets. Unsurprisingly, heat purchase agreements are currently used much less frequently than power purchase agreements (PPAs). Although supplies of heat (or cooling) are similar in many respects to other utility type supplies, in heat networks there is a key difference, namely that the customer's use of the energy supplied has a significant effect on the overall operational efficiency of the network. This is reflected in how heat purchase agreements and their tariffs are structured.  Recently, innovative examples to incentivise heat markets have been developed. For example, a recent study shows that a business model based on heat purchase agreements could be used to lower the barriers to heat pump adoption associated with their high upfront costs. The study is the first to consider economic analysis of heat purchase agreements as a third-party ownership model for electric heat pumps.  Such new business models for efficient heat pumps significantly reduces or even eliminates (depending on the scheme design) the user's initial cost. If appropriately designed, the business model could also include provisions enabling the access to wholesale electricity markets and services, decreasing the fuel-costs (or adding some revenues), and facilitating the integration of renewable generation into the power system. Bristol Energy developed a scheme combining a renewable heat purchase agreement and a "heat as a service" instrument. Combining the purchase agreement with a "heat as a service" was shown to increase the attractiveness of renewable heat for consumers by up to 85%. Consumers are more willing to switch to renewables when the provider can guarantee the desired level of comfort for a predetermined price acceptable to the consumers.

Competitive markets should ensure a level playing field across all energy carriers, considering direct and indirect incentives and disincentives, among which energy taxes are key determinant. Energy taxes account for a significant share of the final prices of energy and vary across consumers (industry vs. households), energy products (e.g. electricity vs. gas) and across Member States. For households, they accounted for an average of 40% of the electricity price, 25% of the gas price, and 31% of the heating oil price in 2017. Electricity, gas, and oil products are taxed at very different rates across Member States, which does not necessarily reflect the energy content (which was one of the recommendations of the Energy Taxation Directive) and are not adapted to the decarbonisation goals of the complete energy system. The current taxation framework provides indirect incentives to fossil fuels' use in the form of tax benefits. A large share of these tax benefits comes from tax reductions for fossil fuels used as heating fuels granted mainly under the Energy Taxation Directive, which is currently being revised through the 'Fit for 55' package.

### 3.2.5. Consumers' choice

Public acceptance is key for achieving climate neutrality as decarbonisation policies directly and indirectly affect our way of life. Therefore, the way consumers are making their choices is of paramount importance. Cost remains the main decision factor for most consumers when it comes to upgrading their heating system. In this light, it is key that the situation where fossil fuel prices increase due to policy while building owners do not have the (financial, legal or technical) possibility to switch to low-emission alternatives, needs to be avoided. Therefore, it is important that policies aimed at levelising the playing field of fossil and renewable energy carriers (e.g. reforms of taxes and levies) are complemented with policies aimed at removing the barriers for switching to renewable H&C systems.

Consumer choice is also directly linked to behaviors (e.g. how a building occupier uses its appiances) and cultural dimensions (e.g. the way people would perceive and establish relationship with the use of biomass for energy purposes) which are key to consider when setting up appropriate policy packages. However, this study/roadmap is more focused on 'hardware' components of the decarbonisation of H&C; soft aspects are beyond its scope.

## 3.3. Energy System Integration building blocks

Sector integration and smart operation of electric heating systems, combined and integrated with thermal storage, as well as local renewable power generation and storage and smart integration of EV charging and storage capacity, will be key to ensure energy efficiency and demand-side flexibility. This in turn will increase grid stability and reduce the investment needs for grid reinforcements.

The evolution of the European energy mix towards a more intermittent and decentralised electricity mix requires the transformation of the energy system, production, end-uses, and infrastructure, to adapt to the challenges at the lowest possible cost. A triple transformation will be required on the production side (providing flexible and dispatchable energy production and storage capacities), at the demand side (absorbing the electricity production when available, by means of electrification and demand flexibility), and at the infrastructure side (balancing production and demand, at all times, from milliseconds to longer timescales, e.g. the coldest wave happening twice a century). A move towards electrification requires an increase in renewable electricity generation capacity, which should ideally be based on the additionality principle[59]. It also carries a risk of black-out (if demand is greater than the system capacity) and the risk of over-reinforcing the electricity grid to cover peak demand if the pace of flexible solutions deployment is slower than the pace of electrification. This would lead to inefficient investments in infrastructure with very low utilisation rates (when demand decreases and/or flexibility increases).

System coupling at production and consumption levels helps mitigate these risks. Flexibility is provided at the production level,by means of Power-to-Gas  (efficient solution for seasonal storage) and Thermal Energy Storage. At the consumption level, flexibility is provided by demand response, but also by hybrid heating solutions, such as hybrid heat pumps, enabling switching from electricity to gas according to the constraints existing on the electricity system, whatever the duration required.

The combination of electrification via hybridisation and thermal renovation can lead to a strong reduction of gas demand in buildings if properly planned, which could possibly represent only a small fraction of the current gas consumption in 2050. This would of course depend on the biogas (and electricity-based gases) potential at local and global levels. The near 100% building flexibility brought by hybrid systems could still be of use in a fully decarbonised society, to respond to production intermittency, and to ensure system resilience. However, its cost effectiveness should be assessed using local parameters.

Also, building automation and control systems (BACS) in all building sizes, when mainstreamed in buildings, would leverage the potential for energy savings, and the capacity of buildings to provide smart and flexible solutions to the energy system by optimising sector integration. BACS ensure that the whole building works at the highest level of energy efficiency, monitors and provides feedback encouraging occupants to use less energy, manages load shifting and storage capacity of a building to optimize on-site renewable self-consumption and to increase grid stability and ensure that equipment only operates when, where and to the extent that is actually required. The remainder of this section addresses three main pillars of energy system integration, or system coupling:

- Direct electrification, especially via heat pumps;
- Renewable fuels of biological origin, in the form of solid, gaseous (to replace natural gas) and liquid (to replace heating oil e.g.) fuels;

[59] Additionality could be defined as the requirement that renewables-based electricity used in electrolysers for the production of renewable hydrogen is additional to the renewables-based electricity, which is used to meet the renewable penetration target with respect to final electricity consumption.

- Renewable fuels of non biological origin (RFNBOs), such as renewable hydrogen produced with renewable electricity, and its derived products like e-gases[60] or e-liquids[61] ;

### 3.3.1. Direct electrification of heating systems

The direct use of electricity in heat pumps and power-to-heat systems is bound to grow strongly in the coming decades along with electrification solutions in other sectors such as transport due to the increasingly competitive prices of renewable electricity production (solar and wind). According to the 1.5TECH and 1.5LIFE scenarios of the EU Long-Term Strategy (LTS) as we approach climate neutrality by 2050, electricity demand is will increase significantly, with the share in total final energy consumption growing from 23% today to 30% in 2030, and 50% by 2050.

Heat pumps are a central technology when it comes to the electrification of heat supply. Since heat pumps do not generate heat from electricity, but rather transfer ambient and geothermal energy from the environment, these systems are highly energy efficient. As such, deployment of heat pumps does not only facilitate higher renewable electricity use but it can also greatly enhance end-use energy efficiency. Heat pump technologies can extract heat from different sources: air source, ground source, water source, waste heat. Each of them has their merits and advantages and disadvantages. Heat pumps are most efficient when the temperature difference between the heat source (from where the heat is transferred) and heat sink (where to the heat is transferred) is not too high and as such the largest potential for this technology lies in the built environment, although they can also be used for low-temperature industrial applications.

One of the challenges with large-scale heat pump (e.g. for DHC) deployment is the impact that these systems can have on electricity infrastructure. However, this impact would also happen with large-scale deployment of small individual heat pumps. Heat demand is typically much larger than the common electricity demand in buildings (except in the case of a very efficient building), and as such electricity distribution grids may face challenges in providing peak capacity when high heat pump penetrations in neighbourhoods occur, depending on the local grid. Also, large-scale deployment of heat pumps and other electric heating technologies can strongly increase electricity peak demand, especially in wintertime. Therefore, to limit the amount of peak electricity generation capacity and transmission and distribution capacity, smart operation of electric heating systems integrated with thermal and other energy storage solutions will be key to ensure energy efficiency and system cost efficiency, and to deferring avoiding electricity network upgrades. This requires heat and infrastructure planning to be coordinated with electricity planning, but also planning building performance improvements via renovation programmes and related policies (cf. section 2.2.2 on coordinated planning).

Today, small-scale electricity consumers, such as households and SMEs are not systematically incentivised to adjust their consumption patterns to the developments in the electricity market. In order to protect consumers, the balancing responsibilities relating to the electricity use of small consumers are borne by suppliers. Even though full exposure of consumers to realistic electricity prices is not desirable, as many consumers will not have sufficient knowledge nor the willingness to actively operate on the electricity market, the possibility for consumers to benefit from providing flexibility could be a valuable way forward. A Smart Readiness Indicator could facilitate consumers in providing flexibility. Likely, the flexible management of electric loads in the residential and small-consumer sphere could be taken up by energy service companies (ESCOs) and/or aggregators. In such cases, the company would provide heat to its customers through the operation of a smart heat pump reacting to price signals, while the collective management and operation of a pool of heat

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[60] E.g. synthetic methane

[61] E.g. liquefied hydrogen, ammonia, methanol, liquid organic hydrogen carrier (LOHC), or Fischer Tropsch e-kerosene, e-diesel, e-gasoline

pumps would ensure they are operated efficiently and cheaply, which could bring financial benefits to consumers.

In industrial and DH applications, large-scale electric boilers can be deployed in times of high renewable electricity supply (low prices) and especially when combined with high-temperature heat storage technologies, such systems can make a significant contribution to the decarbonisation of industrial and DH demand. To make optimal use of such solutions, it is important that companies that apply them are also remunerated for the benefits they bring to system flexibility and stability.

For all electric H&C systems, a sufficiently high renewable or carbon-neutral electricity share is a prerequisite to ensure the GHG emission benefits of deploying these systems. As such, strategies focused on electrification should always ensure sufficient growth in renewable electricity supply takes place simultaneously.

### 3.3.2. Renewable fuels of biological origin

Bioenergy is an important renewable energy source in Europe, currently representing almost 84% of the total renewable energy consumed, and ~80% in the H&C sector.[62] In several EU Member States, bioenergy is a prominent energy source for heating in the built environment as well as in some industrial applications. In Scandinavia, the Baltics, Portugal, Greece and Austria, biobased energy carriers cover a significant part of the final energy demand in households and the tertiary sector.[63] In many cases this involves the use of (fuel)wood in conventional wood stoves or the use of wood pellets. Next to solid biofuels (wood), gaseous biofuels can also play an important role in the decarbonisation of heating. Lastly, even though a rather expensive solution , liquid biofuels can be used to decarbonise heating using oil-fired boilers, but possibly in a limited number of cases .

Biomass energy sources come from agriculture (e.g. crops and by-products), organic waste streams (e.g. from households, economic activities and industry) and forestry by-products. Agricultural biomass is expected to have a prominent role in the future energy mix in European and international scenarios, and aquacultural biomass is also receiving increasing interest in R&D even though the costs of this resource are still inhibitively high.

Even though biomass is a versatile energy source, easily storable, flexible in its use, it is also associated with significant sustainability concerns. When improperly sourced, the production of biomass for energy purposes can contribute to biodiversity loss through (indirect) land use change and improper use of forest biomass can also have a negative impact on climate change. Therefore, sustainable biomass sourcing is an essential element for bioenergy to make a valuable contribution to Europe’s climate and environmental objectives. Consequently, small-scale bioenergy use based on local/regional resources seems to be one of the most promising ways forward, as trade-offs between bioenergy benefits and negative biodiversity, land-use change and other environmental impacts tend to increase with the scale at which bioenergy is deployed. Next to sustainability concerns related to biomass resourcing, bioenergy installations in populated areas, if not properly managed, especially small-scale systems and households, can negatively impact human health through air pollution. To conclude, the expectation of using biomass to produce energy should not be considered in isolation, but should take into account the entire EU and even global bio-economy and use of the resource, limiting to what is strictly available and sustainable.

Heating of buildings using solid biomass is often done using conventional inefficient fire stoves, although, as for any other technology, the performance of individual stoves and boilers has progressed noticeably over the last years/decades. Due to the large number of inefficient systems remaining, a significant share of the heat that is produced is lost to the environment.

[62] Bioenergy Europe (2021) Bioheat: a future-proof solution to achieve the Fit for 55 objectives.
[63] EUROSTAT (2021) Complete energy balances.

This means that replacement of such equipment with new efficient systems and modern bioheat installations can free-up significant volumes of existing biomass consumption for the heating of additional buildings, even without increasing the total volume of biomass consumed. Simultaneously, the replacement of old equipment with new systems can reduce other negative environmental impacts, such as the emission of fine particles, carbon monoxide and black carbon.

On top of large-scale systems (for industry and district heating), individual heating solutions will remain important in areas where connection to the grid is difficult and district heating is not available or complicated to deploy. It will also offer an option for backup used in combination with other renewables such as solar thermal taking full advantage of the synergies offered by hybrid systems, providing  flexibility, and allowing to choose the most suitable set up for the heat needs.

Biobased gases can to a limited extent be used to substitute the existing use of natural gas for heating via boilers or CHP (and as feedstock). Biogas is produced mainly through anaerobic digestion of plant by-products (e.g. from harvesting or garden activities), animal by-products (mostly manure), biowaste from households, industrial & commercial organic waste, sewage sludge (the organic matter obtained from waste water), or energy crops. Biogas is a mixture of methane ($CH_4$), carbon dioxide ($CO_2$) and small quantities of other gases. The methane content of biogas typically ranges from 50% to 70% by volume.[64] Mostly, the gas is used on-site either in CHP installations or in gas boilers. Another, increasingly relevant option is to purify the methane from the biogas to obtain biomethane in a process called upgrading. This biomethane can then be transported though the natural gas network and be used in conventional gas-fired boilers, furnaces or CHP installations. The production of biogas also allows the production of high value fertilisers (digestate) that could theoretically replace mineral fertilisers (which are energy intensive).

One of the places where bioenergy can provide a solution for decarbonising the heat supply is in district heating. In such systems, the fossil-based heat source can be replaced by a CHP or boiler using biogas or biomethane or even syngas derived from the gasification of solid biomass. However, due to the above mentioned constraints to the availability of sustainable biomass, biogas should ideally mainly be used in combination with other renewable heat sources in DHC. Also, large scale use of bioenergy in DHC raises concerns of sustainability and availability as mentioned previously and therefore stresses the importance to diversify away from large scale. A more efficient use of the limited resources comes also with increased boiler's efficiency. In some MS, public acceptance with the use of large bioenergy boilers in DH decreases due to sustainability considerations.

Some studies have made scenarios for very strong upscaling of biogas and biomethane production,  but those need to be backstopped by national or even local potential assessment, as the available feedstock can be complex to assess. Therefore, it is important to note that the potential for biogas/biomethane production in Europe will be largely insufficient to completely substitute the existing natural gas demand for heating. This means that a large part of the existing stock of natural gas-fired heating equipment will need to be replaced by non-gas based systems (see section on fossil fuels phasing out). Renovations aimed at improving the energy performance of buildings can reduce the energy demand per building and as such increase the number of buildings that can use biomethane for heating.

The advantage of biomethane is that due to the fact that it has a very similar composition to natural gas, its transport does not require adjustments to the gas networks. However, due to a temporal mismatch between biomethane production and gas demand the limited storage capacity of distribution grids currently forms a barrier for biomethane injection (especially in summertime). Investments in gas distribution grids are therefore needed in some areas to facilitate higher biomethane injection levels and bi-directional gas flows (e.g. allowing gas to go from the distribution to the transmission level).

[64] IRENA (2018) Biogas for road vehicles – Technology brief. https://www.irena.org/-/media/files/irena/agency/publication/2017/mar/irena_biogas_for_road_vehicles_2017.pdf

### 3.3.3. Renewable fuels of non-biological origin

During the last few years, the attention in the renewable energy debates broadened from a focus on renewable electricity to a wider range of renewable energy carriers, where the importance of "green molecules" has been emphasised by many players. Within this debate, there is a growing support for the idea that renewable (and carbon-neutral) hydrogen and its derived synthetic fuels/E-fuels will play a substantial role in the future energy system. Even though a role of these renewable fuels of non-biological origin (RFNBOs) will undoubtedly have a place in the transition to an emission-free energy system, an important (and still controversial) issue is the role that these energy carriers will play in the decarbonisation of heating and cooling, especially in the building sector.

RFNBOs are mostly produced from hydrogen, which can be obtained through different routes. Acknowledging the importance of hydrogen in the EU's energy transition, the European Commission published its hydrogen strategy in 2020[65], which distinguishes three different forms of hydrogen other than the common fossil based "grey" hydrogen, namely:

- Electricity-based hydrogen' refers to hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), regardless of the electricity source. The full life-cycle greenhouse gas emissions of the production depend on the electricity mix;
- 'Renewable hydrogen' is produced through the electrolysis of water (in an electrolyser powered by renewable electricity), or from biogenic sources (in that case it's not a RFNBO)
- 'Fossil-based hydrogen with carbon capture' often referred to as blue hydrogen is a subpart of fossil-based hydrogen, but where greenhouse gases generated as part of the hydrogen production process are captured. The GHG emissions of the production of fossil-based hydrogen with carbon capture or pyrolysis are lower than for fossil-fuel based hydrogen;

In the short term, the main challenge for large scale use of renewable hydrogen is its high cost, which are mostly due to high electricity prices and electrolyser costs. Therefore, several countries and private stakeholders see fossil-based hydrogen with carbon capture and storage as an important stepping stone to kickstart hydrogen market development. The rate at which the costs for renewable hydrogen production will come down will depend strongly on the pace at which renewable electricity generation capacity will grow and the impact this will have on electricity prices. Furthermore, it will also depend on the rate at which water electrolysers for hydrogen production will be deployed in the coming years, which will determine the pace of technology development and as a consequence the costs of the technology. In the meantime, many EU countries have announced hydrogen-related plans as part of their energy and climate policies and the global pipeline of hydrogen projects that are planned between now and 2030 amounts to a total investment value of US$ 500 billion, where Europe leads with a planned investment of US$ 130 billion (€ 111 billion). Within this pipeline, 359 large-scale projects were announced during the first half of 2021.[66]

Hydrogen is a versatile energy carrier and can be used in a wide variety of applications and sectors. In the short and medium term, hydrogen is expected to play an especially important role in the decarbonisation of energy-intensive industries, particularly in the fertilizers sector and in steelmaking, but also in heavy-duty transport applications as well as maritime transport

[65] COM(2020) 301 final - A hydrogen strategy for a climate-neutral Europe – https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

[66] Hydrogen Council (2021) Hydrogen investment pipeline grows to $500 billion in response to government commitments to deep decarbonisation. https://hydrogencouncil.com/en/hydrogen-insights-updates-july2021/ Last retrieved: 17-12-2021

and aviation. Hydrogen can also be used for heating (in gas-fired boilers) but for the time being this seems to be a costly solution and because of this several societal groups have spoken out against this solution. While the European Commission Hydrogen Strategy[67] recognises the potential of hydrogen in residential and commercial buildings, notably via local hydrogen clusters (or hydrogen valleys), the European Commission for Energy System Integration Strategy[68] states that hydrogen is best used in hard-to-decarbonise sectors, where there are no other solutions, such as the aviation and maritime sectors. On the one hand, this has to do with the availability of rather efficient alternatives (e.g. heat pumps) and the high costs of hydrogen (especially on the short and mid-term). In the long-term the attractiveness of the direct use of hydrogen for heating in the built environment will depend strongly on price developments, which are also linked to the availability of cheap hydrogen imports from other parts of the world. The cost estimates of renewable and decarbonised fuels show different ranges, with important organisations foreseeing a quick downward development. Several ongoing projects demonstrate that the deployment of hydrogen in heating applications could be an option and that some initiatives could be replicated.

For countries with substantial natural gas consumption and expansive natural gas infrastructure, hydrogen is often seen as an opportunity to sustain the use of these assets. In some cases, large gas storage facilities also offer opportunities for seasonal energy storage in the form of hydrogen. Even though the use of existing gas infrastructure (after conversion) for the transport, distribution and storage of hydrogen can be an attractive element of the future energy system in some EU Member States, this still does not mean that hydrogen could substitute all existing natural gas demand. Some studies also showed that despite the associated energy losses, hydrogen can be an attractive long-term energy storage medium, and possibly regenerate power, even in winter depending on the needs.

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[67] COM(2020) 301 final - A hydrogen strategy for a climate-neutral Europe –

[68] COM(2020) 299 final – Powering a climate-neutral economy: An EU Strategy for Energy System Integration - https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0299&from=EN

# 4. H&C decarbonisation roadmap

## 4.1. Barriers hampering H&C decarbonisation

Renewable and energy efficient H&C faces multiple barriers to compete with established H&C technologies and practices. Barriers can be divided into policy, economic/market, financial, capacity, technical, administrative, and regulatory categories. These sets of barriers are important and often interact thereby hindering consumers and industrial players in opting for renewable H&C solutions and energy efficiency investments.

When setting up policy responses, these barriers should be addressed in a coherent way, ensuring they do not jeopardise a complete long-term decarbonisation via lock-ins, avoid the duplication of efforts and prevent that the removal of one barrier worsens another.

**Policy barriers** correspond to those overarching barriers related to the lack of a clear H&C decarbonisation vision and concrete objectives and incentives. Those are mainly addressed by establishing appropriate planning in a coordinated and integrated way and based on specific pathways. The lack of a vision can be caused by the uncertainties surrounding the future role of different fuels and technologies, the need for new or repurposed infrastructure, the evolution of the demand impacting the supply side (e.g. energy efficiency in buildings and industry), the weak understanding of the interactions between all energy system components (incl. infrastructure), or the availability of carbon-neutral heat sources.

Among the **market barriers**, renewable heating and cooling systems are generally not as cost-competitive as fossil fuel-based systems, even though their total cost of ownership (TCO) is often lower. This lack of level playing field is often due to failure of the market to internalise external costs, and the low cost of fossil-based fuels, which are delivered via fully amortised infrastructures (e.g. gas) and mass produced technologies with decades long cost reduction and direct and indirect price subsidies (still ongoing in many cases). Ensuring a level playing field for renewable H&C technologies and solutions thus cannot be seen in isolation from the regulatory and fiscal frameworks (across EU, natural gas is the main incumbent heating fuel in both industry and buildings). In some cases, renewable and carbon-neutral H&C options are already competitive with the incumbent technologies, but are still rarely deployed due to high upfront investment needs, higher cost of capital given the higher risk perception, opportunity cost due to availability of investment opportunities with higher returns, the reduced certainty over long-term profitability of renewable solutions compared to fossil heating, the lack of access to affordable finance (especially for low-income households), or lack of qualified companies and workers with the right capacity and expertise to install and operate renewable H&C technologies. In the early stage of market growth, developing supply chains and new infrastructure can lead to higher system costs (e.g. district heating deployment costs); these costs have already been paid for and amortised for fossil fuels (e.g. gas).

**Financial barriers** are closely linked to market barriers, but should be addressed separately and with a dedicated focus. Financial bottlenecks can be linked to incoherent incentive schemes and unsecure conditions for investors due to regular changes (lack of a global decarbonisation strategy), to split incentives in the rented sector (building owners are supposed to invest, but the tenant benefits in bill savings), or the lack of economies of scale resulting in higher transaction costs.

**Capacity barriers** encompass a broad set of “capacities”, such as awareness, knowledge and understanding of policymakers, technical and economic skills of installers, planners, architects, construction workers and operators. These barriers mainly concern the lack of awareness due to irrelevant or difficult to find information (e.g. uncertainties concerning the best point in time for changing heating technologies, or established, well-developed supply chains for mainstream, often fossil-based H&C technologies, hinder the development of emerging solutions and technologies) or due to behaviours or consumer preferences (e.g. lack of interest of households, heating system installers, construction players, policymakers, building owners and lenders). They are also linked to the lack of confidence in renewable heating, making it harder for the consumer to choose (e.g. perception of renewable systems as inferior in terms of user comfort, exacerbated by failures of previous poorly designed/installed systems, uncertainties concerning reliability of technologies or noise, lack of adequate product standards and clear information promoting efficient systems) or in DHC (e.g. limitation of freedom to choose technology for heating and cooling in own property, limited transparency, DHC construction leads to disturbance). The lack of trained installers and workforce for design/specification, manufacturing, installation and O&M (requiring higher expertise) are also important barriers. The lack of heat data at end-use installation level to select the most adequate option and on the local level to support H&C decarbonisation planning and technological choices on a larger scale also count as important barriers. Finally, the lack of capacity and knowledge of local players, especially authorities, may jeopardise integrated planning and engagement of the concerned actors.

**Technical barriers** encompass infrastructure barriers, local constraints, building conditions, process requirements. In buildings, e.g., not all renewable H&C options may be suitable due to technical constraints (e.g. underfloor heating or heat pumps require low heating needs given the low temperature operation, biomass fuel storage requires space, Photovoltaic (PV) on roofs requires space and orientation), low energy efficiency in building results in reducing system efficiency, limited space in densely populated areas (a challenge to install ground source heat pumps, solar thermal collectors, store bio-energy, or install renewable heat generation for DHC). Users may be discouraged from undertaking deep renovations in their dwellings because of the disruptions associated with it, reducing the window of opportunity for undertaking the renovation. Biomass, which is often the most convenient or even the only renewable source (gaseous or solid), may face sustainability and availability constraints and growing public acceptance issues (see section 2.2.1 and 2.3.2). Additional electricity demand may require reinforcement of the electricity network at both the distribution and the transmission levels. Energy system integration, and especially electrification (e.g. in some industrial processes, electrification technologies may remain immature) is still at its infancy, with limited view on the consequences on the system (e.g. network constraints).

The relative importance of the aforementioned barriers varies between countries, sectors and specific renewable H&C applications. Some of these barriers may become hard constraints and will influence the choice of H&C decarbonisation pathway, by focusing on some renewable options while avoiding others. Strategic heating and cooling decarbonisation planning is essential to adequately identify and overcome the existing barriers in the sector.

## 4.2. Key policy approaches addressing the barriers

The lack of a clear H&C decarbonisation vision, specific goals and strategy can be addressed by establishing integrated H&C planning. Depending on the progress made by an authority, and on the existing framework, such H&C planning may require dedicating considerable resources (knowledge, expertise and data , etc.) and time.

Even before completing the strategis planning process, which can be iterative, several measures can be taken without delay to continue and even strengthen existing policies, to get prepared for a long-term H&C decarbonisation process, and to source investment. Some barriers can be addressed without awaiting for the complete long-term vision and plan to be ready for implementation. The following recommendations focus on the most immediate policy measures and are no-regret options, paying attention to the risk of lock-in effect, and the need to carefully avoid taking an inadequate direction to reach carbon neutrality by 2050.

NOTE: all these policy measures are examples of good practices, they do not constitute a comprehensive set of options guaranteeing a smooth and affordable decarbonisation. A tailored and adapted selection is required to complement existing policy frameworks.

### 4.2.1. Addressing policy barriers

Immediate policy actions should ideally be designed in consideration of the following main principles:

- The building sector, to overcome all (non-price) barriers to renovation and decarbonisation, and to reach targeted groups (owners/landlords, tenants, low-income households), requires a comprehensive and integrated package of regulation and support measures at EU, national and local levels. All are related and should operate in synergy to achieve the common goal;
- Stability is essential for a vision to materialise, to secure investments and long-term developments. Changing the ambition, the direction and associated measures too often compromises the final goal and creates stop and go;
- Important measures may require long lead times from announcement to enforcement, and additional time for mass market results;
- Making the right infrastructure choices is important. There should be an assessment of where the most effort and invesment should be based: on electricity, district heating, or alternative and gas infrastructures.
- Keeping the existing infrastructure as a backbone may not always be the best option, leading to lock-in effect; therefore thinking beyond existing infrastructure should start as soon as possible:
    - Regarding the gas infrastructure, it is reasonable to stop further expansion of gas grids to avoid useless infrastructure and possibly stranded assets as alternatives to gas-fuelled systems exist (e.g. heat pumps, solid or liquids bioenergy heaters, …) and the potential for renewable gas is likely to be already lower than the existing natural gas demand. Secondly, where alternatives are available, affordable, and can easily be deployed (e.g. electricity network with enough capacity to cover the peak need of large heat pump deployment, or when DHC can be deployed), it should be considered that some parts of the gas network may be dismantled. Furthermore, in specific cases, retrofitting gas to hydrogen pipelines may be considered, especially when it comes to industrial gas networks.
    - Regarding electricity infrastructure, in addition to the electricity grid and market challenges (e.g. deploying flexible assets, decentralised renewable production, …), a massive deployment of heat pumps should not lead to heavy and costly grid reinforcement if alternatives are available that lead to a lower overall system cost, and can easily be deployed (e.g. enough resources to produce biomethane, or synthetic natural gas being produced at an affordable cost).
- A progressive fossil fuel phase out should be in focus, even via differentiated approaches (e.g. focus on certain sources first, on certain buildings segments or on certain districts);
- Distributional impacts should be addressed through public funding of building renovation and renewable and carbon neutral H&C system installation amongst households that face energy poverty, low-income and vulnerable households;

These main principles of H&C decarbonisation could be embedded in a legal framework, such as in a Heat Act, Climate Act, Renovation Pact, or equivalent, with the aim of: achieving GHG targets; internalising externalities; fixing rules for the use of renewable resources to segment markets; recognising adequate technologies; emphasising the need for further RD&I; engaging all decision levels in a coordinated planning; ensuring the appropriate mainstreaming of energy infrastructure planning in the concerned legal framework; recalling the urgent need to stop any kind of fossil subsidy; and/or mainstreaming digitalisation in the decarbonisation of H&C. Some best practices include:

- Climate Agreement (Netherlands) - Ministerie van Economische Zaken en Klimaat 2019;
- French strategy for energy and climate - Ministère de la transition écologique et solidaire 2018 ;

Defining clear targets and objectives for decarbonising the H&C sector and for the deployment of renewable H&C is of critical importance in any legal framework or decarbonisation plan. Equally important is the putting in place of measures to reach those objectives and targets. These targets and objects must be realistic and provide a coherent and stable policy and regulatory framework, ensuring predictability for consumers, security for investors, and stability for financial institutions. Achieving the target will depend on the effective implementation of the policy measures, including the ability of those measures to tackle existing barriers.

The following table summarises examples of immediate policy areas to address barriers, focusing on no-regret options. It is important to note that these examples do not constitute a comprehensive set of complementary policy measures; such a set should be developed on case by case basis (incrementally).

| Main policy area | Examples of concrete policy measures |
|---|---|
| **Phasing out of fossil fuels use** | Phase-out regulations for gas and liquid boilers for new buildings, by a predefined date (e.g. 2025) {at EU and national level}[69];<br>Prohibit selling gas and liquid boilers in buildings with sufficiently high energy performance (or when the potential to reach such high performance exists, based on a Building Renovation Passport), by a predefined date, if affordable alternatives are available and if there is no evidence renewable-based gases and liquids will be produced in sufficient quantities {at the national level};<br><br>Deploy Building Renovation Passports encompassing the supply of energy through 100% renewable and/or waste heat/cold recovery, based on building insulation potential {at the national level} |
| **Manage urgent Heating System replacements** | Incentivising replacement of existing H&C systems by renewable systems in time so that urgent replacement is prevented (e.g. via Building Renovation Passports). This could for example be done by giving additional financial incentives like grants for the anticipated of current, functioning heating systems (retrofits) older than 20 years. Measures should make sure that the H&C system and the energy performance of the building are addressed simultaneously so that the deployment of long-term solutions is enabled/facilitated {at the national level}. |
| **Stop supporting fossil energy** | Phase out all subsidies and grants for fossil based heating and cooling systems (e.g. oil, gas condensing boilers or hybrid heating using fossil energy), and revert them to support alternative renewable heat options, waste heat and energy efficiency {at the national level};<br>Replace all support to fossil energy/sources (e.g. support to low income households for their yearly heating oil bill) by alternative support to their energy bill (e.g. prioritised renovation) {at national level}. |
| **Establish a level playing field** | Introduce a gradual and measured carbon pricing for the fuels used in building, providing a long-term vision and stability; depends on the expansion of the ETS to the building sector {at national level};<br>Reform fiscal systems to ensure that tax levels and levies on different energy carriers reflect the differences in GHG emissions intensities and incentivise the use of the least carbon-intense energy carriers {at EU but especially at national level};<br>Creating lower tariff for electricity fed in energy efficiency equipment with low GHG emissions (e.g. heat pumps) {at national and regional level}.<br>Creating stimulating schemes (quota, support, …) for renewable-based gas or liquid use in energy efficient heating systems {at national and local level} |

[69] When applicable, we indicate the  intended level of government which we identify as most suitable to adress the policy measure listed. The level(s) of govermet are indicated beween {} brackets.

| Main policy area | Examples of concrete policy measures |
|---|---|
| **Improve District Heating & Cooling performance** | Establish clear timelines and plans to decarbonise existing DHC systems, providing support where required, and imposing milestones to reach full decarbonisation by 2050 {at national and local level};<br><br>Establish policies and regulations that protect DHC consumers and prevent negative impacts of (monopolistic) market power of suppliers {at national and local level, with EU guidance};<br><br>Promote the development of efficient renewable energy based DHC networks with multiple renewable and carbon-neutral energy sources (incl. as waste heat recovery) and technologies and facilitate / support the access of new entrants {at national and local level}; |
| **Planning Heating and Cooling** | Ensure national long-term renovation strategy (LTRS, EPBD article 2a[70]) instruments and incentives like subsidies or support schemes, or norms (like Minimum Energy Performance Standards) have integrated energy supply and its decarbonisation (e.g. link deep renovation to the replacement of the heating system by renewable systems), to switch to carbon-neutral/renewable heating systems {at national level};<br>Given that most MSs are not implementing their LTRSs (EPBD Art. 2a) quickly enough, ensure adequate financing of all LTRS instruments[71], in line with the ambition and targets {at national level};<br>Ensure proper coordination between all plans and strategies (e.g. national comprehensive heating and cooling assessments under article 14 of EED and article 15(7) of REDII, renewable action plans, NECP, LTRS, …) {at national and local level};<br>Make heating and cooling planning a requirement and empower the concerned authorities and actors {at EU & national level}; |
| **Develop a bioenergy strategy, fully integrated in the bioeconomy policy framework, and streamlining sustainability** | Such a bioenergy strategy should be built on the following main principles<br>○ Sustainability of used biomass and other (renewable) fuels must be guaranteed. The same sustainability approach should apply to all fuels, especially fossil fuels {at national level};<br>○ Incentivise anticipated replacement of inefficient bioenergy H&C systems to increasing efficiency, e.g. by giving financial incentives like grants for the anticipated replacement of heating systems older than 20 years {at national and local level};<br>○ Research projects are needed to assess the extent to which concepts to sustainably produce low ILUC risk biogas crops through double cropping can be scaled up {at national level};<br>○ Clear guidelines, piloting, and support incentives will be required for sustainable sequential cropping {at national and local level};<br>○ Ensure that bioenergy potential and growth take into account competing biomass uses to guarantee the anticipated resources will be available and coordinate such planning at the inter-regional level and with neighbouring countries.<br>○ The implementation of the new Circular Economy Action Plan and waste legislation and sustainable agriculture and forestry management systems could result in increased sustainable production of bioenergy from wastewater, waste and residues[72]<br><br>Think about the geographic location of bioenergy in the entire economy, considering all other uses (especially bio-materials) and services provided by the same resource;<br>Possibly create distinctions between biomass types or categories to design their appropriate use (contaminated vs non-contaminated), between applications (easy to replace or hard to abate), and between technologies (combustion vs gasification) {at national level};<br><br>Require complementary and alternative solutions that can support reducing biomass use for energy purposes where possible {at national level}; |

[70] Article 2a of the EPBD stipulates that "Each Member State shall establish a long-term renovation strategy to support the renovation of the national stock of residential and non- residential buildings, both public and private, into a highly energy efficient and decarbonised building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero- energy buildings."

[71] https://www.bpie.eu/publication/the-road-to-climate-neutrality-are-national-long-term-renovation-strategies-fit-for-2050/

[72] Some farm infrastructures are suitable for an integrated production of solar-origin electricity and heat, creating the potential for renewable energy self-consumption and injection into the grid. In agriculture, through the Common Agriculture Policy, farmers could be incentivised to contribute to a greater mobilisation of sustainable biomass for energy. Renewable energy communities can provide a sound framework for the use of such energy in a local context.

| Main policy area | Examples of concrete policy measures |
| --- | --- |
| | Promote using wood as construction material, and carbon sink (considering the life cycle carbon content) {at national level}; |

### 4.2.2. Addressing market barriers

| Main policy area | Concrete measure – concrete examples |
| --- | --- |
| **Build a level playing field with fossil heating fuels** | Adjustment of markets, investments, regulation, taxes, tariffs and levies to promote the required carbon-neutral technologies, giving the right incentives and signals (in market driven transition) {at national level};<br>Assess and adapt the implementation of the Energy Taxation Directive to provide a level-playing field for all energy sources, considering carbon content & GHG emissions {at national level};<br><br>Decrease the price difference between electricity as well as renewable fuels and fossil fuels (e.g. by a comprehensive and high $CO_2$ price, by adjusting the tax and fee structure, by supporting) {at national level};<br><br>Fully efficient EU ETS to spur low carbon and renewable options in industry, including carbon leakage measures to support industries to invest in the carbon-neutral transition {at EU level};<br><br>Support the market acceleration of renewable heating technologies to achieve cost reductions from economies of scale, and increased knowledge {at EU and national level};<br><br>Better support renewable heating technologies in buildings considering possible adjustments to the heating installations in existing buildings {at national and local level};<br><br>In DHC, support the use of recovered waste heat and of a varied set of renewable energy sources, energy efficiency performance improvements (e.g. lower temperature, efficient equipment and regulation) {at national and local level};<br><br>Ensure a level playing field for renewable infrastructure (mainly on DHC), with existing energy infrastructure (electricity and gas, which were public investments in the past) {at EU and national level};<br><br>Extend TEN-E to DHC, to support development of new heat infrastructure in regions, cities and municipalities {at EU level}; |
| **Support developing the entire supply chain with qualifying companies (design, architects, construction workers, installers, operators, owners)** | In the short term, capacity building programmes can be set up and successful existing programmes such as BUILDUPSKILLS can be strengthened. However, the most efficient way to ensure that professionals will receive sufficient training is to give a clear and stable signal to the market that fossil-based H&C systems will be phased out and the future will lie in renewable and carbon-neutral systems. Long term stability is needed to incentivise companies to invest in the required expertise and capacities. {at national level, with EU guidance} |
| **Heat market facilitation** | Establish an enabling framework for Energy Performance Contracts and ESCOs {at national level};<br><br>Increase and assure price transparency on the one hand in the DHC market itself, on the other hand between different heating and cooling supply options, considering externalities {at national level};<br><br>Set up financial instruments to overcome high upfront costs {at national and local level};<br><br>Promote cooperation between energy and heating technology professionals and consumer organisations to develop new business models and services that support consumers in shifting to renewable H&C systems, reducing the complexity of their choices {at national level, with EU guidance};<br><br>Inform customers about the energy and non-energy benefits of renewable H&C, paying attention to the needs of the entire system (e.g. providing flexibility services |

| Main policy area | Concrete measure – concrete examples |
|---|---|
| | to the energy system like heat pump for the electricity grid) {at national level, with EU guidance} |

### 4.2.3. Addressing financial barriers

The National Recovery and Resilience Plans[73] address the renovation of national building stocks, in line with the Renovation Wave, and often building on the national Long Term Renovation Strategies required under the Energy Performance of Buildings Directive. At national levels, it is also expected that some public funds will be made available for the implementation of additional NECP measures. However, despite the availability of financing and funding, the required renovation rate and investments remain insufficient to reach the 2030 objective of reducing GHG emissions by 60% in the building sector.[74]

The following table summarises the possible measures that can address the main financial barriers, focusing on no-regret options.

| Main policy area | Concrete measure – concrete examples |
|---|---|
| **Integrated financial strategy** | Establish a comprehensive and integrated financial & fiscal strategy, creating a stable and long-term favourable investment environment. Several financial instruments are available at the EU level to finance the decarbonisation of the building and industry sectors. Particularly, the Recovery and Resilience Facility (RRF), which the European Council endowed with 672.5 billion EUR, 37% of which must be targeted towards climate-related expenditures, can support MSs with decarbonisation investments and related reforms. Other EU financial instruments are suggested, such as the European Initiative for Building Renovation by the European Investment Bank (EIB), InvestEU, and possibly revenues from the EU Emission Trading System (ETS) (via the new Social Climate Fund). Further, the NextGenerationEU is also a key financial resource to ensure adequate and well-targeted funding for energy efficiency and renewable measures {at national level;<br><br>Ensure national funds and finance are available, in addition and complementing the EU funding and financing programs, to ensure continuation of all efforts beyond 2027 (end of the RRF) {at national level}; |
| **Address split incentives** | Inform building owners of the multiple benefits of energy efficiency (e.g. tenants staying longer, less complaints, lower maintenance costs, etc) {at national and local levels};<br><br>Facilitate the redistribution of costs and savings between owners and tenants/users (this could include giving owners the possibility to demand a part of the cost savings from the tenants when an investment in improved energy efficiency is made[75].<br><br>Preferably this should take into account the actual energy performance of the new installation to protect tenants from paying for anticipated/estimated savings that did not materialise[76]) {at national level, with EU guidance on best practices}; |

[73] The Recovery and Resilience Plans are plans submited by Member States setting up reforms and invesmtnets to be implemented by end of 2026 and with the aim of mitigating the economic and social impact of the coronavirus pandemic. The European Commission established the Recovery and Resilience Facility to raise funds to help Member States financially in the implementation of these plans. For more information see: https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en

[74] BPIE (2020) Contributions from the building sector to a strenghtened 2030 climate target. Avialable at: https://www.bpie.eu/wp-content/uploads/2020/12/On-the-way-to-a-climate-neutral-Europe-_Final.pdf

[75] JRC (2017) Overcoming the split incentive barrier in the building sector.

[76] *Ibid.*

| Main policy area | Concrete measure – concrete examples |
|---|---|
| **Develop financial instruments to support creating economies of scale** | Implement minimum performance standards for buildings and H&C systems (MEPS in the framework of the EPBD) {at national level};<br><br>Support the financial sector to establish financing instruments that provide capital linked to the building assets rather than the creditworthiness of the owner or tenants; can help incentivise investments in solutions with long payback times that exceed the usual duration of tenant occupancy or ownership[77] {at national level}; Financial instruments: Grants/ capital subsidies; Loans; Rebates; Subsidies for electricity; Heating tariffs; Redesigning demand charges (for large power consumers) {at national and local level};<br><br>Creation of a yearly guarantee fund for low-income households {at national level};<br><br>Adoption of a 0% green loan programme, or other financial instrument {at national level};<br><br>Lower VAT-rates for renovation aiming at increasing energy performance of the building {at national level}; |
| **Integrate Energy Poverty within social programmes and link to financial strategy.** | Focus on specific market segments for the renovation and replacement of heating systems, e.g. giving additional financial incentives (e.g. grants) to low income & social housing households for home renovation {at national and local level}; |
| **Address the barrier of high upfront costs for building renovations and renewable heating equipment through financial instruments, e.g. large revolving funds providing cheap loans.** | Establish financing instruments providing access to cheap capital (e.g. through concessional loans) could spur investments in building renovations and renewable H&C equipment[78] {at national level};<br><br>Provide grants (subsidies) that cover part of the investment costs for renewable heating equipment {at national and local level}. |

### 4.2.4. Addressing capacity barriers

Capacity barriers encompass awareness, knowledge, skills and understanding of all players along the value chain. As all these actors have a key role to play in building the right solutions, dedicating specific efforts to remove capacity barriers in each group is important. The recommendations in this section will be further developed in section 3.4. According to stakeholders' views collected during expert meetings, workshops and through multiple interactions with the heating cooling sector, the capacity gaps are the largest in the installers' trade group.

| Main policy area | Concrete measure – concrete examples |
|---|---|
| **Strengthen policy makers** | At national level<br>○ Ensure that education and occupational training programs for building, energy and heat professionals include capacity building on energy performance/efficiency and renewable H&C technologies;<br>○ Support local governments with provision of high-quality information on regional renewable energy resources;<br>○ Support all levels of policy makers to design and manage EU funding schemes. These funds should specifically address capacity building for professionals (e.g. NRRPs are usually not including capacity building for the construction sector); |

[77] JRC (2017) Overcoming the split incentive barrier in the building sector.

[78] In many cases, investments in building energy performance and or renewable heating systems in the built environment are postponed because of the high upfront costs/lack of capital

| Main policy area | Concrete measure – concrete examples |
|---|---|
| | ○ Set up an expertise centre for decarbonisation of the H&C sector, with experts that can be consulted by small municipalities to provide technical assistance.<br><br>At municipal level (see section 3.3) |
| **Strengthen planners and infrastructure operators** | Coordination among all actors: building and real estate professionals, NGOs, local authorities, communities and energy companies, to better identify the relevant renovation solutions for vulnerable households, enhancing household knowledge and confidence, and coordinating existing grants and financing {at national level}; |
| **Strengthen architects** | Train architects on all carbon-neutral alternatives, especially on H&C systems (heat pumps, solar heat, biomass-based systems, …) {at national level};<br>Make sure that education and training of architects and building design processes pay attention to energy performance as an integral design element from the beginning {at national level}; |
| **Strengthen service providers (auditors, advisors, …)** | Education and training of energy consultancies and heating installers to (i) avoid capacity constraints in the sector and (ii) assure high knowledge about renewable heating {at national level}; |
| **Strengthen construction workers and installers** | Support the training of skilled workers under training programmes e.g. under the Updated Skills Agenda {at national level};<br>Train installers and construction workers on all carbon-neutral alternatives, especially on H&C systems (heat pumps, solar heat, biomass-based systems, …) {at national level}. Here it is important that there are no dedicated installers per technology, but that installers have the know-how to adequately install a wide range of H&C systems;<br>The expertise on how to combine different H&C technologies and storage solutions is another area where expertise should be strengthened. |
| **Strengthen infrastructure operators** | Promote cooperation between grid operators of electricity, gas and DHC grids and involve infrastructure operators in the H&C decarbonisation planning process {at national and local level}. |
| **Consumer awareness, including for building occupants and owners** | General information campaign (e.g. on the best point in time for changing heating system with alternatives, given technology and qualified workers availability), to improve perception and acceptance of RES heat, demonstrating RES system reliability {at national and regional level};<br><br>Information campaign on the advantages of DHC {at national and regional level};<br><br>Improve energy performance certificates (EPCs), and integrate heating system metric {at national level};<br><br>Support for the realization of energy audits in the industry and Building Renovation Passports {at national and regional level};<br>Promoting the deployment of energy management systems (ISO 50001 type) and energy benchmarks in industry and tertiary sectors {at national and local level};<br><br>One-Stop-Shop or any other advisory and technical assistance, with quick and easily RES H&C system available solutions for urgent replacement {at national and local level};<br><br>Recall the importance of behaviours, to act at consumer level (e.g. communicating on instruments like support schemes, …), increase the interest {at national and local level};<br><br>Adjust regulatory frameworks in such a way that households can also (potentially via an intermediary, e.g. their energy supplier) operate in energy markets to operate their H&C equipment in a dynamic, smart and optimal manner {at national level};<br><br>Set up Building Renovation Passports and integrate energy supply {at national level};<br><br>Set up communication programs to inform citizens and consumers about the challenges and their expected roles, to engage them actively in the decarbonisation of their buildings {at national and local level}; |

| Main policy area | Concrete measure – concrete examples |
|---|---|
| | Ensure the regulatory and policy framework facilitate and stimulate for local initiatives (citizens, communities) {at national and local level}; |
| | Define and support nearly zero-energy or zero-energy districts or energy positive neighbourhoods and communities in the frame of the EPBD {at national level}; |
| | Support developing renewable energy communities covering renewable and decarbonised H&C under REDII {at national and local level}. |

## 4.2.5. Addressing technical barriers

| Main policy area | Concrete measure – concrete examples |
|---|---|
| **Set up global monitoring strategy** | Gather data at building level (logbook) {at national level}; |
| | Improve high-resolution knowledge on subsurface temperature gradients and other characteristics to provide regional players with high-quality information on the geothermal energy potential in their region {at national and regional level}. |
| **Digitalisation – Smart systems and operation** | Facilitate new H&C systems, both individual and collective, to be equipped to perform smart operations, providing flexibility services where adapted {at national level}; |
| **Building instruments (MEPS, codes, EPCs)** | Adapt building codes and standards to increase investments in building energy retrofits and other energy efficiency measures in buildings, and to switch to renewable {at national level}; |
| | Establish or reinforce building certificate schemes, ensuring heating systems are correctly addressed {at national level}; |
| **RD&I in industry** | A large and ambitious mission-oriented RD&I program for industrial low-$CO_2$ technologies, including funding for industrial demonstration and scale up {at national level}; |
| | Stimulate Industrial symbiosis and a circular economy through the effective combination of energy recovery and recycling {at national and regional level}; |
| | Policies combining R&D, industrialization, commercialization support and GHG pricing are needed to ensure a coherent and integrated approach to decarbonize industrial processes {at national level}; |
| | EU Innovation Fund can be used to co-finance large industrial scale biomass-to-biomethane gasification plants {at national level}; |
| | Further develop and support the demonstration of renewable and carbon-neutral heat processes in industry {at national and regional level}. |
| **Standardisation** | Work to introduce a common carbon-neutral threshold/standard for the promotion of hydrogen production installations based on their full life-cycle GHG performance {at EU and national level}; |
| | Harmonise gas quality standards for biomethane injection in gas grids and set standards and definitions for hydrogen and blended gases to enable their transport through gas infrastructure and across borders {at EU and national level}; |
| **Energy system integration** | Enable energy system integration (between sectors), by facilitating the provision of flexibility to the electricity sector by the heating and cooling sector, and the use of waste heat {at national level}; |
| | Redesign of power markets Implement and parametrise Power Market considering H&C systems participation {at national level}; |
| | Time of-use tariffs; Redesigning progressive tariffs {at national level}; |
| | Support for digitalisation {at national level}; |
| **Monitoring – improving H&C data availability (demand & supply)** | Heating and cooling should become more visible in energy statistics and reporting (incl. DHC) at national level and EU level {at national level}; |
| | Establish a national (or EU) platform for best practices exchange {at national level}; |

| Main policy area | Concrete measure – concrete examples |
|---|---|
| | Transparent accounting framework for CCU across sectors and value-chains to allow business cases to emerge {at EU and national level}; |

## 4.3. Integrated planning at national, regional and local level

Providing a clear vision for the future of the heating and cooling sector is essential to support market development, avoid undesired lock-in effects and ensure a stable policy framework. The long investment cycles and the long periods needed for planning and constructing the infrastructure, equipment and building systems require an equally long-term policy perspective, and sufficient time for market adaptation to new regulations. This section provides some general guidance on building the steps for the long-term H&C planning.

The main principles of H&C planning encompass

1. 1. the development of a vision and the definition of long term targets, objectives and measures;
2. 2. the evaluation of the existing progress and gaps regarding H&C decarbonisation;
3. 3. the assessment of the potential for renewable production and possible import;
4. 4. the development of scenarios based on existing policies and plans; and
5. 5. the enabling of municipalities and local authorities to conduct and implement local heat planning. These elements could also be set in a legal framework, as seen above.

It should be noted that local level data is an essential input, and not everything can be developed at the national level without due consideration for local parameters. Therefore, an iterative process to integrate planning at local level is important. However, the national planning needs to have a more global perspective (e.g. to indicate whether hydrogen is going to be supported) and set the framework conditions for local planners, who must take those into account when they consider local options. Iterations between national and local planning is important.

Identifying all key stakeholders to engage in H&C decarbonisation is a crucial first step for a successful H&C planning development and implementation.

### 4.3.1. Stakeholders to involve in H&C decarbonisation

Planning of heating and cooling decarbonisation requires engaging local, national and EU level actors. The local level is important due to the local nature of heating and cooling supply and demand. The energy system integrates more and more local or decentralised elements, aiming at increasingly rational use, decarbonisation and resilience. The planning should be conducted from a system perspective. National energy and climate targets can be achieved only if they are locally supported, considering local adoption, transposition and integration.

As highlighted in the Renovation Wave, local authorities and utility companies have an important role in creating the necessary regulatory framework, market conditions and skills and in preparing a robust pipeline of projects to finance the modernisation of heating and cooling systems. Local authorities have control over different levers, such as various local/municipal regulations, the development of the infrastructure, providing financial and technical instruments, urban planning, permitting, incentives to reduce energy demand, mutualising energy needs, mobilisation of the concerned parties (e.g. citizens & industries), or the coordination/facilitation between different actors from the supply and the demand sides, especially to create synergies. All public bodies have a role to play, although in many cases they would not perceive themselves as having a responsibility or any kind of remit in H&C planning, or in setting up enabling frameworks. Municipalities and cities are at the core of a deep transformation of the energy systems, as depicted in the following figure.

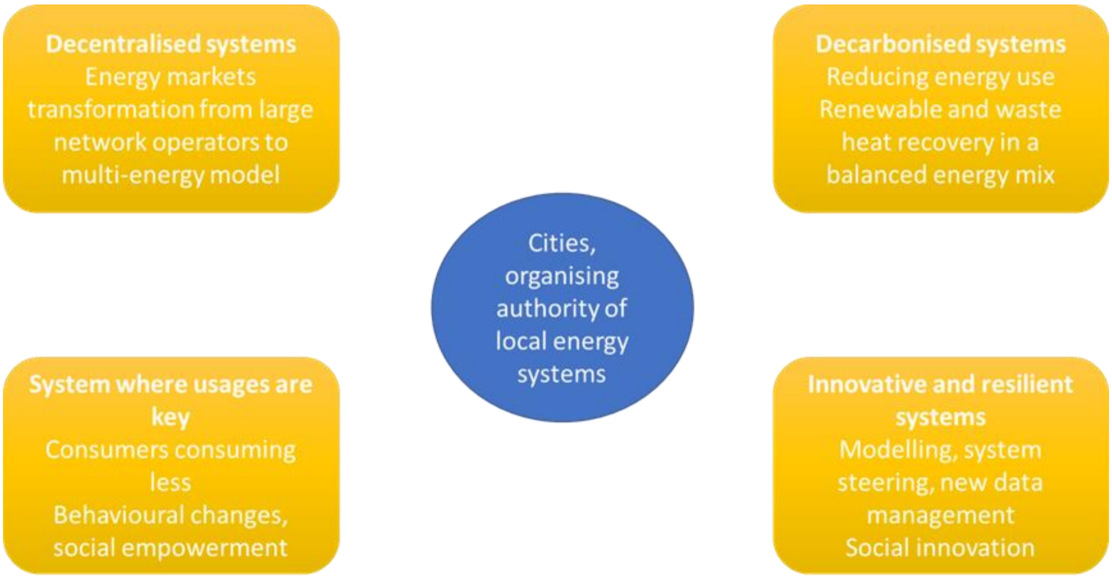


*Figure **Error! No text of specified style in document.**-8 Municipalities at the centre of the H&C planning*

*Source: own elaboration based on Lyon's Metropol Energy Development Plan (SDE[79])*

Regional actors can be an important link between the state government, the municipalities and the citizens. They could have a responsibility for implementing the state's heating and cooling policy, defining a strategic framework, as well as managing support, raising awareness, providing technical expertise and financial instruments, or setting up normative schemes (e.g. urban requirements). Regional authorities can play an especially important role in the support of the decarbonisation of the heat supply of large consumers (e.g. manufacturing companies, industry) and to take the coordinating role connecting different potential H&C consumers and suppliers. Enforcing their competences in the field of the energy transition may also be required to support energy use reduction, address energy poverty, deploy renewable and heat recovery, deploy and reinforce energy networks (electricity, gas, heat). Citizens, households, but also renewable energy communities, workers, Small Medium Enterprises (SMEs) have an important role to play in heating and cooling planning, as potential energy producers, flexibility providers, but also as consumers with mutual interests (benefiting from scaling factors, industrialisation and impactful solutions). Local communities have an important role to play in awareness creation, exchange of experience,  and creating demand for solution providers, planners and system operators. Professionals involved should encompass the building sector (construction, architects, planners, promoters), the financial sector, the smart and digital solution providers, the energy sector (producers, suppliers, ESCOs and operators), the social actors, and network infrastructure operators.

### 4.3.2. Develop a national vision and define national long-term targets

Having in mind the long-term (2050) full decarbonisation of the heating and cooling system, decision makers should define now how to pave the way towards this carbon-neutrality goal.

[79] https://blogs.grandlyon.com/plan-climat/wp-content/blogs.dir/8/files/dlm_uploads/2019/05/2019_Sch%C3%A9ma-directeur-des-%C3%A9nergies-lessentiel.pdf

Defining the vision of a decarbonised H&C would therefore encompass what the sector will look like in 2050, and by which means the society will reach this goal. Given the interconnection of the H&C sector with many other sectors (electricity, liquid fuels, gases, buildings, industry, transport, …), such vision needs to be built taking as context the full decarbonisation of the entire system which means that a holistic approach is required.

The energy infrastructure and the way it will evolve is of paramount importance, as it will determine the availability of energy carriers and the possibility to potentially valorise new energy sources.

Such vision could comprise the following elements:

- Among the list of energy carriers and sources, defining which ones are expected to play a role in the fuel mix in 2050. This should be carried out based on the assessment of available energy sources (or the potential, see below section 3.4.3), also considering import (in most of the cases local or even national resources will not cover all needs). Each source or carrier should be assigned to dedicated applications, to prioritise and fill in potential gaps (e.g. bio-energies production will not be able to cover our current energy demand, and should be preceded by decreased energy use and should be used for high value applications, from a system point of view. A similar logic applies to hydrogen). Local level planning will be strongly dependent on local conditions (availability of infrastructures). It will not always be possible to follow national planning guidelines. Prescribing the role of energy carriers at national level is too restrictive, there might be different energy uses on regional level;

- Decreasing energy consumption in the building sector and the industry, and how it will affect the demand of H&C, but also the required technologies and capacities to achieve this reduction in energy consumption;

- The evolution (reinforcement, expansion or (partial) decommissioning) of the fuel transport, storage and distribution infrastructure should be framed by general rules depending on their expected role in the 2050 scenario. Here an important aspect is to assess which parts of the gas network should be kept (assuming fully decarbonised gas will be available) or adapted to function as dedicated hydrogen pipelines and which parts should be decommissioned (assuming non-gaseous alternatives are preferred options). This would also include the place and role of DHC systems, including the way to fully decarbonise existing DHC (e.g. via electrification like large scale heat pumps, with renewable fuels like geothermal or solar energy combined with heat storage), with various types of bioenergy fuels, with CHP also based on hydrogen, or via waste heat recovery), and the main conditions to deploy new low or zero-carbon DHC should be defined, such as heat consumption density, town planning and technical constraints, the deployment of new districts, …;

- The involvement of all stakeholders is important, and certainly defining their role will also be required. The empowerment of some decision makers at more decentralised levels will be necessary to ensure the mobilisation of the needed workforce and capacity. Technical support should certainly be provided at decentralised levels via a national one-stop-shop or a similar expertise centre with H&C experts providing advice to local governments;

- Building the required green skills by setting new training programmes, encouraging young people to work in the sector by making it more attractive, mainstream H&C decarbonisation technologies in various curricula in collaboration with universities, knowledge institutions, and schools to address the whole value chain stage (architects, construction workers, installers, O&M, utilities, infrastructure system operators). There is a lack of staff to do proper planning, cities have to rely on outsourcing, which has less quality and on the ground knowledge, so trainings and guidance through by strengthening capacity building and upskilling initiatives is paramount,

- Financial support is essential to facilitate the transition, and should be considered as a starting point when developing the concept of a national vision.

### 4.3.3. Evaluate the existing progress and gaps

This section has two related purposes: assess the progress made so far regarding carbon emissions reduction and the deployment of renewable energy in the H&C sector; and building on the existing assessments, plans and strategies, to evaluate where the remaining gaps are.

Monitoring the progress in reducing carbon emissions should be covered in National Energy and Climate Plans. However, most of the plans could have been more precise in the way the MSs intend to decarbonise the heating and cooling sector, both for industry and for the built environment.

Regarding the building sector, what is usually missing is the way the deployment of renewable energy supply will be addressed in the context of the renovation, and how energy efficiency and H&C supply will be addressed in a coherent way. Assessing the progress in this field is essential.

As stipulated by EPBD Article 2a concerning national Long-Term Renovation Strategies, MSs must establish a long-term renovation strategy to support the renovation of their national stock of residential and non- residential buildings. The LTRS should facilitate the cost-effective transformation of existing buildings into nearly zero-energy buildings in order to ensure a highly energy efficient and decarbonised national building stock, thereby facilitating the decarbonisation of energy supply through reduced demand. The assessment should evaluate how each instrument of the LTRS (normative or incentive) considers the switch from fossil to renewable fuels.

As stipulated by EED Article 14 concerning the promotion of efficiency in heating and cooling, MSs had to undertake a National Comprehensive Assessment (NCA) to establish the technical and socially cost-effective potential for high-efficiency cogeneration (CHP) and efficient district heating and cooling (DHC). Both DHC and CHP are closely linked to the use of renewables in H&C and these NCAs should include an assessment of the potential to use renewable energy as well as waste heat and cold for heating and cooling under Article 15(7) of REDII.

The evolution of DH is characterised by a movement towards lower temperatures, higher efficiencies and a broader variety of energy sources within one system. DH is currently in the transition from the 3rd to the 4th, and even 5th generation, characterised by the use of more renewable energy sources, possibly at lower temperature, such as solar, geothermal, ambient, bioenergy and waste heat (from the industry or urban activities), combined with large thermal storage. CHP plants also could have a dominant role to play in DH, but this will require a shift towards bioenergy carriers or hydrogen.

As more renewable energy sources are introduced into DH systems, the need for more flexible energy production and consumption increases to ensure the adequate level of security of supply, which could be further strengthened by the implementation of larger thermal storage. Lower temperatures are a necessity for achieving higher efficiencies. The evaluation should assess how DH are adapted to increase the share and low-temperature options of renewable energy sources.

CHP can be used in industrial applications, to supply DH, large buildings, and even micro-CHP for small buildings (e.g. for households). Most of the CHP across the EU is still fossil-based. Its decarbonisation will rely on on bioenergy (solid, liquid & gaseous) and e-fuels (e-gases & possibly e-liquids) produced from renewable electricity (RFNBOs). The evaluation should assess whether fuel switching from fossil to renewable (potentially combined with adjustment or replacement of the existing CHP plant) is realistic and if not, a switch to another type of renewable energy source should be considered.

- The evaluation should describe today's energy use and supply for space and water heating, and for industrial energy needs at national levels, including information on energy consumption for the technology distribution, the building structure, as well as the regulatory frame in place. Data should be as recent as possible: Heat demand structure and energy use (to be used to the regular energy statistics) should comprise; energy demand in the building and the industry (final energy demand by energy carrier and energy source, by sub-sector, by type of application); the building stock (floor areas per sub-sector and levels of performance where available); industrial process heat profiles; weather conditions; generation mix for electricity and DHC (with a focus on renewables). This should also comprise the evolution over time (2 decades) and the success factors (e.g. implementation of measures) highlighting the progress made in the deployment of renewable in H&C or in increasing energy efficiency. Gathering data on supply and demand is complicated (at the national level, but also at local level), e.g. data on solar collectors can be based on sales statistics, but these are combined only at national level (not at local), while data on waste are hard to get at national level. Heat or energy suppliers might be reluctant to provide data (mandate to access these data should be given to authorities/regulators);

- Technologies used for individual H&C and for DHC should cover: the current levelized cost of heat (based on regional cost factors); market share of different individual technologies (air-source & ground-source HP; oil-fuel boilers; gas fuel boilers; solid fuel boilers; solar thermal; micro CHP); large scale heat production for DHC (gas, oil and solid CHP and boilers; large solar thermal plants; large HP; waste heat recovery; geothermal);

- Policies and measures for H&C, renewable H&C and the decarbonisation of H&C, encompassing: regulations (e.g. building codes, urban constraints, zoning deployment, permitting, …); fiscal and financial instruments (e.g. carbon taxes, specific loans, risk mitigation instruments, tax exemptions, reduced tariffs etc. …); incentivizing instruments (e.g. support schemes, quota for decarbonised heat, …); institutional framework (e.g. mandating local level to develop H&C plans);

A complete monitoring system should be put into place, and track record of the following items

- Progress in renewable heat production and carbon emissions saved;

- Review of policies and measures following the problems experienced;

- Uptake of individual and DHC technologies, to enable cost control measures as and when needed;

### 4.3.4. Assess the potential for domestic renewable production (and import)

For each renewable source, a good understanding of domestic potential is important. This would help address the importance of decreasing energy demand, and of evaluating fossil import reduction potential, as well as possible renewable energy import needs from abroad. A local focus would ensure domestic heating and cooling needs are fully accounted in H&C decarbonisation. The assessment of the potential should make a clear distinction between buildings and industry, considering the needs and conditions are quite different. Article 14 of the EED requires National Comprehensive Assessments; these already provide a framework for such renewables' potential assessment in accordance with Article 15(7) of REDII .

Assessing potential requires an appropriate monitoring scheme. Heating and cooling mapping is central to properly plan the decarbonisation of the sector, and should comprise the identification, analysis (modelling) and national mapping of resources and possibilities to supply H&C at the municipal level in a resource- and cost-efficient way, while considering national supply . Such a mapping exercise and the resulting database should help authorities to develop local, regional or national heating and cooling strategies, in alignment with national and EU renewable energy and $CO_2$-emission targets. Defining RES production potential may be a complicated exercise, even for countries well advanced in the mapping of energy demand, as more local data are required to assess the potential . Strong coordination between regions, and ideally Member States, is required for the global assessment of the availability of a resource (biomass). Considering the potential and developments (objectives, policies and measures) beyond state boundaries, encompassing a broader economic scope, taking into account interconnected cities across borders can also be an efficient approach (like in Luxembourg, with its neighbouring countries, and especially with large cities). This could highlight the importance of urban-rural partnership to supply the missing renewable energy.

The assessment could be driven by the following considerations:

- A significant transition towards renewables in European electricity systems is expected from the fall in price of solar and wind technologies and the policy action across H&C the EU. This will present a significant opportunity for the H&C sector, but also an integration challenge, which will be reflected in electricity market prices, which are expected to fluctuate considerably more than today. An important tool for integrating wind and solar energy into the electricity system will be more flexible in the generation and use of electricity, via heat pumps, small-scale CHP, or electrolysers to produce $H_2$. However, this later solution is currently expensive and should probably be dedicated to a limited number of applications (including processes involving industrial process heat);

- Bioenergy, as discussed in chapter 2, is a valuable but limited resource and should therefore be used with care. This entail the consideration of the consequences of replacing the current level of natural gas consumption with biomass and renewable gases (greening the gas via biogas and e-gases), which can lead to the conclusion that this would not be a viable option due to lack of sufficient resources and the enviromental and food security impacts (e.g. a large share of arable land would likely need to be dedicated to produce energy crops). It is therefore essential to concretely implement the Energy Efficiency First Principle to seriously decrease the heating demand, and then to allocate bioenergy to specific applications where alternatives may still be too expensive, or do not exist. However, local application of bioenergy (mainly biogas and solids biomass for H&C), where its sustainability can be easily monitored and enforced, remains an important pillar of decarbonisation. Biogas production in the agricultural sector, for instance, also provides a way to recover a green fertiliser, from digestate[80]. Therefore, bioenergy remains part of the decarbonisation portfolio but its exact role should be clearly defined. A no-regret measure is to ensure a more rapid replacement of existing inefficient bioenergy-based heating equipment such as fireplaces and wood stoves by more efficient alternatives;

- As more renewable energy sources, such as wind and solar, are added into the energy system, the need for thermal power generation is declining, and thus the role of CHP will evolve. This role will also be affected by the progressive prioritisation of biomass for the production of high-energy density fuels, or materials. CHP plants were mainly considered electricity suppliers with heat as a by-product. The changed role of the CHP plants has turned the focus towards new heat supply technologies, such as heat pumps. Heat pumps allow for efficient integration of renewable electricity into the heat sector. The combination of electricity generation from renewable energy source, such as wind and solar, and heat pumps in cooperation with industrial surplus heat e.g. could possibly replace the role of the CHP plants. Still, some capacity of renewable fuel-based CHP

[80] Anaerobic digestion produces two main products: digestate and methane. Digestate is the material remaining after the anaerobic digestion of a biodegradable feedstock. More can be found on https://www.europeanbiogas.eu/digestate-factsheet/

installations might still be required for the provision of dispatchable power generation capacity;

- Heat pumps (environmental heat, including geothermal) are subject to constraints in terms of heat demand, heat sources and electricity supply. On the demand side, the temperature level to be provided is determined by the heat transmission system. The lower the necessary flow temperature, the more efficient the heat pumps. The heat source will depend on the environment (availability, accessibility, and quality of geothermal heat, or ambient heat). The deployment of electricity networks should also be able to cope with heat pump deployment, which means that coordination with electricity Distribution System Operators (DSOs) is key when planning for large-scale deployment of heat pumps in certain areas;

- The potential for solar thermal energy is limited by the following factors: dimensions and orientation of existing roof surfaces, or available fields; competition with PV modules for surface areas; restrictions due to structural stability and design conditions. However, the bulk of solar heat is expected from large-scale solar thermal plants, the potential of which is determined to a lesser degree by the availability of surfaces than by the availability of DH for feeding in solar heat or other low-cost heat sources (including, for instance, waste heat from urban activities) and the willingness to use arable land for the installation of solar thermal plants. Solar thermal can also be a valuable way to upgrade low-temperature waste or cooling heat to a temperature that can be used directly (after storage) for heating purposes with minimal energy input from heat pumps required;

- In many areas in Europe, there is a potential to provide (at least low-temperature) heat from (deep) geothermal sources. The challenge is how to upscale this industry, increase the competition between market players to reduce drilling costs (possibly by de-risking) as these still represent the lion's share of the overall costs in geothermal projects. Facilitation of geothermal energy can be done by ensuring good geolological mapping is performed so that this information can be accessed by regional and local stakeholders. Furthermore, protection against the financial risks for failed drilling holes can help to reduce the investment risk related to geothermal projects.

- The energy system is moving from a centralised system with a few large producers, to a distributed, decentralised energy system with many smaller producers. Additionally, significant numbers of producers of fluctuating renewable energy have entered the energy system. This transition requires a much more flexible and robust infrastructure to maintain adequate security of supply. The trend of shifting from central to decentral energy production is expected to continue for years to come, creating possibilities for new technologies to enter the energy system;

### 4.3.5. Develop scenarios based on existing policies and plans

Building on the current situation, the development of scenarios requires combining a long-term vision with the evolution of energy demand and renewable potential based on geographical distribution, timescale, availability and deployment cost. Scenarios will link all relevant components in a comprehensive way to allow for (the most) energy efficient and cost-effective solutions to emerge. Scenarios should help in the following:

- Fix the energy sources and carriers mix, and technologies to be used, and determine how to deal with their deployment. Consider decarbonisation of the current fuels, especially greening of gases (biomethane, and RFNBOs), at national scale, but also via import. Renewable-based liquids (biofuels, and RFNBOs) may also play an important role in more rural areas;

- Central systems (DHC) and individual systems are fit for different situations and contexts, and reach different levels of performance (where feasible, DHC will bring down cost, improve energy performance, and allow more low-temperature renewable sources to be valorised). Consider the decarbonisation of existing DHC; the deployment of new zero-carbon DHC; and the use of individual heating systems;

- Link with other plans, such as the decarbonisation of the electricity and transport sectors; urbanisation strategies, the NECP, LTRS, …;
- Facilitate synergies between sectors, such as tertiary and housing, industry, transport infrastructure, agriculture, considering the share of resources (e.g. waste heat recovery, digestible organic waste, …), the combination of flexible options (e.g. the more variety of energy use profiles, the more flexible the solutions);
- Environmental taxation policies or other economic incentives should ensure that solutions that are desirable from a social perspective are also advantageous from a economic and consumer viewpoint;
- The future of the infrastructure is a central issue, to avoid lock-in effect and possible stranded assets on the long term;
- It is important that the first steps towards full decarbonisation by 2050 are taken now. When designing H&C decarbonisation pathways and policies, the search for the perfect most cost-effective strategy is often the worst approach in the long-run; a good, cost-effective strategy is often the best strategy because it is often more feasible and economically sustainable.

### 4.3.6. Municipal Heat Plan - enabling municipalities/local authorities to conduct & enforce local heat planning

Introductory remark: there are already many planning requirements at local level, which can be a burden for planners. Therefore, streamlining and consolidating the different planning requirements is of paramount importance (e.g. with energy efficiency plans, urban planning, etc.). This could be done by developing guidance documents with clear information on planning requirements as well as tools to support the development of local heating plans. Establishing networks to support the coordination of local decarbonisation plans would be beneficial in involving different types of stakholders in the planning process. Furthermore, building staff competences, is a crucual element to provide capacity at local level for the development of decarbonisation plans.

Guidance for local authorities on heat planning is important and should be provided by national authorities or at the European level. Dedicated financing and human resources for small and medium size local authorities is of paramount importance (such as through the Just Transition Fund). Finally, rural communities with low population densities would probably require dedicated programmes.

#### *Municipal Energy Planning*

A Municipal Energy Plan is a planning tool that allows municipalities to plan local energy conditions for a more flexible and energy efficient energy system. The planning must, among other things, help to systematically explore the possibilities of promoting renewable energy and energy savings, as well as help to utilize the potentials in a socially appropriate way. Municipal Energy Planning encompasses all forms of energy consumption and energy supply in all sectors (households municipal and other public service, private service, manufacturing, transport).

Usually, municipalities are not yet required to meet a specific target in reduction of $CO_2$ emissions and renewable energy share in the H&C sector, although there is currently an increasing number of ambitious municipalities and cities. Commonly seen is a target of 100% renewable energy share in DHC, where the heat would be produced from biomass boilers (straw, wood pellets or wood chips), solar heating, electrical boilers, heat pumps (based on air, seawater, wastewater or surplus heat) and geothermal energy. 100% renewable energy shares at the municipal level (within the geographical boundaries of a given municipality) is often difficult to reach as municipal options to act and local resources remain limited. E.g. replacing oil furnaces and individual natural gas boilers with individual heat pumps requires the will and investment from house owners, not from the municipality.

In energy planning, the municipality can play several important roles to influence the development in the energy field. Depending on the national (and regional) context, the municipality can be a company, a planning and approval authority, the owner of utilities, a facilitator, or an information provider (raising awareness). In some cases, the municipality has a direct opportunity to take action and develop concrete projects, while in other cases it would act via its network and would then play a coordination role. Another key role of the municipality is to make sure low-income households are sufficiently supported and facilitated in the decarbonisation of their H&C systems and that this transition does not generate or aggravate energy poverty.

### *Process to prepare a Municipal Energy Planning*

Municipal Energy Planning can be divided into four main steps, which should certainly done through an iterative process with interactions and loopbacks between the different steps. Many municipalities may already have worked on several components of the entire process, possibly in another context, while a few know quite well how to deliver Municipal Energy Plans. In any case, it is crucial to build on existing work and utilize the experience, the plans, the built knowledge and existing networks.

- In the initial step, the Municipal Energy Planning process is organized. The political willingness is the starting point, and decision makers should be involved at strategically important times in the process. Engaging the municipality's stakeholders at the earliest stage is usually seen as a second key success factor, building on the identification of stakeholders and cooperation opportunities within and outside the municipal boundary. Thirdly, this step will also define the main strategic (and political) principles that will guide the process, answering the main questions regarding the decarbonisation of H&C and of the energy system. Fourthly, it will define the long-term goal to be achieved;
- During the mapping step, data is collected regarding the current situation of the municipality's energy consumption and supply, to prepare a reference scenario. Data gathering should also support the next step and include an assessment of the potential for renewable within the borders of the municipality and outside, the energy performance of the building stocks and performance improvement possibilities, increased energy efficiency in small and middle size industry (large industries will also require the involvement of national authorities in most cases), the existing infrastructure, and all local constraints and challenges;
- The analysis step confirms the decarbonisation goals and vision, and therefore it includes a review of the municipality's starting point and ongoing projects, and subsequent analysis and prioritization of decarbonisation opportunities towards the goal and vision. This is then used to set up scenarios on the steps and milestones to reach the long-term goals. A specific guidance for municipalities to develop these scenarios will be needed to give clear direction;
- The planning and implementation step articulates all actions to achieve the target and goals, forming the basis to prepare the Municipal Energy Plan in connection with municipal investment projects, urban developments, approval of projects, or other climate actions;
- During these steps, municipalities can also analyse to what extent the broader national framework (legal, regulatory, markets, infrastructure) enables or hinders them in implementing decarbonisation plans and actions, and how discrepancies with national framework and shortcomings or gaps can be addressed.

### *Spurring Municipal Heat Planning*

As suggested earlier, a national legal framework (e.g. Heat Act) could mandate municipalities to prepare and implement a Municipal Heat Plan, as part of a Municipal Energy Planning , in close collaboration with gas and electricity DSOs (and where needed TSOs) to ensure the infrastructure is at the core of the planning. For instance, such a framework could give them more responsibility in climate action; mandate them to phase out fossil fuels; municipalities with more than 10.000 inhabitants could be obliged to carry out such Municipal Heat Planning with a full decarbonisation target; they could become responsible for setting up knowledge and learning programmes; they could be obliged to study DHC infrastructure development in the case of any intervention (telecommunication, waste water, electricity, gas, …); they could be obliged to ensure the integration of renewable energy and waste heat recovery in their territorial policy and plans; municipalities should streamline the permitting procedures allowing a timely and predictable set of infrastructures and interconnections... The other side of increased responsibility is the need to equip municipalities with the necessary new resources (personnel, financial, training, skills, capacities) to deal with their tasks associated with Municipal Heat Plans.

The Municipal Heat Plan can be considered a tool to prioritise which heat supply solutions must subsequently be analysed in more detail in accordance with a national vision regarding the decarbonisation of the H&C sector. Through the Municipal Heat Plan, the municipality can ensure that the increasing interdependency between sectors (sector coupling) is reflected in both long-term heat planning and the planning in other sectors. As previously described, the district heating sector may have a special role in providing flexibility to the energy system.

In other parts of the energy system, the municipality does not have many competences and options to act, although they have a number of potential opportunities for promoting long-term development towards a fossil-free energy supply, which is why Municipal Energy Plans are also useful for municipalities to integrate the rest of the energy system.

The process to prepare and implement a Municipal Heat Plan could be driven by the following:

- A National regulatory framework regarding municipal heat planning must define the authority role and mandatory tasks;
- It should be driven by political engagement with a strong impetus from the national ambition, to ensure resources and commitment to heat planning, which is not only an administrative task (although administration role is central);
- It should contribute to the LTRS and NECPs objectives and actions;
- All interested parties should be involved in the preparation process to have all necessary data available and to get a concrete commitment in the vision and action plan: real estate, system operators, architects, planners, construction companies, building occupants, social housing, industry, agriculture, authorities, administration, regulator and infrastructure operators;
- All non-sensitive building information and sensitive energy consumption data should be made available to municipal workers with heat planning and energy optimization. The respect to GDPR is therefore essential;
- Capacity building is part of the process, and also knowledge sharing among all stakeholders involved in heat planning;
- Integrating all private initiatives related to H&C decarbonization;
- Securing the financing of the required investments
- Setting up multilateral municipal coordination groups and educational programs, also ensuring the representativeness of all groups of society (citizen, enterprise, agriculture, system operator, …). Public consultation should also be at the core of the process;

- A key step is to decide on common H&C planning assumptions (also based on generic assumptions like technology cost ), to support setting the baseline, and possible developments;
- If DHC is considered necessary to meet climate targets, this should be facilitated at the municipal level, therefore requirements for zoning (perhaps including mandatory connection) should be considered. Conditions for heat recovery options should be developed so that the risk for lock-ins is mitigated;
- Coordination is necessary between all infrastructure operators, especially when synergies (or system integration) are expected, at the earliest stage of development. All operators should be concerned: electricity network, DHC, gas, industrial and commercial zoning, urban infrastructure;

# 5. Conclusions

The decarbonisation of the heating and cooling sector (H&C) is pivotal for the success of the transition to a climate neutral energy system, given the central role of H&C in energy demand. This change in the H&C sector will require strong action and adequate coordination, addressing simultaneously the **reduction of energy use and the deployment of renewable** based heating and cooling solutions.

The transition can build on a broad set of energy sources, carriers, infrastructure types and end-use technologies, depending on local needs and considering the benefits, constraints and risks of each solution. As such, there is no "fit-for-all" solution, nor a single option that would realise the full decarbonisation of H&C, but rather a **set of diversified and combined options,** complementing each other and balancing each other's disadvantages and risks. Pathways to a fully decarbonised H&C systems will differ and depend on the specific conditions of each Member State, region, municipality and even district. Some pathways could centre around electrification through the use of heat pumps, whereas others might focus on district heating & cooling, and/or exploit different sets of heat-sources from ambient, geothermal, solar energy sources, where possible heat/cold recovery from waste heat/cold, and/or exploit various types of bioenergy and biogas combined with renewable fuels of non-biological origins (RFNBOs). The different energy sources, carriers, related infrastructure and technologies will all play a role to various degrees in each Member State's specific mix. The selection of the most suited and balanced mix will vary between countries and even regions, depending on resource availability and other local parameters, including the heating/cooling demand pattern, existing infrastructure, and cost considerations.

Today, natural gas is one of the dominant fuels used for heating in the EU. As recently stated by the EC in its Communication on the Gas Package, "*In line with the policy scenarios that underpin the "Fit for 55" initiative, biogas and biomethane, renewable and low-carbon hydrogen and synthetic fuels (E-gas) will gradually replace fossil natural gases*". The same communication also recognises that "In most areas, direct electrification will be the most cost-effective and energy-efficient way to decarbonise final energy demand… ", while " … electrification is not feasible in all sectors. Some will continue to rely on gases". This emphasizes that governments should not aim to count on fully replacing existing natural gas demand with renewable gases, but rather deploy the valuable yet limited supply of renewable gas in sectors where there are not many viable alternatives.

A central aspect of H&C decarbonisation is **setting clear goals and objectives, and having clear plans at national, regional and local level** as regards what the cheapest and most environmentally sustainable resources and solutions are, and how to implement, finance and maintain them. This is crucial to coordinate the many actors concerned by heating & cooling systems, including end users such as building occupants/owners and industries, energy suppliers and service providers, system operators, equipment manufacturers, installers, architects, engineering, and municipalities. The planners (e.g. public authorities, regulators, system operators, architects, builders, …) should take into account the need for coordinated action, not only in the H&C supply but also on the demand side. Among others, adequate planning should address energy resource availability, total energy system cost, a level playing field with incumbent fossil-based options, contribution to energy system flexibility, sustainable sourcing, decisions regarding (dis)continuation of existing infrastructure, heat and cold demand patterns and state of the building stock, technical constraints, but also consumer's interests and preferences.

**Integrated H&C decarbonization planning** is required, with three main dimensions of integration. Firstly, all parties involved in the energy transition, such as decision makers, as well as all relevant stakeholders from the energy system, the building sector, industry and households should be involved as they all have a specific role to play in the process. Secondly, all decision levels need to be engaged, to ensure the link between the macro level giving the main direction (and market framework) and the local or micro level having an important influence on the way the infrastructure and the local market systems should be shaped. Thirdly, to avoid additional workload and ensure policy coherence, especially for local authorities in charge of local planning, the integration should build on existing energy and territorial plans, or any plans related to H&C infrastructure.

Therefore, providing the **local authorities with the right levers and tools** to start such H&C decarbonisation planning, in close collaboration with the national authorities, should no longer wait, as it is a key step towards the long term full decarbonisation of the H&C system. Furthermore, **policy measures and instruments to promote the transition in the H&C sector should be urgently implemented**, where possible by reinforcing current policies. Taking the appropriate measure to introduce a level playing field for renewable based solution should be seen as the priority, certainly by removing any subsidies and benefits for fossil-based systems and energy carriers. Ideally, the risks for stranded assets should also be evaluated for such measures, to ensure compliance with long-term climate goals and secure efficient investments.

**Finally, a larger workforce and additional skills** are needed along the value chain, to get the decarbonisation of H&C implemented. The pace of energy renovation in the coming years/decades should accelerate dramatically, which requires major upscaling efforts across sectors, including the training and upskilling of construction workers, but also architects, planners, installers and engineers. Coordination and collaboration between professionals is essential, to mainstream energy efficiency and renewable deployment in a comprehensive and integrated way. When it comes to the design and installation of renewable H&C systems, it is essential that service providers have expertise on all relevant technologies and can combine them to deliver tailored solutions that are optimized for each specific context. Energy service companies supporting the consumers and authorities at national, regional and local levels should be reinforced.

# Policy Support for Heating and Cooling Decarbonisation

Meta-study

Part 1: Strategies and policies for decarbonising heating and cooling in buildings

Part 2: Decarbonising industrial heating and cooling

Part 3: Technologies and infrastructures

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Trinomics B.V.

Westersingel 32A

3014 GS, Rotterdam

the Netherlands

**Contact main author(s)**

Sibylle Braungardt (Oeko-Institut)

s.braungardt@oeko.de

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**In association with:**


Authors:

Sibylle Braungardt, Benjamin Köhler, Irina Ganal (Oeko-Institut)

Liliana Guevara Opinska, Tycho Smit, Koen Rademaekers (Trino

# Policy Support for Heating and Cooling Decarbonisation

Meta-study

Part 1: Strategies and policies for decarbonising heating and cooling in buildings

# 1. Introduction to the Meta-study

The decarbonisation of heating and cooling (H&C) is a key priority for meeting the EU energy and climate targets. H&C account for about half of the final energy demand in the EU, with almost 80 % of the demand provided by fossil fuels[81].

With heating in buildings accounting for about 30 % of the EU energy demand of the H&C sector[82], strategies are needed to accelerate the retrofit of buildings and the transition to zero-carbon heating and cooling supply. At the EU level, the 'Fit-for-55' package includes proposals for strengthening the provisions for the decarbonisation of this sector across several directives: The proposal for the revision of the Renewable Energies Directive[83] (RED) foresees a strengthening of the target for increasing the share of renewable energy in H&C (Art. 23) as well as the introduction of a new target for the buildings sector (Art. 15). The proposal for the revised Energy Efficiency Directive[84] (EED) foresees strengthening the requirements for public buildings (Art. 5), as well as provisions for energy efficiency obligations (Art. 7). The proposal for the revision of the EU Emissions Trading System (ETS) in the ETS Directive[85] introduces a separate ETS for heating and road transport. The proposal for the revision of the Energy Performance of Buildings Directive (EPBD)[86] provides a framework for introducing Minimum Energy Performance Requirements (MEPS) for existing buildings, whose potential role for substantially increasing the renovation rate was highlighted in the Renovation Wave Communication[87]. In addition, the revision of the Ecodesign and Energy Labelling regulations for boilers and water heating are currently ongoing. Along with a strengthening of requirements for decarbonising buildings, the new funding schemes in the context of the Multiannual Financial Framework and the Next Generation EU programme (NGEU) provide the opportunity to support the investments necessary to transform the sector.

In the context of the dynamic policy developments in the sector, a large body of literature has been developed by scientific institutions and think tanks in recent years, covering a variety of aspects related to the transition of the heating and cooling sector.

The meta-study collects the background scientific literature that informed the preparation of the heating and cooling decarbonisation Roadmap, which is one of the deliverables under this project. In addition, the aim of the meta-study is to support stakeholders and decision-makers involved in the decarbonisation of heating and cooling in the EU and its Member States by providing an overview of the scientific knowledge base. The meta-study reviews recent studies addressing the decarbonisation of the sector. The studies were identified by searching the CORDIS and Web of Science databases and through internet research.

The meta-study consists of three parts:

- Part I: Strategies for the decarbonisation of H&C in buildings, covering an overview of studies providing modelling pathways at EU level, contributions assessing policies and

[8181] According to the Eurostat SHARES data, the share of renewable energies in H&C was 22%.

[82] See https://heatroadmap.eu/wp-content/uploads/2019/03/Brochure_Heating-and-Cooling_web.pdf

[83] RED proposal : https://ec.europa.eu/info/files/amendment-renewable-energy-directive-implement-ambition-new-2030-climate-target_en

[84] EED proposal: https://ec.europa.eu/info/files/proposal-directive-energy-efficiency-recast_en

[85] ETS proposal: https://ec.europa.eu/info/files/revision-eu-emission-trading-system_en

[86] EPBD proposal: https://ec.europa.eu/energy/sites/default/files/proposal-recast-energy-performance-buildings-directive.pdf

[87] https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf

financing strategies as well as national strategies for the decarbonisation of heating and cooling.

- Part II: Decarbonising industrial heating and cooling, covering studies addressing decarbonisation strategies for process heat.
- Part III: Energy carriers and infrastructure, covering an overview of the different decarbonisation options including heat pumps, biomass, solar thermal, geothermal, hydrogen and e-fuels as well as the studies addressing sector coupling and infrastructures.

This section presents part I of the meta-study, reviewing recent works addressing pathways, policies and strategies for the decarbonisation of heating in buildings. The meta-study was conducted between January 2020 and September 2021. **Error! Reference source not found.** provides an overview of the studies contained in this part of the meta-study.

Chapter 2 provides a synthesis of the analysis of the studies. Chapter 3 includes summaries of the individual studies.

**Table 1**

*Overview of studies reviewed in Part I: Strategies for decarbonising heating in buildings*

| **Transition pathways at EU level** | |
|---|---|
| 1 | GHG-neutral EU2050 – a scenario of an EU with net-zero greenhouse gas emissions and its implications (UBA 2019) |
| 2 | Towards fossil-free energy in 2050 (Element Energy and Cambridge Econometrics 2019) |
| 3 | Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) - Work package 3: Scenarios for heating & cooling demand and supply until 2020 and 2030; Work package 4: Economic Analysis (Fraunhofer ISI et al. 2017a)(Fraunhofer ISI et al. 2017b) |
| 4 | Hotmaps (Aalborg University et al. 2020) |
| 5 | Decarbonisation pathways (Eurelectric 2018) |
| 6 | Towards a decarbonized heating and cooling sector in Europe<br>(Aalborg University 2019) |
| **Policies and Strategies** | |
| 7 | Lessons learned to inform integrated approaches for the renovation and modernisation of the built environment (BPIE et al. 2021) |
| 8 | Renewable Heat Policies. Delivering clean heat solutions for the energy transition (IEA 2018) |
| 9 | Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) - Work package 5: Barriers, Best Practices and Policy Recommendations (Fraunhofer ISI et al. 2017c) |
| 10 | Best practice in heat decarbonisation policy: A review of the international experience of policies to promote the uptake of low-carbon heat supply (UKERC 2016) |

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|---|---|
| 11 | progRESheat: Policy recommendations to decarbonise European heating and cooling systems (Fraunhofer ISI et al. 2017e) |
| 12 | Policies to enforce the transition to nZEB: Synthesis report and policy recommendations from the project (TU Wien et al. 2014) and Overview and assessment of new and innovative integrated policy sets that aim at the nZEB standard (Bürger 2013) |
| 13 | National restrictions on fossil fuels in heating systems in the context of the Ecodesign Directive (Öko-Institut and Klinski 2021) |
| 14 | Filling the policy gap: Minimum energy performance standards for European buildings (Sunderland and Santini 2021) |
| 15 | Minimum energy efficiency standards for a fair energy transition (BPIE and RAP 2018) |
| 16 | Policy proposals and concepts for tools of the Green paper on good practice in EPC assessment, certification, and use (QualDeEPC 2021) |
| 17 | Next-generation EPC's user and stakeholder requirements & market needs (D2EPC 2021) |
| 18 | The Concept of the Individual Building Renovation Roadmap – An in-depth case study of four frontrunner projects (iBROAD 2018) |
| 19 | Pricing is just the icing: The role of carbon pricing in a comprehensive policy framework to decarbonise the EU buildings sector (Thomas et al. 2021) |
| 20 | Efficient District heating and cooling systems in the EU (Tilia 2016) |
| 21 | Transition Zero - Make Net Zero Energy Refurbishments for Houses a Mass Market Reality: Position Paper on Funding Instruments (Energiesprong 2017)<br>Report on Market Assessment and Bottlenecks (Energiesprong 2018) |
| 22 | Low-carbon heating of homes and businesses and the Renewable Heat Incentive (National Audit Office 2018) |
| 23 | Evaluating the renewable heating and efficiency obligation for existing buildings – insights into the mechanisms of mandatory building requirements (Pehnt et al. 2019) |
| 24 | ZEBRA 2020 – Nearly zero energy building strategy 2020 (TU Wien - Energy Economics Group et al. 2016) |

| | |
|---|---|
| 25 | Building sector Efficiency: A crucial Component of the Energy Transition (Agora Energiewende 2019) |
| 26 | Building energy renovation for decarbonisation and Covid-19 recovery (Zangheri et al. 2020) |
| 27 | Digitalisation: Opportunities for heating and cooling (JRC 2019) |
| **Financing** | |
| 28 | De financiële gevolgen van de warmtetransitie: Een onderzoek naar de investeringsuitdaging, effecten op energie-betaalbaarheid en het potentieel van (nieuwe) financieringsvormen (ECORYS 2019) |
| 29 | Financial Incentives for Renewable Heating and Cooling (EREC 2007) |
| 30 | Identification of EU funding sources for the regional heating and cooling sector (PNO Consultants 2019) |
| 31 | Matching money with green ideas (Agora Energiewende 2021) |
| 32 | Innovative financing schemes (Covenant of Mayors 2019) |
| 33 | Policy developments in the EU and strategies for P4P business models (SENSEI 2021) |
| **National Strategies** | |
| 34 | Climate Agreement (Netherlands) (Ministerie van Economische Zaken en Klimaat 2019) |
| 35 | Heat Transition 2030 (Agora Energiewende 2017) |
| 36 | Energy Efficiency Strategy for Buildings (BMWi 2015) |
| 37 | Systemic challenges of Germany's heat transition (Fraunhofer ISE et al. 2020) |
| 38 | French strategy for energy and climate (Ministière de la transition écologique et solidaire 2018) |

# 2. Synthesis of Findings: Part I

## 2.1. Decarbonisation pathways

The meta-study reviews recent modelling studies projecting pathways for the decarbonisation of space heating (see Table 1). While the transition pathways differ in the level of detail, approaches, scope and technological focus, the analysis aims to assess the key elements required for the transition: The reduction of energy demand and the role of energy efficiency measures (Section 2.2.1), the share of renewable energy sources (Section 2.1.2), the supply structure (Section 2.1.3), the level of electrification (Section **Error! Reference source not found.**) and the role of synthetic gases (Section 2.1.5).

### 2.1.1. Reduction of energy demand

The **reduction of the energy demand** in buildings is seen as key for achieving the long-term greenhouse gas (GHG) reduction goals. Reducing the energy demand by enhancing energy efficiency also prepares the ground for a large-scale application of renewables in the heating sector by reducing the needed temperatures in the heating systems of buildings (Element Energy and Cambridge Econometrics 2019). The reduction of heating demand until 2050 ranges between 28 and 47 % compared to 2015 in the various studies (excluding process heat). The highest overall reduction of 47 % by 2050 is reported in (UBA 2019), with space heating demand being reduced by almost 60 %, water heating by 13 % and space cooling by 5 %. Simultaneously, the final energy demand for ventilation is increased by 1,500 %. In the project Hotmaps (Aalborg University et al. 2020; TU Wien et al. 2019) a reduction of 28 % (current policy scenario) and 35 % (ambitious policy scenario) for heating and cooling is expected. Space heating will still have a share of 66 to 71 % in the total final energy demand for heating and cooling in residential and non-residential buildings. The share of cooling increases from 2 % to 8-9 % and the share of hot water from 13 % to 19-22 %.

Key elements for achieving a reduction of energy demand are the increase of the **rate and depth of renovations** of buildings as well as a switch to **highly efficient heat and cold supply** technologies. In addition, it is essential that **new buildings** are constructed in a way that the energy demand is minimised, and the remaining energy demand is supplied to a large extent by on-site renewables. With regard to the **increase of the renovation rate**, the study GHG-neutral EU2050 (UBA 2019) assumes an increase of the refurbishment rate from 1 % to 2.5 % in non-residential buildings and to 2.75 % in residential buildings. Thereby, the final energy demand for space heating decreases by 25 % every five years, starting from 2020.

All studies assume an **increase of the minimum efficiency standards** for thermal retrofits. In (UBA 2019), starting from a maximum energy consumption of 80 kWh/(m²a) in 2015, a reduction by 25 % is assumed every five years starting in 2020. With regard **to new buildings**, (UBA 2019) assumes that all new buildings achieve a “passive house” space heating demand of 15 kWh/(m²a) from 2040 onwards, while the other studies do not explicitly specify the assumptions regarding buildings standards for new buildings.

### 2.1.2. Transition of the energy mix

The assessed studies strongly differ in the rating of different renewable energy sources, especially regarding the use of biomass in the (building) heating sector. While the use of biomass for space is reduced from 528 TWh to 39 TWh in GHG-neutral EU2050 (UBA 2019), the share of biomass in the overall heating and cooling supply is assumed to increase until

2030 in (Fraunhofer ISI et al. 2017b) and biomass is still seen as the most important renewable energy source in 2050 in Hotmaps (TU Wien et al. 2019). In all studies, a strong increase of the use and share of solar thermal energy and heat pumps is expected. In Hotmaps, heat pumps are seen as the dominating technology for heat supply especially in rural areas; they provide about 63 % of the final energy demand for heating. The remaining 32 % are provided by geothermal, solar thermal, biomass and secondary fuels like biofuels, hydrogen ($H_2$) and district heat. In (UBA 2019), solar thermal is expected to cover 14 % of the heating and 19 % of the hot water demand and electrical heat pumps 8 % of heating and 24 % of hot water demand.

Synthetic gases and fuels are an option to store electricity from fluctuating renewable generation seasonally and furthermore make renewable energy available in sectors which are difficult to electrify directly. However, the importance of synthetic gases and fuels for decarbonising the building and district heating sectors differs among the studies. In (UBA 2019), results show that renewable fuels cover 230 TWh or 16 % of the heating demand and 10 % of the hot water demand in 2050. However, buildings only account for 5 % of the renewable fuel demand, while demand from the industry reaches almost 1,000 TWh for process heat and almost another 1,200 TWh for feedstocks. Overall, the industry sector is responsible for 45 % of renewable fuel demand. The conversion sector uses another 800 TWh for peak gas turbines and district heating. The importance of synthetic gases is highlighted in (Element Energy and Cambridge Econometrics 2019) for countries with seasonal fluctuations in heat demand like in central and northern Europe. In these areas it is favourable to produce hydrogen in periods of high renewable electricity supply, which can then be stored for use in periods with high heat demand.

In addition to the need for seasonal storage, developments until 2030 could lead to lock-ins if there are still many gas-burning technologies being installed in buildings, which have a technical lifetime of 20 years, but are often used much longer. In mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables), the current policy scenario shows that natural gas is still the dominating fuel in heating and cooling with a share of approx. 40 %, which either has to be replaced by fuel-switch within 20 years, or at least partly be supplied by renewable gases.

### 2.1.3. Electrification

Electrification plays an important role in most of the scenarios, and electricity demand for heating is expected to increase considerably. An increase in electricity demand of 50 % is calculated in (UBA 2019), while in (Eurelectric 2018) the assessed scenarios show that 38 % to 60 % of the final energy consumption is directly electrified and 45 % (Scenario 1) to 63 % (Scenario 3) of the building energy consumption could be supplied by electricity (mainly electric heat pumps). In contrast, the current policy scenario of the study Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) expects a decrease of the electricity demand (for heating and cooling) of 7 %.

Besides investments in electricity driven heat generation technologies, investments in the electricity grid are essential. Even though large investments are needed, the study Towards fossil-free energy in 2050 shows that electrification scenarios lead to the lowest annual costs associated with the transition to a net-zero emission energy system with lowest costs achieved in scenarios with a focus on demand side flexibility. This is related to lower needs in terms of electricity generation capacity as well as lower transport capacity requirements.

### 2.1.4. District heating

While final energy demand covered by district heating is assumed to decrease in absolute values in most scenarios, the studies highlight the importance of district heating for the decarbonisation of the heating sector especially in urban areas. The highest share of district heating is found in the study (Aalborg University 2019), in which a share of about 50 % in the final energy demand for heating is assumed. In all scenarios, the importance of integrating district heating systems and the installed supply technologies in the overall energy system (sector coupling) is emphasised. In this regard, a fuel switch to electricity driven technologies like large-scale heat pumps is an essential part for decarbonising the heat supply and providing flexibility to the electricity grid needed for integrating fluctuating renewable electricity production. Furthermore, CHP capacities are needed to generate electricity when needed in the grid. However, the fuels used in CHP plants will switch from mainly coal and natural gas to partly biomass and waste as well as synthetic and renewable fuels.

- **Focused local policy and coherence with urban planning**: energy supply must be integrated in long-term urban planning (including zoning for different heat and cold supply options), focus on compact and mixed-used districts, mandatory connection to grid (if possible and economically feasible)
- **Alignment of interest/ cooperation maturity** between DHC operators, consumers and municipality/ local authority

## 2.2. Policies and strategies

The studies included in the meta-study identify a multitude of barriers for the decarbonisation of H&C, including economic barriers (high investment costs, low prices for fossil fuels, lack of economies of scale resulting in higher prices), structural barriers (split incentives, lack of supply chains), technical barriers (suitability of the building stock and process heat technologies), psychological barriers (lack of awareness, hassle factor) and a lack of data at various levels (IEA 2018).

These multiple barriers need to be addressed by multiple policy instruments, working together in a consistent policy set. Several studies included in the meta-study identify the need for an integrated policy mix including regulatory, economic and other complementary policies (Fraunhofer ISI et al. 2017e; IEA 2018; BPIE et al. 2021; UKERC 2016; Fraunhofer ISI et al. 2017c; Thomas et al. 2021).

The following subsections provide an overview of the findings across several elements of the decarbonisation of heating in buildings.

### 2.2.1. Reduction of energy demand

Increasing energy efficiency in buildings is key for the cost-optimal achievement of climate targets (Agora Energiewende 2019). If less energy savings in buildings are achieved, more renewable energy must be generated, heat pumps run with lower efficiency, and more synthetic fuels must be supplied. Due to the long lifetimes of building components, this requires immediate action in the building sector. Energy efficiency in buildings reduces the overall economic costs including the expenditure for energy generation and distribution and efficiency measures in buildings are a door-opener for low-temperature applications (Agora Energiewende 2019). To this end, an efficiency roadmap including long-term goals for the building stock is an essential component to avoid lock-in effects.

### Nearly zero-energy buildings and minimum energy performance standards

A key challenge is the **increase of the energy efficiency by deep renovations of existing buildings**. All assessed studies highlight the importance of establishing and defining binding long-term efficiency targets for new and existing buildings.

New buildings must be "nearly zero-energy buildings" (nZEB) as defined in the Energy Performance of Buildings Directive (EPBD). The exact definition of an nZEB is developed at the Member State level. An overview of the status of the implementation and definition of the nZEB standard as well as the nZEB market development is presented in (TU Wien - Energy Economics Group et al. 2016). The study shows that it is essential to have a **clear and shared long-term vision for the building stock** at Member State level, but also for the whole EU. This is of major importance to **define suitable and target-compatible nZEB definitions** and thereby guarantee that **future-proof buildings** are constructed.

For existing buildings, Minimum Energy Performance Standards (MEPS) are seen as a key instrument to drive renovations aligned with the EU climate targets (Sunderland and Santini 2021; BPIE et al. 2021). MEPS can help overcome important barriers when introduced as part of a comprehensive renovation policy framework including financial, technical and practical support and measures to limit the burden especially for low-income households (BPIE et al. 2021). MEPS for rented buildings have the potential to support a fair transition by alleviating energy poverty and providing health benefits (BPIE and RAP 2018). Regarding the market for building renovations, MEPS produce a "demand floor" for renovation finance and create continuity, predictability and scalability in the market by helping to align the demand and the supply chains (BPIE et al. 2021). With MEPS typically being defined based on the energy classes provided in energy performance certificates, it is essential to enhance their quality and foster their deployment (see Section 0).

### Energy performance certificates

Energy performance certificates and building renovation passports are seen as important instruments not only as a supporting tool to introduce MEPS but also to increase motivation and acceptance for deep retrofits among building owners (BPIE et al. 2021). To this end, it is important to transform Energy Performance Certificates into Building Certificates or "Building Passes" considering the whole lifetime of a building, which could increase their reliability and credibility (TU Wien - Energy Economics Group et al. 2016). Furthermore, the gathering, availability and harmonisation of building data and information and the introduction of digital building logbooks are seen as key elements (BPIE et al. 2021).

### Serial retrofit and digital technologies

The Energiesprong concept (see (Energiesprong 2017) and (Energiesprong 2018)) first established in the Netherlands is one option to **increase the refurbishment rate** and thereby increase the energy efficiency of the existing building stock. The project Transition Zero aimed at establishing the **right market conditions** for the broad introduction and market acceleration of net zero energy homes in Europe with a focus on the UK and France. It built on the experience of the Energiesprong concept in the Netherlands. Five main bottlenecks were identified in the project, amongst them high transaction costs and often poor-quality delivery due to a fragmented supply side, but also a lack of demand for integrated components/ solution sets and a lack of skilled workers. It is highlighted that chances for (deep) refurbishment usually only appear once in several decades and therefore the importance of policymakers addressing what is needed and not only what is thought to be possible is emphasised to achieve the long-term climate protection targets at EU level. A possible solution is an **energy performance guarantee** at least for refurbishments. For new buildings, an efficiency standard of <30 kWh/m²a (thermal) is recommended and for refurbishment the net zero standard is suggested. Both should be introduced as a binding standard as soon as possible. To achieve the latter,

**prices for refurbishments must drop dramatically** in order to ensure that energy cost savings cover the refurbishment costs, and refurbishment needs to be delivered within a shorter period.

On the side of the building end-user, building energy management systems can support the reduction of energy demand in buildings (JRC 2019). Such systems combine software with smart thermostats and sensors to detect behaviour and use weather forecasts and energy prices to predict energy demand and control heating and cooling. A cost-effective first step is to provide regular feedback (e.g. via smart meters, in-house displays, energy bills or emails). However, several studies show that it is difficult to engage households on energy issues, especially if the information received is not clear, actionable and timely or frequent enough. With new developments in artificial intelligence, systems can also increasingly be interconnected and controlled on smartphones. Thus, artificial intelligence offers the opportunity to significantly increase the balance between energy savings and user-defined comfort.

### 2.2.2. Renewable heating

The transition to renewable energies in decentralised heating in buildings requires a regulatory framework for phasing out fossil boilers as well as economic instruments (Öko-Institut and Klinski 2021; IEA 2018; Fraunhofer ISE et al. 2020).

Economic instruments can address the challenge that renewable heat appliances are typically more expensive than fossil-based alternatives. Support can be provided by directly supporting the investment (e.g. through grants, loans and tax breaks), by incentivising the renewable heat output through renewable heat incentives (National Audit Office 2018) or through the introduction of bonus/malus schemes (see also Section 0). Aside from investment support, carbon pricing can be an important driver for increasing the viability of investment in renewable heating and cooling equipment (see Section 0).

In addition, regulations to support the phase-out of fossil fuels are required to ensure target achievement and to support the development of the market for renewable heating and cooling technologies. These can be introduced as renewable heat obligations (Pehnt et al. 2019) or as bans for fossil fuel boilers (Öko-Institut and Klinski 2021).

When scaling up the market for renewable heating and cooling technologies, policies that address the quality and technological performance are important. This includes labels, training for installers and the introduction of mechanisms for consumer complaints (UKERC 2016).

Heat pumps are expected to play a leading role in future energy consumption (see Section 2). For heat pumps, it is important to support the development and deployment of digital solutions. Digitalisation potentials are seen alongside the deployment of heat pumps, where sensors are used that provide data on temperature, weather and electricity prices, as well as smart controllers that understand the thermal behaviour of the building and the user and can provide this data to optimise the application (JRC 2019).

### 2.2.3. Economic measures and financing

#### Investment support and financing

Access to finance is a key consideration for many projects focused on decarbonising the H&C sector and significant investment is still required for the widespread deployment of renewable and low-carbon solutions in the sector. In this context, financial incentive schemes in the form of grants, loans, guarantees, etc. can facilitate the overcoming of market barriers and speed up the transition process in the H&C sector. They can be used to reduce upfront investment cost and stimulate market development and availability of RES H&C technologies among other benefits (EREC 2007). There is a variety of existing financing instruments including grants and loans for specific target groups (involving vulnerable households, elderly), social tariffs, tax breaks and energy saving obligations (BPIE et al. 2021). Other financing mechanisms include renewable heat incentives (National Audit Office 2018) and fiscal measures through a bonus-malus system, where building owners with a building that is "future-proof" (e.g. based on the EPC rating or building renovation passport) receives a tax credit, while buildings trailing the standard will have to pay a fine (BPIE et al. 2021).

Investments in H&C projects, energy efficiency and renewable energy, still have relatively long payback periods or/and are perceived as high risk. In order to have a convincing business case such investments often require the maximisation of public funding. Although there are currently no dedicated financing instruments for H&C at EU level, a large number of generic energy subsidies and grants are available and can be accessed for the purpose of financing H&C initiatives (PNO Consultants 2019). One reason why these instruments are not fully exploited by the sector is lack of information on the side of key stakeholders. The compilation and accessible description of relevant funding sources can be useful to support stakeholders in the field.

Innovative financing instruments, such as on-bill schemes and energy performance contracting, are promising solutions as they can leverage private sector resources, however such instruments are still not mainstream. There is a lack of de-risking strategies, with insufficient evidence on the performance of energy efficiency investments in buildings making financial risk harder to assess and mobilisation of both public and private investments more difficult (BPIE et al. 2021). Another approach for financing energy efficiency and renewable energy investments in buildings are transaction models building on pay-for-performance (P4P) schemes, where payments for energy efficiency are based on proven and measured savings (SENSEI 2021)

Innovative financing instruments that have been deployed in some municipalities and regions include green municipal bonds, earmarking environmental or energy taxes, energy performance contracting, local energy cooperatives, soft loans for renovation projects, on-tax financing, third-party investments and revolving funds (Covenant of Mayors 2019).

Energy efficiency obligations can drive the retrofit market by stimulating the development of new business models such as ESCOs and provide an additional income stream for renovation programmes (BPIE et al. 2021).

### Carbon pricing

The need for levelling the playing field for renewable heating by introducing carbon pricing is highlighted in several studies (Agora Energiewende 2019; BPIE et al. 2021; Thomas et al. 2021; UKERC 2016; Fraunhofer ISI et al. 2017d). Carbon pricing increases the economic viability of renewable heating and cooling. However, in view of the variety of non-economic barriers, carbon pricing can only play a complementary role in the transition and a strong regulatory framework is needed (Thomas et al. 2021). Carbon pricing can also support the transition if the revenues are used to support energy efficiency and heat decarbonisation policy measures. The emission reductions induced by revenue recycling to support investments deliver emissions savings going beyond the effect of the price alone and supporting low-income households can help to address social challenges and increase acceptance (Thomas et al. 2021).

### 2.2.4. Capacity building, qualification, information, motivation, and advice

The transition to renewable heating and cooling requires a supportive policy framework to increase **awareness, skills and competences** including local communication activities, the involvement and empowerment of consumers and citizens as well as addressing intermediaries such as craftsmen, architects or project developers (Fraunhofer ISI et al. 2017e). This includes 1) the communication of low-carbon transformation plans at the local level, e.g. by implementing visible demonstration projects; 2) consumer empowerment and transparency of costs and benefits; 3) intensifying policies for crucial change agents such as craftsmen, architects and planners, e.g. through regional training programmes, the initiation of local networks, changes in the education system for craftsmen and by addressing change agents in RES policies; 4) capacity building and supporting tools for the municipal level, e.g. based on EU projects like ProgRESheat, Celsius and Hotmaps. Furthermore, the development of one-stop-shops facilitating retrofit measures are highlighted in various studies.

Several studies highlight one-stop shops as important enablers for increasing the rate and depth of thermal retrofit (BPIE et al. 2021; D2EPC 2021; Boza-Kiss and Bertoldi 2018) and several examples of one-stop-shop approaches have been implemented in EU Member States (Boza-Kiss and Bertoldi 2018).

A bottleneck for the building sector is the **availability of skilled labour** (Agora Energiewende 2019).

### 2.2.5. District heating

District heating provides the possibilities of large-scale integration of renewables and is a key strategy for decarbonising heating especially in densely populated areas. In order to support the decarbonisation of heating and cooling, the expansion of district heating grids as well as a reduction of the grid temperatures is needed. Furthermore, a transition to renewable energies is required. The transition can be supported by a variety of policies (UKERC 2016; Fraunhofer ISE et al. 2020; Tilia 2016):

**Strategic municipal heat planning** is essential to avoid parallel expensive infrastructure and conflicts. This is of major importance for the gas and district heating infrastructure, but also for the use of ambient heat from the ground or ground water with heat pumps. Heat planning can be fostered by introducing an obligation for municipalities above a certain size and/or by providing financial support and guidance to municipalities.

As investment cycles in the district heating sector are long and the transition and expansion of district heating systems needs time, transition pathways including **quota for renewable energies and waste heat** in district heating systems until 2050 need to be defined.

An improvement of the **regulatory frame of the systems** (currently single systems can be considered as local monopolies) and an adjustment of support schemes is required in order to ensure the needed grid expansion, densification, temperature adjustments and integration of renewables.

**Financial support schemes are important** for the deployment of district heating in liberalised markets. Financial support may be provided for network development, to consumers for connecting to DH (e.g. subsidy for replacing fossil-based heating systems), or for heat production technologies such as (biomass) CHP (e.g. tradable certificates for renewable electricity, production-based incentives). The sequencing of policies supporting CHP and the deployment of DH is important.

Planning frameworks supporting or mandating district heating (**zoning regulations**) can reduce the financial risk of developing district heating projects. European countries with high levels of district heating have greatly reduced the risk of demand uncertainty through heat planning, including granting monopoly powers to district heating companies, leading to the ability to access capital at very low rates, and willingness to invest for relatively low rates of return.

**Price regulation** can be important to increase consumer confidence and ensure consumer protection in district heating, in particular, where planning has created monopoly operation. For example in Sweden, cost-based pricing was mandatory and district heating companies were prohibited from making profits before the liberalisation. Price regulation ended with liberalisation, leading to protests from consumers who argued that district heating operators were then in a position to take advantage of operating as a natural monopoly.

**Digital technologies** can make DHC more efficient, intelligent and cost-effective by enabling data management in terms of temperatures, flow, leak detection or pressure. New district heating technologies improve energy efficiency and make it easier to integrate renewable energy, e.g. by establishing platforms for real-time collection of energy consumption data, identification of building heating and cooling needs depending on energy efficiency, energy consumption and building type, forecasting short- and long-term weather conditions and upcoming heating and cooling needs, and monitoring and controlling the level of energy storage. Several EU-funded projects have developed innovative approaches for DHC as well as platforms supporting smart DHC, e.g. TEMPO[88], CELSIUS[89], COOL DH[90], RELaTED[91], THERMOS[92] or FLEXYNETS[93].

### 2.2.6. Examples from Member States

Most of the analysed national heat strategies have quantitative targets for the reduction of energy demand for heating, which in some cases are complemented with specific targets for the improvement of existing buildings (e.g. 1.5 million by 2030 in the Netherlands; thermal retrofit of 1,200,000 homes in the decade 2021-2030 in France). Key policy measures to support these targets are various funding schemes (most countries), the improvement of energy labelling of buildings (France), building-specific renovation roadmaps (Germany), consulting and information (Germany), minimum standards, training of professionals (France) and energy efficiency obligations (France).

While all considered national strategies foresee a considerable increase of the share of renewable energy sources, the approach to decarbonise the heating sector differs among the strategies. The Netherlands propose a district approach, in which municipalities take the lead in the transformation through "heat visions", which are developed at municipal level. The decarbonisation measures proposed in the strategies in France and Germany largely address building owners as well as professionals in the building sector. The strategies do not provide quantitative targets for individual RES-H technologies. In addition to subsidy schemes, the

[88] https://www.tempo-dhc.eu/

[89] https://project.celsiuscity.eu/

[90] http://www.cooldh.eu/

[91] http://www.relatedproject.eu/

[92] https://www.thermos-project.eu/home/

[93] http://www.flexynets.eu/en/

strategies highlight regulatory measures (RES quota) to increase the share of renewable energies for heating.

In Germany, the installation of mono-fuel oil boilers is phased out from 2026. Denmark has the most comprehensive approach for restricting the use of fossil fuels, based on a use obligation for renewable energies for new and existing buildings, connected to heat zoning. In Austria, the installation of oil boilers has been banned in new buildings since 2019. The Netherlands have introduced restrictions for the connection of new buildings to the gas grid, thus phasing out the use of gas in new buildings. In Norway, oil for heating is banned since 2020, covering not only the installations of boilers but also the use of fuels in existing boilers (Öko-Institut and Klinski 2021). For RES-H obligations in existing buildings, despite being part of the EU Renewable Energy Directive, the experience is still limited. The RES-H obligations implemented in the EWärmeG in Baden-Württemberg (Germany) provide an example (Pehnt et al. 2019).

The role of the gas infrastructure as well as synthetic gases is explicitly addressed in the strategies of the Netherlands and France. The French strategy contains a target for biomethane and foresees the use of hydrogen only for industrial processes and not for space heating. In the Netherlands, green gases and hydrogen form part of the transition pathways that are analysed by municipalities in the context of the heat vision.

All strategies considered in the meta-study foresee a growth in district heating as well as its transformation to renewable energies. The French strategy contains a quantitative target for heat and cold delivered by district heating and supports this target through various subsidy schemes as well as the requirement for municipalities to conduct feasibility studies. In the Netherlands, district heating is one of the strategies analysed in the context of the heat vision. None of the national strategies explicitly address the transformation of existing district heating networks, however the pathway projections in (Agora Energiewende 2017) conclude that it is essential that temperatures are reduced and deep geothermal energy, large-scale solar thermal installations and/or ambient heat/waste heat utilisation (drain water, industry, rivers, sewage water, etc.) with large-scale heat pumps are expanded.

# 3. Summary of studies: Part I

## 3.1. Modelling pathways

| **GHG-neutral EU2050 – a scenario of an EU with net-zero greenhouse gas emissions and its implications (UBA 2019)** |
|---|
| ***Overview***<br>The aim of the study is to provide a scenario GHG-neutral EU2050 for an EU with net-zero GHG emissions in 2050. The study differs from other scenarios such as the EC's Strategic Vision "A clean planet for all" with respect to the use of bioenergy and CCS, which are strongly restricted in the scenarios. While the study covers the emissions in all sectors, the focus of the summary is on the heating and cooling sector (space and water heating and process heat). |
| ***Key assumptions and drivers*** |

For the development of **space heating**, the study is based on the following assumptions and drivers:

- The refurbishment rate increases from 1 % to 2.5 % (non-residential buildings) and 2.75 % (residential buildings)
- The final energy demand for space heating (residential as well as non-residential) is lowered by 25 % every five years, starting from 2020. From 2040 onwards all new buildings achieve a "passive house" space heating demand of 15 kWh/(m²a). The refurbishment standard for newly refurbished buildings starts with 80 kWh/(m²a) in 2015 and is reduced by 25 % every five years starting in 2020 (for countries with a current demand below this level the starting point is the current demand).
- The equipment rate for cooling systems is kept constant at 0.1 % (residential buildings) and 0.5 % (non-residential buildings).
- The residential floor area increases from 22.5 billion m² in 2015 to 28.3 billion m² in 2050 (+26 %) and the floor area in non-residential buildings increases from 6.3 billion m² in 2015 to 7.3 billion m² in 2050 (+17 %).

For electricity generation, the study assumes no construction of new **nuclear power plants**, while existing power plants and those under construction continue to be operated until the end of their technical lifetime, resulting in a total of 4.1 GW of nuclear power plants still in operation in 2050.
The study excludes the large-scale use of **carbon capture and storage technologies (CCS)**.
The **biomass available for energy purposes** is limited to waste and residual materials.

***Results for space and water heating***

**Reduction of final energy demand**

A reduction in final energy demand of -47 % is achieved for the combined demand for space heating, hot water, ventilation and space cooling in 2050 as compared to 2015 (space heating: almost- 60 %; hot water: -13 %; ventilation demand: +1500 %; space cooling: -5 %)

**Energy mix in 2050**

For space heating (1,443 TWh total demand), the use of solar thermal energy and heat pumps increase strongly (25 TWh to 198 TWh and 33 TWh to 114 TWh). Demand for district heating and direct electricity decreases (48 % and 24 % reduction, respectively). The decentralised use of biomass for heating purposes is substantially reduced from 528 TWh to only 39 TWh to make the biomass available for other purposes including grid heat. Renewable fuels cover 230 TWh or 16 % of the demand in 2050. For hot water (674 TWh), half of the demand is supplied by renewable sources (heat pumps, solar thermal and biomass), with strong increase in solar thermal energy (26 TWh to 130 TWh) and heat pumps (23 TWh to 159 TWh). The need for electricity increases by 20 %, driven by the increase in heat pumps, while district heating decreases by 50 % to a share of 18 % in 2050. Renewable fuels account for 10 % of the demand.

**District heating**

In district heating, 20 % of generation come from local renewable sources, i.e. solar and geothermal energy, 4 % from non-renewable waste and the remaining part from electricity, either directly through heat pumps and electrode boilers, or indirectly through renewable fuels.

***Results for process heat***

Total energy demand in industry is reduced by 12 % in the year 2050 and the energy demand is met by electricity, ambient heat and renewable fuels. The demand for electricity increases by 50 % while the demand for district heating is roughly cut in half. Radical technology switches in production processes and innovations are required:

- Iron and steel industry: Radical switch away from blast oxygen furnaces to the mature but not common technology of hydrogen-based direct reduction of steel and scrap-based electric arc furnaces.
- Diffusion of new kinds of low-carbon cements as well as recycling in the sector of non-metallic minerals.
- In the chemical sector, alternative synthesis using hydrogen and methanol.

The study highlights that for all the radical innovations required, pilot and demonstration plants need to be built to prepare for market introduction. It may take ten years to progress from lab-scale to market, where certification processes such as those needed for new cement types can prolong the time taken even more. Consequently, the current policy mix needs to be adjusted to effectively support R&D activities directed at the GHG neutrality of all subsectors.

***Renewable fuels (hydrogen, synthetic hydrocarbons, biogenic energy sources)***

Buildings account for 5 % of the renewable fuel demand, while demand from the industry reaches almost 1,000 TWh for industry process heat and almost another 1,200 TWh for feedstocks. Overall, the industry sector is responsible for 45 % of renewable fuel demand. The conversion sector uses another 800 TWh for peak gas turbines and district heating.

Biogenic resources play a minor role, as almost all biogenic sources are used as a feedstock in the chemical industry. Hydrogen is relevant in two industry processes, namely steel and ammonia production.

**Towards fossil-free energy in 2050 (Element Energy and Cambridge Econometrics 2019)**

***Overview***

This study combined an energy systems model and macro-economic model to assess the impacts of different technological choices on the transition to a net-zero emission energy system in 2050, which also has important implications for heating and cooling. The two main types of pathways that are being investigated are those with a strong focus on electrification and those with a stronger focus on renewable molecules (e.g. renewable gases like hydrogen). The analysis differentiates the results based on groups of countries based on country archetypes, which are related to the nature of their renewable energy resources (wind vs. solar) and heating demand profile.

***Electrification and electricity infrastructure play a key role across scenarios***

Due to large-scale electrification of the energy demand and a strong growth of renewable electricity generation capacity across scenarios, all scenarios show significant investment needs relating to electricity infrastructure. Even in the high molecules scenario, the electricity network capacity needs to grow by 64 % and in the high-E scenario the capacity needs to double.

***Scenarios with a strong focus on electrification result in the lowest annual costs***

The electrification scenarios show the lowest annual costs associated with a transition to a net-zero emission energy system, with the scenarios deploying strong demand-side flexibility having the least cost. This is related both to a lower need in terms of total electricity generation capacity as well as a lower transport capacity requirement and hence lower investments in infrastructure. Within these demand-flexibility options, smart operation of heat pumps plays an important role. In the high molecules scenario, investment needs for district heating networks are lower, but this is more than compensated by the increased investment costs for electricity generation, due to the energy losses associated with hydrogen production. For Germany's country archetype the cost differences seem to be larger than for Spain's country archetype.

**Improving building performance can bring important system benefits**

Ambitious retrofits of building envelopes to reduce their heat loss and allow for lower-temperature heating systems brings along large cost savings. These cost savings derive from lower capital investments in electric heating technologies (mostly heat pumps), energy savings and hence lower demand for electricity generation capacity and lastly lower investment needs relating to infrastructure expansion. In order to reap the benefits of these savings in system costs, it is important that means are found to remunerate/reward people for these avoided costs.

**Hydrogen important for long term energy storage**

In countries with high seasonal fluctuations in heat demand (archetype Germany), mostly the northern countries and countries in central Europe, there is a need for seasonal energy storage. Increasing the electricity generation capacity is very inefficient, as this will lead to strong curtailment in other sectors (very low load factor) and thus high costs. Therefore, it is favourable to produce hydrogen in periods of high renewable electricity supply. This hydrogen can then be stored for use in periods with high heat demand. In these periods, the hydrogen is used for additional electricity generation in gas turbines in the high electricity scenarios, where the additional electricity is used to drive heat pumps and electric boilers. In the scenarios with high use of renewable molecules, some of the hydrogen is used directly for heating in boilers.

## Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) - Work package 3: Scenarios for heating & cooling demand and supply until 2020 and 2030; Work package 4: Economic Analysis (Fraunhofer ISI et al. 2017a)(Fraunhofer ISI et al. 2017b)

***Overview***

The aim of the study is to provide a detailed overview of the heat and cold supply as well as use in Europe in 2012. The study covers all 28 EU Member States plus Iceland, Switzerland and Norway. It is composed of five reports and a complete dataset. The reports are:

- Report 1: Work package 1: Final energy consumption for the year 2012
- Report 2: Work package 2: Assessment of the technologies for the year 2012
- Report 3 and 4 (published in one document): Work package 3: Scenarios for heating & cooling demand and supply until 2020 and 2030; Work package 4: Economic Analysis
- Report 5: Work package 5: Barriers, Best Practices and Policy Recommendations

This summary describes Reports 3 and 4. The other reports can be found in the respective sub-chapters by following the link given above.

The report on work packages 3 and 4 (i) analyses three scenarios for the development of the heating and cooling demand until 2020 and 2030 in all relevant sectors (households, tertiary and industry): current policy scenario and two different RES H/C obligation scenarios considering RES quota with trade options and (ii) a macro-economic impact analysis (GDP, employment, investment costs, benefits) of an increased share of renewables in the heating and cooling sector for the two scenarios developed in work package 3. The scenario analysis provided scientific backgrounds for the development of the RED II proposal (mainly articles 23 and 24).

***Key assumptions and drivers for the scenarios*** *(see (Fraunhofer ISI et al. 2017b))*

**General:**

For the scenario development, the bottom-up sector models FORECAST and Invert/EE-Lab are used to simulate the final and useful demand and supply of heating and cooling. Furthermore, the model Green-X is used to assess the development of district heating supply in detail.

**Current policy scenario:**

The scenario considers targets and measures concerning renewable heating and cooling as well as energy efficiency already agreed or implemented latest by the end of 2015. All implemented instruments including financial support programmes in the assessed countries are assumed to be in place by 2030 without significant changes in the period until 2030

**RES H/C obligation scenarios:**

The two scenarios analyse the introduction of renewable obligations for heating and cooling suppliers and distributors. The scenarios are based on the current policy scenario and assume additional obligations starting in 2020, which must be met by suppliers to increase the renewable share in heating and cooling across Europe. The scenarios are:

- Q0.55: Supplier obligation with a quota increasing annually by at least 0.55 % on member state level. Certificates can be traded within single countries. No other subsidies for renewable heating and cooling are in place after 2020.

Q27: Quota for the year 2030 at EU level of at least 27 % in the total final energy demand (excluding electricity). It allows the trade of certificates among suppliers across member states. No other subsidies for renewable heating and cooling are in place after 2020.

***Results***

**Scenarios until 2030** (Fraunhofer ISI et al. 2017b)

**Current policy scenario:**

- Final energy demand for heating and cooling decreases by approx. 7 % from 6,350 TWh to 5,930 TWh in 2030 mainly driven by thermal efficiency measures in buildings and higher average outdoor temperatures
- Final energy demand in the industry sector increases (+5.7 %) and only slightly decreases in the tertiary sector (-1 %), while it strongly decreases in the residential sector (-20.6 %); industry sector has a share of 42.5 % in total final energy demand for heating and cooling in 2030 overtaking the household sector as the dominating one
- Primary energy demand decreases by 9 % from 7,495 TWh/a in 2012 to 6,823 TWh/a in 2030
- $CO_2$ emissions drop by 22.5% from 1,427 million tons per year in 2012 to 1,106 million tons in 2030 (strongest decrease of 40.9 % in residential, lowest decrease of 5.3 % in industry sector)
- The **use of renewable energy sources increases** to 1,093 TWh (**+38 %**), while the direct use of fossil fuels is reduced by 15 %
- Electricity demand decreases by 7 %
- District heating demand decreases by 3 %

- **Natural gas is still the dominating fuel for heating and cooling** in 2030 (share of approx. 40 %)
- **Sharp decrease of heating oil deployment** (-43 % leading to an overall share of only 8 % in 2030)
- Share of biomass increases from 11 % to 14 %; most important renewable energy source in the heating and cooling sector
- **Strong increase of solar thermal energy** (+455 %), but still small share in the overall final energy demand (approx. 5 %)
- No significant change in the electricity demand for heating and cooling
- Share of district heating around 9 %, but with large differences amongst countries (in some countries strong increase)

**Q27:**

- **Needed certificate price** for reaching a renewable share in heating and cooling of 27 % RES-H/C at EU28 level is **3.5 €/MWh$_{th}$**
- **Achieved share of renewables is 27.2 %** (average annual increase of 0.58 % between 2020 and 2030)
- The share of renewables strongly differs amongst member states (between 12 % in UK and 67.2 % in Sweden)
- In Denmark, the scenario setting leads to an annual decrease of the renewable share of 0.03 %
- Between 2020 and 2030 an additional amount of 250 TWh of renewable energy is deployed
- **Compared to the current policy scenario**, the achieved **share of renewables is 1.4 percentage points higher** in the Q27 scenario

**Q0.55:**

- For each country, a specific certificate price to induce an annual increase of the deployment of renewable energies of 0.55 %/a is determined. In some countries, already a price of 0 €/MWh$_{th}$ leads to a higher increase and therefore the price is set to 0 €/MWh$_{th}$ in the respective countries. The countries are Czech Republic, Greece, Croatia, Malta, Sweden and Slovakia; in many countries the target is substantially exceeded
- The **desired increase is achieved in all countries except Cyprus (0.1 %) and Italy (0.54 %)**
- In the EU28, an **average annual increase of 0.61 %** is achieved leading to a **share of renewables in heating and cooling in the EU28 of 27.6 %** in 2030 (+267 TWh between 2020 and 2030, of which 109 TWh are induced by the certificate prices)
- The certificate price varies substantially across countries from zero to almost 20 €/MWh; the **weighted average certificate price is approx. 7.7 €/MWh in the EU28**
- The achieved share of renewables in heating and cooling varies between 12 % in the UK and 65.7 % in Sweden
- The achieved annual increase is between 0.1 % in Cyprus and 2.05 % in Malta
- **Compared to the current policy scenario**, the achieved **share of renewables is 1.7 percentage points higher** in the Q0.55 scenario

**Major differences of current policy and quota scenarios:**

- **Highest absolute increase of used renewable source is in biomass** (+42 TWh in Q27 and +81 TWh Q0.55); in the **medium term, biomass is the most relevant substitute of fossil fuels in high temperature industry** applications, but also for space heating in the tertiary and household sectors in countries with sufficient potentials
- **Strong increase of the use of ambient heat** in Q0.55 compared with the other scenarios: Heat pumps are a good option in countries with limited biomass resources and relatively cheap electricity supply

- **Strong increase in the use of solar thermal** (+22 %) in the quota scenarios compared to the current policy scenario
- **Importance of district heating decreases** in the quota scenarios compared to the current policy scenario (-3 % and -5 %)
- The **strongest decrease of non-renewable fuels** is observed for **natural gas** (-55 and -112 TWh)
- The primary energy demand in Q27 increases by 0.3 % and decreases by 0.1 % in Q0.55 compared to current policies
- The Q27 scenario only leads to a $CO_2$ emission reduction of 0.1 % compared to the current policies, while the Q0.55 scenario leads to a reduction of 2.8 %

**Economic analysis** (Fraunhofer ISI et al. 2017b)

In the economic analysis the ASTRA-EC model is applied. The assessed scenarios are the same as above (current policies, Q0.55 and Q27). Furthermore, detailed input from all used bottom-up models for the industry, tertiary and household sector as well as district heating is used. The analysis shows that for the Q0.55 and Q27 scenarios only **additional investments** of 14.6 and 11.4 billion € **compared to the current policy scenario are needed in the EU28**, which is **less than 1 % of the investments of the current policy scenario**. The **switch from a system based on public subsidies to subsidies provided in the quota system** (certificate prices) on the one hand **reduces public spending by about €38 billion**, on the other hand **provides subsidies of €145 billion (Q0.55) and €59 billion (Q27) within the obligation scheme, which is not funded by states**. The analysis shows an **increase of the GDP** for EU28 of 0.12 % in 2030 in Q0.55 compared with current policies. The **full-time equivalent (FTE) employment increases marginally** by 0.04 %. Furthermore, investment and consumption increase by 0.32 % and 0.33 % respectively. An even lower positive economic effect is detected for the Q27 scenario. GDP only increases by 0.07 % compared with the current policies scenario and the FTE employment is 0.02 % higher. Investments increase by 0.25 % and consumption of private households by 0.12 %.

## Hotmaps (Aalborg University et al. 2020)

***Overview***

The goal of the project is to develop an open source heating / cooling mapping and planning toolbox. Furthermore, default data for EU28 is provided at national and local level. The data and tool shall allow public authorities the identification, analysis, modelling and mapping of resources and possibilities to supply energy within their municipalities, counties etc. in a resource- and cost-efficient way. The tool and other results ought to help authorities to develop local, regional or national heating and cooling strategies. The renewable energy and $CO_2$ emission targets at national and EU level are integrated.

The tool is available online: https://www.hotmaps.eu/map

***Data and assumptions***

The project provides a starting data set, calculation modules for the assessment of renewable heating potentials and future scenarios. In addition, own datasets can be uploaded and used in the modules. The tool provides information on the heating and cooling demands in different areas, potential and most economic areas for DHC,

potentials of building renovation, renewable heating and industrial excess heat and favourable decarbonisation pathways.
The starting dataset comprises data for the residential (three different building types), service (six sub-sectors), industry and transport sector for the whole EU 28. Data was collected at national level and – if available – at regional/ local levels. A detailed description of the development of the data set can be found in (Eurac Research et al. 2019). The generated heat density maps are available at hectare level (100 m x 100 m).

***Case studies***

The tool was tested and applied in several pilot cities. These are Aalborg, Bistrita, Geneva, Frankfurt, Milton Keynes, Kerry County and San Sebastian. Main results and important pillars with respect to the decarbonisation of the heating and cooling sector from the case studies are:

- Aalborg: already long experience with strategic heat planning since late 1980s and many plans already developed; main focus in project: share knowledge and learn from others
- Bistrita: Reduction of heat demand in buildings through renovation; supply of remaining heat demand with locally available renewable and excess heat
- Geneva: obligation to realise own territorial energy planning based on cantonal energy master plan; planning process ongoing; use of own data for assessment of status quo, identification of coherent DH supply areas and comparison with planned network extensions and non-DH areas
- Frankfurt: goals: reduce energy demand by 50 % (50 % of remaining demand covered by renewables from region and 50 % by local sources), climate neutrality in 2050; challenges: growing population and workspaces; opportunities: increase refurbishment rate, use excess heat and expand DH system; DH is the system with lowest cost for providing 100 % renewable heat, however business case for local utility might not exist; main challenge also in 2050: provide the peak heat demands with renewables
- Milton Keynes: New city (founded in1967); goal: net zero carbon city by 2030, HotMaps for fast identification of heat resources in the region, identification of opportunities and comparison of scenarios; low carbon heat or housing and businesses identified as major elements and strategy document for planners and developers prepared
- Kerry County: rural, touristic area  (population doubles during summer due to tourists, many hotels leading to high heat demand in summer), goals: identification of heat demand and feasible DH areas, cost indication, reduce dependency on fuel imports and create opportunities for local renewable energy sources; process ongoing
- San Sebastian: Only few small DH systems so far; existing plans: SmartCity Plan, Climate Strategy, Sustainable Mobility, Green City, Agenda 21 and more, but no strategic plan for heating and cooling existed; Based I Energy demand calculation different scenarios and Heating Strategy developed: possible heat savings through retrofit is 25 – 40 % (40 – 74 % of entire buildings gross floor area would need to be renovated), excess heat of waste incineration plant could provide a high share of heat demand with low costs

Besides the focus on the case studies, scenarios for the EU 28 at country level were developed. They describe pathways for the space heating (residential and non-residential), industry, electricity generation and district heating as well as transport sector (TU Wien et al. 2019). For heating and cooling, a reduction of 28 % (current policy scenario) and 35 % (ambitious policy scenario) is expected. Space heating will still have a share of 66 to 71 % in the total final energy demand for heating and cooling in residential and non-residential buildings (in 2012 84 %). The share of cooling increases from 2 % to 8-9 % and the share of hot water from 13 % to 19 – 22 %. In the scenarios, gas remains the main energy carrier even though the share is declining. The most important renewable energy source is biomass.

## Decarbonisation pathways (Eurelectric 2018)

***Overview***

The Paris Agreement requires an increasing contribution of the EU to mitigate climate change. From the authors' point of view, an increased electrification is essential for a cost-effective decarbonisation of the EU and the power/electricity sector plays an important role. The power sector aims to achieve carbon neutrality well before 2050 in order to support the overall $CO_2$ emission reduction targets. The electrification potential is substantial in all energy-using sectors. In the study three different scenarios were developed:

- Scenario 1: 80 % emission reduction; emission reduction of approx. 4 %/a; acceleration of current technology trends, policies and customer uptakes
- Scenario 2: 90 % emission reduction; emission reduction of approx. 6 %/a; significantly shift policies to remove barriers and promote decarbonisation and electrification
- Scenario 3: 95 % emission reduction; emission reduction of approx. 8 %/a; towards full decarbonisation of the EU economy; support early technology breakthrough and deployment by global coordination

***Main results***

For achieving an overall emission reduction of up to 95 % a fast removal of barriers to adopt electric technologies in combination with technological progress are essential. In the assessed scenarios, 38 % to 60 % of the final energy consumption is directly electrified. To achieve the goal, an increase of 1 % to 1.5 % of direct electricity consumption is required in the whole EU. In the same time, the total final energy consumption must be reduced by 0.6 % to 1.3 % per year.

In the building sector energy efficiency is seen as the key driver for emission reductions. District heating and cooling are assumed to play an important role in some areas and 45 % (Scenario 1) to 63 % (Scenario 3) of the building energy consumption could be supplied by electricity (mainly electric heat pumps). The switch to electric heat pumps is seen as a main contributor to energy efficiency gains as their efficiency is about four to five times higher than the efficiency of typical gas boilers. Also in the industry sector a switch to electric processes is seen as a key driver for energy efficiency gains especially in the steel production where electric arc furnaces use five to six times less energy than traditional coal-based production routes.

***Key drivers and pre-requisites***

Scenario 1:

- Implementing what is promised under the Paris Agreement
- Technology: acceleration of current trends and learning curves
- Increase of market share of currently available low-carbon technologies
- User behaviour: cost/convenience remain most important factors, but increase in end user awareness for clean technologies; taxes etc. hinder switch to electric solutions
- Policies including emission-related and pricing policies start to drive market forces towards clean technologies

Scenario 2:

- More ambitious implementation of Paris Agreement in context of increased international coordination; ambitious review process of Agreement

- Early technology development and deployment leading to steep cost reductions of mature technologies until 2030; currently new technologies deployed at large scale after 2040
- Complex industry processes still challenging to decarbonise, but many industry processes are redesigned
- User behaviour: Clean technologies become mainstream and competitive; electricity is becoming competitive against other energy carriers
- Tighter regulation on $CO_2$ emissions, environment, fossil fuels and infrastructure
- Removing barriers to support earlier electrification by major shift in policies, tariffs and taxes

Scenario 3:

- Decision to fully decarbonise EU's economy in context of concerted efforts around the world
- Technological breakthroughs: major early cost reduction of non-mature technologies by high adoption of electric technologies, innovation, R&D
- User behaviour: fast and large-scale adoption of clean technologies worldwide due to high competitiveness of electricity vs. other energy carriers
- Regulation: regulations and mechanisms of Scenario 2 established worldwide; earlier implementation of regulation compared to Scenario 2
- Overcoming several challenges needed:
    - Only 1/3 of annual energy productivity gains of 2 % - 2.8 % driven by electrification; removal of currently observed barriers to energy efficiency measures essential
    - Decarbonisation of industry might come at extra cost
    - Materialisation of significant technological progress needed (e.g. cost competitive and clean $H_2$ and synthetic fuels at scale)
    - Ramp-up in supply chain and infrastructure needed for adoption of electric solutions
- Acceptability of e.g. CCS

***Sector results: Buildings***

The total final energy consumption in buildings is reduced from 18.5 EJ in 2015 to 15.6 EJ (Scenario 1), 13.0 EJ (Scenario 2) and 10.8 EJ (Scenario 3) in 2050. In Scenario 3, so-called emitting fuels only have a share of 5 % in the final energy consumption of buildings in 2050 while electricity delivers 63 % of the final energy consumption (the remaining 32 % are provided by geothermal, solar thermal, biomass and secondary fuels like biofuels, $H_2$, district heat).

- Electrification in commercial sector
    - Scenario 1: Space heating 25 %, water heating 25 %, cooking 75 %
    - Scenario 2: Space heating 43 %, water heating 43 %, cooking 90 %
    - Scenario 3: Space heating 53 %, water heating 53 %, cooking 95 %
- Electrification in residential sector
    - Scenario 1: Space heating 21 %, water heating 22 %, cooking 75 %
    - Scenario 2: Space heating 32 %, water heating 32 %, cooking 90 %
    - Scenario 3: Space heating 44 %, water heating 44 %, cooking 95 %

**Towards a decarbonized heating and cooling sector in Europe (Aalborg University 2019)**

***Overview***

The study is based on the results of the Heat Roadmap Europe studies and develops a roadmap for the Heat Roadmap Europe 4 (HRE4) study. The report analyses and quantifies (if possible) the potentials of district energy and energy efficiency as enablers of the decarbonisation of heating and cooling in Europe. Based on the analysis, a roadmap for decarbonising the heating and cooling sector was developed and key milestones were described. According to the authors, district energy can play an essential role for the decarbonisation of the sector by (i) energy efficiency, (ii) renewable energy and (iii) sector coupling. Previous Heat Roadmap Europe studies showed that energy systems with a share of 50 % district heating and sector integration have a higher efficiency than decentralised systems. They furthermore allow a higher share of renewables at lower costs.

***Main results***

An affordable decarbonisation pathway requires a 30 % end-use saving in heating by 2050 (compared to 2015) and an expansion of district heating to a share of about 50 % in the final heating energy demand. The remaining heating energy demand (mainly in rural areas) is provided by heat pumps. Thereby, a $CO_2$ emission reduction of 85 % (compared with 1990 levels) and a reduction of primary energy demand of 13 % compared with a conventionally decarbonised energy system scenario are achieved. It is essential that district heating systems become integrated parts of other sectors of the energy system, e.g. by CHP, use of waste heat and use of electricity in large scale heat pumps and electric boilers. District heating systems also have to switch from supply- to demand-driven systems with automatic controls. Furthermore, the temperature levels of the system will be reduced by efficiency measures in buildings (i.e. refurbishments) and efficiency measures in the systems themselves. The switch to low-temperature networks could save up to 120 TWh and up to €6 bn on the supply side.

***Roadmap for realising the Heat Roadmap 2050 scenario***

It is essential that the transition of the heating sector is well established and underway in 2030 in order to achieve the long-term goals in 2050 (completely decarbonised energy system). District heating systems are essential enablers for:

- Increased energy efficiency and access to heat sources, which are difficult/ impossible to use in single buildings
- Energy system and sector coupling benefits

The study identified prospective supply districts based on minimum heat demand densities and maximum investment costs with a potential for about 25,000 district heating systems. In order to activate the potential, a significant expansion between 2025 and 2035 is needed (increase from approx. 500 new systems in 2025 to a peak of 2,000 new systems (invest of 47.6 bn €) in 2030). The expansion of district heating systems is accompanied by large investments in an energy-efficient building stock (i.e. refurbishments) also peaking in 2030 (427.3 bn €). Even though the needed investments seem to be high they lead to an overall cheaper energy system than a “conventionally decarbonised” system due to lower costs for fuels, $CO_2$ and O&M.

***Milestones and policy recommendations***

2020 – 2030:

- Establishment of **local and national plans and potentials** for district heating and cooling
- Increased investments in **energetic building retrofits and other energy efficiency measures in buildings**: enabling policy framework consisting of e.g. building codes and standards as well as renovation strategies

- **Stop investments in decentralised fossil fuel heating capacities** (gas and oil boilers) and fuel-switch to heat pumps
- Commitments to **deploy actions together with local (regional, municipal) authorities** as heating is a local energy demand; important to enable coordination between national and local level
- **Data availability** must be improved in the heating sector especially concerning heat demands, building stock quality, availability of heat sources and installed heating technologies
- Investigation of **district cooling potentials** must be started as cooling demands are increasing fast and district cooling systems must be integrated in the overall energy system as well
- **Adjustment of markets, investments, regulation, taxes and tariffs** in order to promote technologies needed in a low-carbon and energy-efficient future. If the transition is to be market-driven, right incentives and signals are essential
- **System approach** needed in order to enable synergies between sectors (e.g. use of waste heat, provision of flexibility to the electricity sector by the heating and cooling sector)
- **Ramp up installation of new district heating systems**; approx. 8,700 new systems should be installed in the period
- **Increased investments in district heating supply and distribution infrastructure** (between 2020 and 2030 118 bn € and 223 bn € respectively)

2031 – 2040:

- **Saturate heating markets**: established supply districts should start to cover majority of feasible supply areas; meanwhile, energy retrofits should still be a major focus and remaining "low hanging fruits" should be exploited
- **Build remaining approx. 11,000 district heating systems**
- **Investments in district heating supply and distribution infrastructure should grow and reach** 127 bn € and 273 bn € respectively
- **Progress monitoring for district heating and cooling:** especially benefits captured from increased use of district heating and cooling should become visible in energy statistics and reporting
- **Phase out remaining fossil fuel capacities:** most likely requires ban of fossil gas and oil boilers and replacement schemes

2041 – 2050:

- **Achievement of remaining sector coupling benefits**: exploit all flexibility measures and sector coupling benefits available as last fossil fuel capacities will be phased out
- **Expansion of district heating market share to 50 %**; build remaining district heating systems
- **Replacement of remaining fossil fuels in energy system**, e.g. gas in CHP, back-up capacities, transport sector
- **Ambitious decarbonisation policies** will still be needed towards a complete decarbonisation of the energy supply
- **Connecting remaining demands to district energy systems**: most district heating and cooling areas are established and last remaining demands in existing systems/ areas are connected

## 3.2. Policies and strategies

**Lessons learned to inform integrated approaches for the renovation and modernisation of the built environment (BPIE et al. 2021)**

***Overview***

The report analyses policy instruments and strategies for the renovation and modernisation of the building stock and the built environment and derives lessons learned for the design and amendment of policies to support the achievement of the EU climate targets. The study covers seven strategic areas: 1) Built environment sustainability and adaption to climate change; 2) Clean and sustainable mobility; 3) Digital technology; 4) District approaches; 5) Engaging transformation and phasing out inefficient buildings; 6) Financing renovation; 7) Health and wellbeing.

With the focus of this meta-study being on the decarbonisation of heating and cooling, the review focuses on strategic areas 3-6.

***Lessons learned***

*Digital technology*

There are solutions to digitalise the buildings renovation supply chain, but their application in practice is still low. Important potentials for digital technologies to support the decarbonisation of heating include the digitalised data collection of information about the building stock across Europe, however there is no harmonised framework. Another important application are digital technologies for flexible energy consumption patterns to support the global energy system, however an administrative framework is lacking. Another area of application highlighted is the optimisation of energy uses, however, as for the other applications the current deployment of such technologies is low.

*District approaches*

Local approaches to decarbonising heating and cooling (e.g. micro-grids, energy communities) often focus on renewable energies and do not sufficiently take into account the efficiency of the building envelope. Streamlining and aggregation of renovations at the district level are promising solutions but are currently implemented mainly in pilot projects. The diffusion of comprehensive (sub)urban strategies combining energy and carbon efficiency of the building stock is currently low. Trust and communications are mentioned as key success factors at district level and the study highlights the role of EU support to demonstrate the benefits of district approaches.

*Engaging transformation and phasing out inefficient buildings*

There is a lack of sufficiently effective, coherent, and well-targeted enabling frameworks for deep renovations that are not yet cost-effective. The comprehensive existing policy mix is not sufficiently effective to drive renovations aligned with the EU climate targets. The impact of measures to accelerate the market penetration of innovative solutions for deep renovations (e.g. based on prefabrication and automation) is still rather low. The study identifies one-stop shops and comprehensive building renovation roadmaps as factors that may trigger acceptance and behavioural change among building owners and occupants towards deep renovations. It highlights mandatory minimum requirements as one of the most promising policy instruments to achieve deep renovations addressing the split-incentive dilemma.

*Financing renovation*

There is a variety of existing financing instruments including grants and loans for specific target groups (involving vulnerable households, elderly), social tariffs, tax breaks and energy saving obligations. Innovative financing instruments, such as on-bill schemes and energy performance contracting, are promising solutions as they can leverage private sector resources, however such instruments are still not mainstream. There is a lack of de-risking strategies, with insufficient evidence on the performance of energy efficiency investments in buildings making financial risk harder to assess and mobilisation of both public and private investments more difficult. Most countries address barriers to energy efficiency in buildings through financial support instruments, however, a stronger policy framework to address non-economic barriers would be beneficial. Energy efficiency obligations can drive the retrofit market by stimulating the development of new business models such as ESCOs and provide an additional income stream for renovation programmes. Thus the study highlights the need to target the (scarce) resources in grant programmes, e.g. by addressing vulnerable groups and by requiring minimum performance levels. The study suggests the use of fiscal measures through a bonus-malus system, where building owners with a building that is “future-proof” (e.g. based on the EPC rating or building renovation passport) receive a tax credit, while owners of buildings trailing the standard will have to pay a fine.

*Cross-cutting*

- The objectives can only be achieved with a sound policy mix, where regulations and mandatory minimum requirements are an indispensable part.
- For achieving an accelerated deployment of deep retrofit, additional trigger points are required (e.g. measures to facilitate accessibility).
- The lack of data on the EU building stock needs to be addressed, e.g. by providing financial support for data collection, by harmonising and standardising data collection activities and by supporting the deployment of digital logbooks.
- Strengthening energy performance certificates is beneficial as data availability is increased and EPCs can provide the basis for other policies, such as MEPS.
- Urban planning can be a promising way for supporting integrated policy approaches
- Fostering dissemination of new approaches is needed, e.g. ways to de-risk investments in energy efficiency, new ways of financing such as on-bill or on-tax financing, project aggregation and an overview of renovation services via one-stop shops, defining and delineating the neighbourhood/district approach.
- Financing remains a bottleneck and new business models are required to facilitate the Renovation Wave (e.g. aggregation of renovation projects, the use of prefabricated systems for deep renovations, and the use of robotics and automation).
- The roll-out of available digital technologies supports promising approaches to support the creation of a sustainable built environment.
- Transparent communication and stakeholder engagement are important success factors.
- Market-based approaches have limited significance in existing policy mixes, which may partly be due to the importance of non-economic barriers in the built environment.

***Policy actions***

The identified policy actions are clustered in six groups:

1. Align policies with long-term objectives, including a definition of “decarbonised buildings stock” and the requirement for MS to introduce local LTRS to build positive energy districts, requirement for MS to upgrade nZEB definitions aligned with 2050 objective; development of a detailed climate change adaption strategy for the European buildings stock and built environment; revision of the cost-optimal definition to incorporate all renovation-related benefits.

2. Regulatory and market-based instruments for a transformation of the European building stock, including the introduction of an EU-wide carbon price for heating and road transport; introduction of MEPS for existing buildings; minimum mandatory green public procurement criteria for all new buildings and renovations; mandatory minimum standards for indoor air quality for schools and hospitals; requirement for inspection of stand-alone ventilation systems in residential buildings; address climate change adaption in buildings.
3. Enhance the gathering, availability and harmonisation of building data and information, including an improvement of the reliability and increase of scope of EPCs; requirement for MS to introduce building renovation passports; introduce requirement for assessing and reporting lifecycle aspects; requirement for MS to make data available through digital building logbooks.
4. Facilitate the market penetration of innovative financial mechanisms; including support to Member States for introducing national decarbonisation funds; mainstreaming energy performance contracting and use financial guarantees to enable deep renovations; establishing a regulatory framework for on-bill financing schemes and allow for transferable loans attached to the meter; support national one-stop shops.
5. Accelerate renovation and flexibility in the built environment by utilising digitalisation and automation; including a requirement for public and large new buildings to include an interoperable energy management system; continuing to remove legal barriers to enable demand-side flexibility in buildings; introduction of integration of BIM in urban planning and as a requirement for larger new buildings and public infrastructure projects; enabling public and private entities to aggregate demand for energy renovations, to facilitate higher production rate and industrialised renovation approaches.
6. Achieve policy integration through information exchange hubs and integrated urban planning, including guidance and requirements for municipalities to identify and support energy-poor groups; requirements for integrated municipal planning; ensuring district-level application of green and blue infrastructure for new and renovated buildings and in public space; supporting regional exchange platforms to trigger innovations, collaboration and replication of good practices.

**Renewable Heat Policies. Delivering clean heat solutions for the energy transition (IEA 2018)**

***Overview***

The report examines the key economic and non-economic barriers for the deployment of renewable heat and discusses policy options to increase its share. The study analyses the policy approaches of nine case study countries and derives policy recommendations for different country groups. The selection of case study countries encompasses countries that have achieved high renewable heat penetration (Denmark, Finland, Sweden), countries that have lower shares but ambitious energy transition goals for which heat decarbonisation will be important (France, Germany), countries with low renewable heat penetration and extensive natural gas grids (Netherlands, United Kingdom) and the global top two heat consuming countries (China, United States).

***Barriers to renewable heat***

The study distinguishes between economic and non-economic barriers and identifies the following key barriers:

*Economic barriers:*

- **Higher investment costs** than fossil fuel alternatives and lack of access to affordable finance and capital for renewable heat investments. *Policy solutions:* Investment support via grants and low interest loans (e.g. France zero-loan interests); Heat generation-based subsidies to reduce payback periods and Energy Service Company approaches (e.g. Renewable Heat Incentive (RHI) in the UK).
- **No level playing field with fossil heating fuels**, as externalities such as carbon or air quality impacts not included for fossil heating fuels and/or fossil fuels are subsidised. *Policy solutions:* Energy taxation and carbon pricing (e.g. energy and carbon taxes in Nordic countries); Removal of fossil fuel subsidies (e.g. fossil fuel subsidy reform in countries such as India, Malaysia and Indonesia).
- **Current low and cyclical fossil fuel prices** impeding long-term certainty and competitiveness of renewable solutions as compared to fossil fuel base heating. *Policy solutions:* Adjustable energy/carbon taxes to provide price stability through ''floor'' price (no known examples specifically for heat); Mechanisms to increase liquidity and tradability of biomass fuels (e.g. Baltpool Exchange, ENplus certification, futures contracts for wood pellets).
- **Split incentives** in the private rented sector. *Policy solutions:* Grants and ESCO approaches; Measures to pass the initial investment cost on to a third party (e.g. Green Deal scheme in UK, discontinued); Obligations (e.g. Baden-Württemberg renewable heat law, Germany).
- **Lack of economies of scale** resulting in higher system costs and **lack of district heating infrastructure** reduces cost-effective opportunities to integrate renewable heat. *Policy solutions:* Long-term policy support measures to allow supplier base and supply chains to grow (e.g. RHI in the United Kingdom); Incentives for local authorities, cities and industry to encourage investment in efficient district heating schemes with low-carbon supply (e.g. Fonds Chaleur in France).

*Non-economic barriers:*

- **Building suitability:** Renewable heat options may not be suitable in certain buildings (e.g. apartments, low-efficiency buildings). *Policy solutions:* Integrated energy efficiency and renewable heat grant schemes (e.g zero-interest loans in France and KfW programmes in Germany); Ensuring high efficiency through building codes (e.g. EPBD).
- **Industrial heat requirements**, e.g. temperature levels, pressure and quantity of heat can be a challenge for RES-H. Biomass can be restricted due to stringent emission requirements. *Policy solutions:* Technology-related research, development and demonstration funding (e.g. H2020 funding); Carbon taxation on industrial emissions to encourage use where possible (e.g. EU ETS).
- **Lack of awareness and confidence in renewable heat technologies** (applying to households, heating system specifiers and lenders). *Policy solutions:* Information programmes and advice provision (e.g. RHI roadshows in the UK); Equipment certification and standards as well as after-installation technical support services (e.g. Microgeneration Certification Scheme (MSC) in the UK).
- **Lack of supply chains (e.g. biomass from agricultural residues) and trained installers**: *Policy solutions:* Coordinated policies for agriculture, forestry and energy; Training and certification programmes, better recognition of technology certification among countries (e.g. Pan-European Heat Pump Keymark scheme).
- **Distressed purchase and consumer inertia:** Short-term decision-making when existing boiler breaks down tends to favour replacement with the same (e.g. fossil fuel) technology. *Policy solutions:* Renewable obligation for boiler replacement (e.g. Baden-Württemberg renewable heat law, Germany).
- **Disruption and "hassle" factors:** Retrofit installation of renewable heat systems may entail disruption (e.g. underfloor heating, biomass fuel storage) and may require more space and higher maintenance requirements. *Policy solutions:* District heating to allow offsite deployment (Municipality activities in

Nordic countries); Installation of renewable systems during wider building renovation and regulations to ensure integration in new-build properties (Merton Rule policies for commercial buildings in the UK).

- **Lack of heat data, statistics and heat demand mapping,** needed to select favourable locations for installations, develop supply chains and planning of district heating networks. *Policy solutions:* Organisation and funding for heat mapping and zoning by local authorities (e.g. Heat Networks Delivery Unit support in the UK, zoning in Denmark).

***Key RES-H Policies highlighted in the report***

- Long-term heat policy with ambitious targets and an effective regulatory framework (Denmark, Finland, Sweden).
- Comprehensive heat planning at local level, with district heating as public infrastructure (Denmark, Finland, Sweden).
- Energy taxation with exemptions for renewables (Denmark, Finland, Sweden).
- Regulatory measures restricting the use of fossil fuel heating (Denmark: ban on oil and gas heating in new-build properties since 2013 and on new oil heating installations in existing buildings in areas supplied by district heating or natural gas since 2016).
- Support schemes for energy retrofits in existing buildings and RES-H technologies
- Premium tariff payments for biogas used in heating and for biomethane for grid injection (Denmark and Finland).
- Energy saving obligation scheme (Art. 7 EED): In Denmark, the district heating sector is included in the obligation scheme, resulting in a deployment of solar thermal solutions as heat produced from solar energy is also allowed to be counted as energy savings.
- The SDE+ scheme (Netherlands): Combined support scheme for renewable electricity, biogas, and renewable heating technologies through feed-in premium allocated via a tendering procedure.
- The UK Renewable Heat Incentive (RHI): Long-term support programme for renewable heat with payments based on heat generated.

***Policy recommendations***

The report provides differentiated policy recommendations for different country groups:

**1. Countries with extensive district heating networks**

*a) Countries that already have high shares of renewable heat (40+%)*

- Put more focus on sector coupling, especially in countries where there is also rapid growth of variable renewable power (e.g. incentivising the use of heat pumps for demand response).
- Ensure cost-optimal alignment between energy efficiency and heat policy (e.g. to avoid stranded district heating assets where they are the best option to supply renewable heat).
- Ensure biomass resources are allocated optimally between district heating and other sectors where they are needed for decarbonisation.

*b) Countries with medium shares of renewable heat (20-40%)*

- Set targets and develop strategies for further decarbonisation of district heating.
- Develop instruments to overcome non-economic barriers (e.g. support for developing supply chains).
- Incentivise options for renewable heat in industry, especially those that provide opportunities for connection to district heating through use of co-generation or excess heat.

**2. Countries with relatively low shares of renewable heat (10-20%) and some district heating**

- Consider regulations for building renovation requiring a specific share of renewable heat (or connection to district heating).
- Incentivise accelerated district heating expansion focused on low-carbon heat sources.
- Ensure that energy taxes and other charges (e.g. surcharges for renewable electricity) do not disincentivise renewable heat, in particular the use of heat pumps.

**3. Natural gas countries (extensive gas grids, low gas prices, very little renewable heat or district heating)**

- Set clear targets; develop trajectories and strategies for increasing the share of renewable heat over time.
- Implement carbon pricing, with progressive increases over time.
- Develop effective regulations (e.g. building codes for new buildings that require the installation of renewable heat options to provide more market certainty).
- Support R&D into innovative options such as the production of hydrogen with RES and its use in the gas grid.

### Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) - Work package 5: Barriers, Best Practices and Policy Recommendations (Fraunhofer ISI et al. 2017c)

***Overview***

The aim of the study is to provide a detailed overview of the heat and cold supply as well as use in Europe in 2012. The study covers all 28 EU Member States plus Iceland, Switzerland and Norway. It is composed of five reports and a complete dataset. The reports are:

- Report 1: Work package 1: Final energy consumption for the year 2012
- Report 2: Work package 2: Assessment of the technologies for the year 2012
- Report 3 and 4 (published in one document): Work package 3: Scenarios for heating & cooling demand and supply until 2020 and 2030; Work package 4: Economic Analysis
- Report 5: Work package 5: Barriers, Best Practices and Policy Recommendations

In the following, Report 5 is described in detail. The other reports can be found in the respective sub-chapters by following the link provided above.

The report on work package 5 covers barriers, best practices and policy recommendations. In the centre of the analysis are the identification of factors and bottlenecks (economic aspects, behavioural issues, decision-making routines, financing conditions, subsidy programmes among different stakeholders) influencing the diffusion of renewable heating and cooling technologies and that might be overcome with suitable policies.

**Barriers, Best Practices and Policy Recommendations** (Fraunhofer ISI et al. 2017c)

In the centre of the analyses was the identification of factors and bottlenecks, like economic aspects, behavioural issues, and decision-making routines influencing the market acceleration and helping to overcome bottlenecks of renewable heating and cooling technologies. Furthermore, financing conditions and subsidy programmes for different stakeholders were assessed. From the assessment, suitable policies were derived. The **major barriers identified** are:

- Access to capital
- Imperfect information

- Bounded rationality
- Split incentives
- Perceived and measured risks
- Hidden costs

Furthermore, **barriers and bottlenecks were assessed along the product life cycle**. The identified obstacles are:

- Too little R&D expenditures; missing goal orientation by R&D (product R&D)
- No lifecycle-cost analysis from buyers' point of view (machines and plant manufacturer)
- Sale price minimisation; minimisation of warehouse costs (manufacturer and wholesaler)
- Lack of market overview, too little knowledge, mistrust in external consulting; purchasers, rules, lack of capital (investment)
- Lack of knowledge; lack of incentives, comfort zone (usage)

Barriers, best practices and policy recommendations are structured according to the main heating and cooling sectors, which are space heating and cooling (residential and non-residential buildings), process heating and cooling (industry and tertiary sector) as well as district heating and cooling.

The **two major obstacles identified for a broad deployment of renewable heating and cooling technologies in residential and non-residential buildings**, which are (i) the **high initial costs** and (ii) a **lack of awareness** of energy-efficient and renewable technologies of building owners, tenants and energy consultants. To overcome the first obstacle the study suggests **removing all subsidies and other incentives for fossil fuel-based heating and cooling technologies** to correct market distortions and price signals. For the second one the study suggests **fostering information campaigns** for both the supply and demand side. Suggested items are **building certificates**, **energy labels** and **customer relationship activities by local experts**. Furthermore, **good professional education and up-to-date training** are needed.

In addition, **suitable financial support schemes and incentives** are needed addressing the specific needs of the various stakeholders/ owner types (single family homeowners, shared property in multi-family houses, housing companies, etc.). Furthermore, the cost sharing concepts between owners and tenants must be adapted in many countries. A **harmonisation of tenants' law across member states** could also bring in sharing concepts at EU level.

The **process heating and cooling** sector also faces **two major barriers**, which are (i) **concerns and changes affecting the core business of enterprises** and (ii) a **lack of strategic priorities and governances** based on fossil fuel prices and market conditions. The first barrier can be overcome by **information and best practice examples** (well-operating pilots and demonstration projects, energy efficiency networks). The second barrier could be overcome by **removing subsidies and incentives for using fossil fuel-based technologies** to create impulses towards a broader application of technologies using renewable fuels/energy. Furthermore, it is highlighted that especially **small and medium-sized companies face budget constraints** when it comes to large investments in new/renewable technologies. This constraint can be tackled by tailored **financial incentive schemes**. **Larger enterprises** mainly face **organisational barriers**, which are difficult to address from outside. An additional obstacle is that **not all companies in the EU are in the scope of the ETS**. The companies outside of the scheme lack incentives to switch from fossil to renewable technologies/fuels.

**District heating and cooling** face **high initial investment costs** for (i) the installation of large heat and cold generation capacities and (ii) for the development of their networks. To overcome this barrier **innovative financial instruments and new business models** are suggested in the study. They must be accompanied by **suitable policies**. Furthermore, many possible customers do not know (enough) about the possible benefits from the connection to a district heating or cooling network; **information campaigns** are therefore essential.

**Best practice in heat decarbonisation policy: A review of the international experience of policies to promote the uptake of low-carbon heat supply (UKERC 2016)**

***Overview***

The report provides an overview of policies supporting the deployment of heat pumps and district heating. The report draws upon experience from countries where these technologies have shown large deployment, such as the Nordic countries and Germany. The report highlights key factors for successful policies for both technologies, including policy continuity, financial support and the quality of the consumer experience. It also describes important differences between policy support for heat pumps and heat networks, with the latter requiring a higher degree of regional or urban coordination and planning.

***Policies supporting the deployment of heat pumps***

The report identifies three key barriers for the deployment of heat pumps and analyses successful policies addressing these:

1. Heat pumps have a relatively higher investment cost than fossil fuel-based heating technologies
2. Pricing structure of heating fuels and electricity that disencourages the use of heat pumps
3. Lack of quality and customer satisfaction

***Financial support schemes***

Investment subsidies, grants and tax exemptions can be effective in stimulating deployment, where capital grants covering a proportion of installation costs and tax breaks on labour costs have been two of the most common approaches. As a condition for receiving a subsidy, countries may require heat pumps to achieve a minimum level of performance (e.g. a mean seasonal COP (Coefficient of Performance) of 4 in Austria).

Some countries implemented subsidy schemes for the replacement of specific technologies with heat pumps, e.g. direct electric heating in Sweden, or fossil fuel systems in Austria. The report remarks that the impact assessment of a Swedish subsidy scheme found considerable free-rider effects (85% of those surveyed would have installed heat pumps even if the subsidy had not been available).

***Carbon and energy pricing***

Energy and carbon pricing on fossil heating fuels is highlighted as a key driver for the deployment of heat pumps (e.g. Sweden and Denmark). However, carbon pricing can also have negative impacts when leading to increased electricity prices. As an example for the dependence of heat pumps on the pricing of fossil fuels, the report describes that heat pump markets developed in several countries after the oil crisis in the 1970s, however, the markets collapsed as oil prices decreased.

***Policies addressing technological performance and the availability of information***

The report flags technical standards and quality assurance as key measures required for a successful deployment of heat pumps. Based on previous experience (e.g. Sweden), where heat pumps suffered from a poor reputation due to a lack of quality control, the report highlights the importance of combining other support measures (e.g. subsidies) with measures for quality assurance. The following successful approaches are suggested:

- Establishment of test facilities in Switzerland for raising the technical standards of heat pumps and providing quality assurance
- Quality labels, e.g. EHPA quality label setting minimum standards for heat pumps

- Procurement programmes, e.g. by NUTEK, Sweden: In cooperation with a group of purchasers and specialists, NUTEK developed the requirements for a competition to procure technically advanced heat pumps which were 30% cheaper and 30% more efficient than existing heat pumps on the market.
- Independent complaints board or ‘Heat Pump Court’ (VPN ) in Sweden to address litigation cases relating to the false claims of installers about heat pump performance. Court decisions on cases are made public so that companies linked to substandard installations are effectively ‘named and shamed’.

**Building regulations**

Building regulations may directly or indirectly support the deployment of heat pumps through requirements for the use of renewable heating in new buildings and existing buildings (e.g. the renewable heating obligation in Baden-Württemberg); Building codes mandating high efficiency levels in new buildings tend to require controlled ventilation and may contribute to supporting air-to-air heat pumps over GSHPs (e.g. Sweden).

***Policies supporting district heating***

The report describes the contextual factors that are important for the deployment of district heating: ownership structures, degree of liberalisation, energy prices. These factors are key as the deployment of district heating is capital intensive and has uncertain returns unless established as a monopoly. In Denmark and Sweden, most development took place before energy market liberalisation, with district heating companies owned and/or controlled by municipalities, and risk reduced through planning and regulation of heat supply.

**Financial support schemes** are important for the deployment of district heating in liberalised markets. Financial support may be provided for network development, to consumers for connecting to DH (e.g. subsidy for replacing fossil-based heating systems), or for heat production technologies such as (biomass) CHP (e.g. tradable certificates for renewable electricity, production-based incentives). The sequencing of policies supporting CHP and the deployment of DH is important.

**Carbon or energy taxes** on fossil-fuel based heating technologies can incentivise heat network development and may have a significant impact on the heat sources used to provide networks with heat.

**Urban heat planning**

Planning frameworks supporting or mandating district heating in certain areas can reduce the financial risk of developing district heating projects. European countries with high levels of district heating have greatly reduced the risk of demand uncertainty through heat planning, including granting monopoly powers to district heating companies, leading to the ability to access capital at very low rates, and willingness to invest for relatively low rates of return.

Besides the structural and legal framework for heat planning, the report states that such approaches show limited application in some countries as they are considered unpopular (e.g. Germany). Urban planning supporting DH may include the following elements:

- Requirement for local authorities to produce local heat plans that identify existing and future heat demands of buildings and current and potential heat sources, and assess which heat sources are most socio-economically cost-effective and locally appropriate (e.g. Denmark, Sweden). The report highlights the importance of providing clarity on what the plans should include and on sanctions for municipalities not producing plans.

- Mandates for local authorities to set obligations for new buildings to connect to DH, or ban the use of technologies (e.g electric resistance heating or fossil fuels) in DH areas.

**Regulations relating to building energy efficiency and the use of waste heat**
Obligations for the use of renewable heating in new buildings may cover DH (e.g. the German EEWärmeG includes DH if heat is produced by a substantial share of renewables, at least 50% CHP, or a combination of both).
Building regulations addressing primary energy (rather than final energy) provide the advantage for DH as they account for the efficiency benefits of DH from CHP or renewables.

**Price regulation** can be important to increase consumer confidence in district heating, in particular where planning has created monopoly operation. For example in Sweden, cost-based pricing was mandatory and district heating companies were prohibited from making profits before the liberalisation. Price regulation ended with liberalisation, leading to protests from consumers who argued that district heating operators were then in a position to take advantage of operating as a natural monopoly. The report highlights the importance of implementing price regulation or other consumer protection alongside the deployment of DH.

## progRESheat: Policy recommendations to decarbonise European heating and cooling systems (Fraunhofer ISI et al. 2017e)

***Overview***
The progRESheat project develops heating and cooling strategies focusing on six target countries across Europe (AT, DE, CZ, DK, PT, RO) through an analysis of (1) heating and cooling demands and future developments, (2) long-term potentials of renewable energies and waste heat in the regions, (3) barriers & drivers and (4) a model-based assessment of policy intervention in scenarios up to 2050. Here, we summarise the key policy recommendations at EU, national and local level that are derived from the study.

***Recommendations for local, national and European policy making***
*Heating and cooling planning*
The report highlights strategic **heating and cooling planning** as a key element for the decarbonisation of heating and cooling. While heating and cooling planning needs to be performed at the local or regional level by the municipal or regional authorities, the European and national level need to provide policy support for local implementation. This includes 1) the provision of binding targets for the H&C sector (at EU, national and local level); 2) the provision of funding for local planning (national level); 3) the establishment of local planning as a mandatory part of municipal service tasks (national level); 4) the analysis of H&C demand and supply (local level); 5) enabling a long-term investment horizon (local level, national level); 6) cooperation among stakeholders (local level).
*Awareness raising, skills and competences*
Other important elements highlighted in the report are **awareness raising, skills and competences** including local communication activities, the involvement and empowerment of consumers and citizens as well as addressing intermediaries such as craftsmen, architects or project developers. This includes 1) the communication of low-carbon transformation plans at the local level, e.g. by implementing visible demonstration

projects; 2) consumer empowerment and transparency of costs and benefits; 3) intensifying policies for crucial change agents such as craftsmen, architects and planners, e.g. through regional training programmes, the initiation of local networks, changes in the education system for craftsmen and by addressing change agents in RES policies; 4) capacity building and supporting tools for the municipal level, e.g. based on EU projects like progRESheat, Celsius and Hotmaps.

*Regulatory instruments*

The regulatory instruments for the decarbonisation of H&C concentrate mainly on the national and EU level, however, the municipal level is highlighted for defining areas of priorities for different decarbonisation options ("heat zoning"). At the national and EU level, the following instruments are proposed: 1) Ban of fossil fuel technologies, RES quota and use obligations; 2) non-renewable primary energy demand requirements; 3) extension of pollution permits to $CO_2$ and energy efficiency; 4) mandatory energy management systems in industry companies.

*Improvement of economic conditions*

The study suggests the following economic instruments. 1) Implementation of efficient price-based economic regulations through energy taxes and/or carbon pricing (national and EU level); 2) Focus financial support on technologies in line with targets (local and national level); 3) Coherent and innovative financial support instruments such as contracting schemes, crowdfunding, ESCOs (national level).

**Policies to enforce the transition to nZEB: Synthesis report and policy recommendations from the project (TU Wien et al. 2014) and Overview and assessment of new and innovative integrated policy sets that aim at the nZeB standard (Bürger 2013)**

***Overview***

The project ENTRANZE aimed at supporting the deployment of nearly-zero energy buildings (nZEB) and RES-H&C through collecting data on the EU building stock, an analysis of stakeholder behaviour and acceptance of various technologies, cost-optimality calculations and model-based policy scenarios of building-related energy demand. The project provided an extensive assessment of barriers and policies and discusses how individual policy instruments can be combined to consistent policy packages.

***Policy instruments***

The report discusses a variety of policy instruments:

- Regulatory instruments: For the buildings sector, the following regulatory instruments are considered: Building codes, refurbishment obligations, RES-H obligations
- Economic instruments: The economic instruments considered include 1) Grants/preferential loans, where different options for financing the programmes are outlined (state budget, state-like budget, surcharge on energy and climate taxes, levy on buildings); 2) Tax incentives, differentiating between positive incentives (tax credits, tax deductions, reduced VAT) and negative incentives (bonus/malus on property tax or property purchase tax); 3) Energy tariffs that depend on consumption, e.g. higher tariffs when a given consumption level is exceeded; 4) Non-fiscal instruments strengthening support and financing activities within the market, e.g. energy saving obligations, quota for RES-H, bonus/premium

scheme (e.g. the renewable heat incentive in the UK), contracting (including ESCOs and Energy Performance Contracting), bank obligation to grant interest-reduced loans.

- Capacity building qualification and quality assurance, including professional training and vocational education, branded quality standards and qualified building-specific refurbishment plans
- Information, motivation and advice, including the combination of financial support with mandatory advice and establishing competence centres for thermal building retrofit.
- Market transformation (supply side) measures: 1) R&D support to ensure innovation and technology improvement; 2) Technology procurement, including public procurement as well as procurement groups; 3) Premiums for providers of efficient technologies; 4) Organising competitions or tenders between technology providers; 5) Creating networks; 6) Labelling, testing and certification

***Policy packages***

For the combination of different instruments to a policy package, the report provides the following guidelines:

- Instruments should 1) address the main barriers; 2) address the main target groups; 3) reflect the maturity of the market of the different technologies
- Avoid redundancy: If a certain barrier (e.g. a financial barrier) is addressed by two or more instruments, this should be adequately justified (e.g. if instruments address different target groups).
- Efficiency: Keep the administrative costs low, e.g. by exploiting synergies by administering several instruments together
- Public acceptance and communication: Keep the packages as simple as possible to ensure easy communication.

## National restrictions on fossil fuels in heating systems in the context of the Ecodesign Directive (Öko-Institut and Klinski 2021)

***Overview***

This study examines whether and how the use of fossil fuels for space and water heating can be further restricted and later phased out under German law in accordance with the EU legal framework. The focus of the analysis is the compatibility of these measures with the Ecodesign implementing Regulations (EU) 813/2013 and 814/2013, setting EU-wide binding energy efficiency requirements for space and combination heaters as well as water heaters and hot water storage tanks. The study further examines additional aspects, such as the compatibility with the provisions of the Treaty on the Functioning of the European Union (TFEU) on the free movement of goods. The analysis is complemented by a survey of existing restrictions on the use of fossil fuels for heating in other European countries.

***National phase-out regulations: Examples***

The study examines existing phase-out regulations in Austria, Denmark, the Netherlands, Switzerland and Norway and furthermore elaborates on the German regulation phasing out the installation of monofuel oil boilers from 2026. According to the study, Denmark has the most comprehensive approach for restricting the use of fossil fuels, based on a use obligation for renewable energies for new and existing buildings. The use obligation is connected to zoning. In Austria, the installation of oil boilers is banned in new buildings since 2019. The Netherlands have introduced restrictions for the connection of new buildings to the gas grid, thus phasing out the use of gas in new buildings. In Norway, oil for heating is banned since 2020, covering not only the installation of boilers but also the use of fuels in existing boilers (which however make up for a minor share of heat supply).

***National phase-out regulations: Legal assessment***

The study assesses whether there are legal barriers for the introduction of phase-out regulations at national level arising from the requirements for space and water heaters introduced in the context of the Ecodesign Directive. The study finds the ecodesign requirements do not limit national phase-out regulations addressing the use of fuels in heating systems, as the fuels used in the system are not specified as ecodesign parameters. The findings are supported by the EU Commission's decision (EU) 2020/654 of 13 May 2020 to approve the German Regulation on small and medium-sized combustion units (1st BImSchV – Ordinance for the Implementation of the Federal Immission Control Act) stipulating requirements for solid fuel boilers as derogations from Ecodesign Regulation 2015/1189.

## Filling the policy gap: Minimum energy performance standards for European buildings (Sunderland and Santini 2021)

***Overview***

This study analyses options for the implementation of minimum energy performance standards in the EU and its Member States. It describes the role of MEPS to support the transition of the buildings stock, reviews existing MEPS in several countries and describes options for the introduction of MEPS at EU and national level.

***Key design features of MEPS***

The report reviews existing approaches for MEPS in various countries and identifies the following key design features for MEPS:

1. Metric and standard: The most common metrics used are carbon ($CO_2$ per $m^2$), energy ratings (kWh per $m^2$) or the EPC class. MEPS can also be designed as requirements for a minimum set of building fabric and/or heating system measures.
2. Section of stock: The standards reviewed address different building stock sectors, tenures and ownership and can also be based on building type or size.
3. Trigger(s) for compliance: The trigger for compliance with a standard can be a hard date by which all obligated buildings must comply; this may also be accompanied by a timeframe for incremental improvements. Existing standards use building life-cycle trigger points, including major renovation, inspection or building transactions such as sale or change of rental contract. Other policy proposals use further repair, maintenance and improvement trigger points, like building extensions and replacements.

***The role of MEPS in overcoming the barriers to renovation***

The study suggest that MEPS can help overcome the significant barriers when introduced as part of a comprehensive renovation policy framework. Important elements of the framework are funding, finance and incentives, technical and practical support and measures to limit the burden especially for low-income households. MEPS can produce a "demand floor" for renovation finance and create continuity, predictability and scalability in renovation markets. MEPS signal the destination for the whole stock and individual buildings, which helps align the demand and the supply chains, providing space for business and social innovation.

***Options for MEPS at EU and national level***

This study proposes several options to introduce MEPS at EU level, including (1) expanding existing MEPS legislative provisions, (2) proposing MEPS for the European building stock while leaving some flexibility to Member States for the implementation, (3) creating an obligation for Member States.

At the Member State level, the study recomments to introduce integrated and informed strategies based on clear defnitions, interactions with key stakeholders as well as taking into account the learnings from existing systems. Regarding the comprehensive framework, the study highlights the importance to support the supply chain, to ensure that financial support is available (especially for low-income households) and that buildings assessment tools, EPCs and planning instruments are strengthened.

**Minimum energy efficiency standards for a fair energy transition (BPIE and RAP 2018)**

***Overview***

The policy brief summarises key findings regarding the role of minimum energy efficiency standards for addressing energy poverty and supporting a fair transition of the buildings sector in Germany. The focus is on minimum energy efficiency standards for rented buildings.

***Energy poverty and health***

The report argues that energy poverty is prevailing in tenant households, while at the same time these households have limited possibilities to improve the energy performance of their homes (split incentives). Furthermore, it points out the link between energy poverty and health effects, stating that households affected by energy poverty are more likely to suffer from health problems related to insufficient heating and poor building fabric.

***Minimum energy efficiency standards***

The report proposes dynamic minimum standards for rented buildings, successively phasing out all energy classes lower than A+ until 2050. The current lowest energy class G is phased out in 2025, followed by a phase-out of the subsequent energy classes in four-year steps. The study proposes to link the enhanced energy performance to indoor air quality parameters and highlights the need to provide appropriate financing models to prevent rent increases, ensuring the renovations are carried out in a socially responsible manner. The importance to improve data quality in order to design minimum standards for specific target groups is highlighted.

**Policy proposals and concepts for tools of the Green paper on good practice in EPC assessment, certification, and use (QualDeEPC 2021)**

***Overview***

The QualDeEPC project aims to both improve quality and cross-EU convergence of Energy Performance Certificate schemes, and the link between EPCs and deep renovation. The project analyses existing EPC schemes in various EU MS and derives recommendations to improve  EPCs across the following dimensions: A) Improving the recommendations for renovation provided on the EPCs, towards deep energy renovation; B) Online tool for comparing EPC recommendations to deep energy renovation recommendations; C) Creating Deep Renovation Network Platforms; D) Regular mandatory EPC assessor training on assessment and recommendations required for certification/accreditation and registry; E) High user-friendliness of the EPC; F) Voluntary/mandatory advertising guidelines for EPCs; G) Improving compliance with the mandatory use of EPCs in real estate advertisements

***Key recommendations***

The report provides recommendations for Member States to define deep renovations by linking them to the nZEB framework. For full retrofits it recommends values for non-renewable primary energy savings above 60 % and for staged approaches, the component energy efficiency levels that are legally required or usually necessary to achieve deep energy renovation in the nZEB-based definition is recommended. The report further highlights that the recommendations for retrofit measures provided in EPCs are typically not aligned with deep renovation approaches and provides guidance for improving the recommendations. In this context, the project develops an online tool for assessing the energy performance of buildings and for deriving deep retrofit recommendations, as well as an online platform that provides a one-stop shop including relevant information. The project develops support for regular trainings for EPC assessors and derives recommendations for increasing the user-friendliness of EPCs. It further addresses the presentation of EPCs in real-estate advertisement and the compliance with the mandatory use.

**Next-generation EPC’s user and stakeholder requirements & market needs (D2EPC 2021)**

***Overview and results***

The D^2EPC aims to support the development of dynamic Energy Performance Certificates (EPCs) for buildings using digital technologies. The report highlights the need to improve the recommendations for renovation measures in EPCs and provides a list of recommended measures. The project develops an online tool that provides recommendations for retrofit measures for individual buildings and compares recommendations in EPCs to deep retrofit measures. The project establishes deep renovation network platforms that act as one-stop shops and connect different actors of the renovation market. The project further points out the need for strengthening the training of EPC assessors and proposes a framework to increase the user-friendliness of EPCs. Lastly, it addresses the advertisements of EPCs in real estate transactions, covering recommendations on the content of information, the way of displaying it as well as the legal framework for voluntary and mandatory provision of information.

## The Concept of the Individual Building Renovation Roadmap – An in-depth case study of four frontrunner projects (iBROAD 2018)

***Overview***

Building renovation faces a variety of barriers such as a lack of knowledge about the process or a perception of burden due to time-consuming planning or unreliable professionals. The EU-funded project iBRoad works to remove such barriers by offering an individual renovation plan for single-family houses. This considers both the needs of the residents and their specific situation (e.g. age, financial situation). A Building Renovation Passport is a document outlining a long-term step-by-step renovation roadmap for a specific building. It results from an on-site energy audit fulfilling quality criteria and indicators established during a design phase, following a dialogue with building owners. The expected benefits of the building renovation passport are lower heating costs, improved comfort, and reduced $CO_2$, which should be explained in a user-friendly way. It is possible to combine the plan with a repository of building-related information in a logbook on aspects such as energy consumption or energy production.

***Main results***

This study provides an overview of how to create building renovation plans and addresses the key issues for developing and implementing the process. Four practical examples are highlighted from Denmark (BetterHome), Flanders (Woningpas and EPC+), France (Passeport Efficacité Energétique) and Germany (individueller Sanierungsfahrplan). Most of these examples are entering or have concluded the testing phase and will soon start implementation.

The report also includes important insights that could be gained from the four analysed examples to implement individual renovation roadmaps. The process can be summarised in four blocks: exploration, concept design, implementation and evaluation. Careful planning is important for the successful implementation of the whole process. An evaluation should be carried out after the tool has been available on the market for at least one year to assess and measure the success of the tool. This will also allow adjustments and improvements to be made to the tool to ensure and increase its usability and added value.

The study states that despite a promising start, it is too early to judge whether the four examples from Denmark, Flanders, France and Germany will ultimately lead to success. However, research could help to identify mistakes early to avoid them in the process. For a successful implementation of the instrument, the early involvement of the right stakeholders is initially relevant. In this context, the composition of an interdisciplinary project team from different disciplines is an important success factor. Furthermore, funding should also be guaranteed throughout the entire period in order not to jeopardise the process. It is additionally important that the information of the renovation roadmap as well as the logbook goes beyond energy and includes useful information about the building. As the roadmap is created for the users, it should also be user-friendly and affordable. Finally, marketing the product through the right channels is also important to attract users and increase demand. Creating an obligation could also be a key success factor.

## Pricing is just the icing: The role of carbon pricing in a comprehensive policy framework to decarbonise the EU buildings sector (Thomas et al. 2021)

***Overview***

The report considers the possible role of carbon pricing in the decarbonisation of buildings in the EU and its Member States. It describes the opportunities and risks of introducing carbon pricing and considers its integration in a supporting policy mix.

***Opportunity and limits of carbon pricing in the buildings sector***

The study argues that carbon pricing can play an important role for the decarbonisation of the buildings sector if combined with a strong policy mix, however, that carbon pricing alone is not sufficient for achieving decarbonisation. It highlights the need to introduce carbon pricing along with regulatory and financing measures as well as with 55%-proof Effort Sharing Regulation (ESR) targets.

The study points out two important roles for carbon pricing in the building decarbonisation policy framework:

1. Making investments in energy efficiency and renewable heating more cost-effective by applying the polluter pays principle: Currently, in most EU MS electricity is more expensive than fossil fuels for heating, as electricity prices have been increased due to taxes and levies. Carbon pricing for heating is needed to rebalance the prices, as decarbonisation efforts are underminded without a level playing field.
2. Generating revenues that can be used to support energy efficiency and heat decarbonisation policy measures: Recycling the revenues from carbon pricing to support investments delivers emissions savings going beyond the effect of the price alone. The report argues that revenues should be targeted at supporting the households that would be most affected by price increases and least able to invest in low-carbon technologies. Explicitly linking the carbon price to supporting policy measures could increase public support for carbon pricing.

The study argues that carbon pricing needs to be implemented along with a strong regulatory framework to address the structural barriers in the sector and to ensure target achievement. If relying solely on carbon pricing, the study points out the risk that carbon pricing with a fixed cap would potentially lead to very high prices for heating and thus create unacceptable burdens especially for low-income households.

## Efficient District heating and cooling systems in the EU (Tilia 2016)

***Overview***

The study was conducted for the Joint Research Centre (JRC). It focuses on

- High-quality, low-carbon and efficient district heating and cooling (DHC) systems
- A holistic approach: national policy frameworks, local conditions, business models
- The in-depth analysis of eight case studies
- The identification of key success factors

***Objective and approach***

The main objective was to identify the key success factors for the development of highly efficient and low-carbon DHC systems. Furthermore, it was discussed if and how these factors could be replicated in other European Member States. Therefore, eight of the most efficient DHC systems in the EU (according to the authors) have been thoroughly analysed with a holistic approach assessing the national policy framework, local conditions and business models. They are located in Denmark, Estonia, France, Germany, Italy, Spain and Sweden. For the identification of efficient DHC systems, six indicators, which were identified as the most relevant ones out of many more defined at the beginning of the project, were used. These are (i) the economic viability of the DHC grid, (ii) affordable heating and cooling prices, (iii) resilient and stable supply, (iv) service quality, (v) adaptability of the service (mid- to long-term), and (vi) low $CO_2$ emissions and environmental impacts.
In the centre of the analysis were several meetings and exchanges with the main stakeholders (DHC operators, national and local authorities, site visits, own expertise). In order to get a broad overview of different settings, the case studies were chosen in a way that they cover different conditions: older systems, which were upgraded over time, new systems with a low-carbon design, different countries, large and medium sized (7 – 3,600 $MW_{th}$).

***Results***

The analysis showed that there is not one model for the development and operation of low-carbon and efficient DHC systems, which can always be used. However, several success factors were identified, which occurred in different case studies. These are:

- **Adequate national policy and regulatory environment**: Renewable energies and CHP must be supported in the heating and cooling sector and ambitious $CO_2$ emission reduction targets are required. Three main models for national regulation were identified (DHC only regulated through contracts without central regulation; central regulation of the market; hybrid of central and local regulation)
- **Financial support** (direct and indirect): Long-term debt funding, investment subsidies, tax incentives
- **Focused local policy and coherence with urban planning**: energy supply must be integrated in long-term urban planning (including zoning for different heat and cold supply options), focus on compact and mixed-used districts, mandatory connection to grid (if possible and economically feasible)
- **Alignment of interest/cooperation maturity** between DHC operators, consumers and municipality/ local authority
- **Availability and relevance of local resources**: renewables, waste heat and cold etc.
- **Comprehensive project development**: assessment of demand, secured and optimised supply, continuity throughout system lifetime
- **Price competitiveness**: competitive prices against alternative solutions throughout a system’s lifetime
- **Flexibility** of heat and cold production based on diversified, flexible (e.g. CHP) and complementary energy carrier mix in combination with thermal storage, continuous optimisation of operation
- Combination of **technical and non-technical innovation**: use best available technologies, research and development, governance and social initiatives (e.g. citizen empowerment, awareness raising on benefits of DHC,…)

Besides key success factors, four other, secondary success factors were identified in the study. These are the size of the system (economies of scale), customer empowerment (mainly in Denmark), long-term secured prices as an incentive and base for investors, and climate conditions (cold climates improve the business case of district heating).
Furthermore, potential implications on selected policy guidelines were identified and described:

- **Support in-depth design and comparison of optimal systems**: programmes and initiatives for detailed design focusing on pre-optimisation (concept development and modelling), holistic assessment of different local supply options based on defined criteria
- **Revisiting and updating regulatory patterns** like benchmarks, contractual patterns and guidelines, customer involvement on local level
- **Better support for co- and trigeneration**: CHP and CCHP are the cornerstone of smart local systems and provide high systemic benefit; these benefits should be valued better in market design and support schemes
- A **stronger focus on DHC systems** should be put **in overall smart grid and innovation programmes**: focus on multi-energy systems with a stronger integration of DHC systems, up-scaling of EU R&D programmes for public authorities to develop new system designs (flexibility, sector-coupling…)

The study highlights the dependency of the success of DHC systems on local conditions (economic and population dynamics, climate etc.) and policy frameworks (local, state, national). Therefore, models and strategies can only partly be replicated in other locations or even Member States.

## Transition - Make Net Zero Energy Refurbishments for Houses a Mass Market Reality: Position Paper on Funding Instruments (Energiesprong 2017) Report on Market Assessment and Bottlenecks (Energiesprong 2018)

***Overview***

The project Transition Zero was conducted by Energiesprong. Its aim was to establish the right market conditions for the broad introduction and market acceleration of net zero energy homes in Europe with a focus on the UK and France. It built on the success of the Energiesprong concept in the Netherlands and focused on the social housing sector as a catalyst. First, the concept was introduced under current market conditions. Furthermore, opportunities were identified how a better combination of policy, funding and regulation could pave the way for the establishment of a mass market for the deep-retrofit concept of Energiesprong.

***Approach***

The aim of the project was to facilitate commitments for 5,000 houses to be refurbished to a net zero-building and creating a pipeline of additional demand. It was aimed to achieve this by a viable refurbishment proposition for social housing companies, financiers and governments. The addressed stakeholders should be enabled to adjust their financing products and regulations. By creating a large demand, the construction sector is challenged to deliver the value proposition (viable, cost efficient net zero energy refurbishments).

***Market assessment (Energiesprong 2018)***

For the creation of a viable and scalable market two main elements are needed:

- **Demand**: a **large number of commitments for net zero retrofits**. Thereby, the industry can invest in the required R&D/innovation needed to reduce the costs and increase the quality of the solution sets needed

- **Supply**: stakeholders in the building sector who are willing to invest in the design and delivery of the required solution sets and provide **long-term performance warranties**. Scaling up the market and establishing **industrialised processes** in the delivery of the solution leads to **significant cost reductions**

The project identified several **critical issues** in order to establish a mass market for net zero energy retrofits. These are:

- A **minimum secure market** is needed to convince the industry to invest in innovations
- Housing companies usually **only** want to apply **solutions that have proved** to deliver the desired performance
- In the Netherlands the issue was solved by establishing a "**large volume deal**" among four solution providers and six housing companies. This deal allowed experiments and prototypes (ca. 1,000 units) before upscaling to high performance solutions (next 10,000 units) and upscaling to a large volume of 100,000 units
- Other countries (in this project France and the UK) were able to build on the Dutch experience. However, they also needed **national learning to happen** (other stakeholders, different market and political conditions etc.)
- There is usually an **uncertainty on the volume** combined with **public procurement constraints**, which lead to market inertia (e.g. no large commitment from housing companies, solution providers reluctant to invest in prototypes)

***Bottlenecks (Energiesprong 2018)***

Five main bottlenecks were identified in the project. Most of them are interrelated. The bottlenecks are:

- **Contracting and procurement barriers**: in some countries social housing providers are subject to national versions of EU public procurement rules. On the one hand, these rules ensure competitive pricing, on the other hand they are a barrier to kick-starting an early market.
- **Supply side is very fragmented**: construction companies, architects, developers, technical consultants, industrial component suppliers etc. result in high transaction costs and often poor-quality delivery --> deeper supply chain integration and co-design of products / solution set are needed to deliver high performing solutions at affordable prices
- A **lack of trust in the value chain** (industry to end user): amongst different players/stakeholders; furthermore, terminology like 'modern methods of construction' or 'prefabrication' are often viewed with suspicion / have a negative image (historic associations with insolvency risk, poor technical or quality issues etc.)
- A **lack of demand for integrated components / solution sets**: industry mainly provides materials and loose components instead of integrated components for refurbishments; lack of co-design and use of available materials and components to design solutions leads to high margins and costs
- **Lack of skilled workers and low productivity levels**: almost no increase in productivity in the construction sector in the past 20 years; workforce size and demographics are a high risk and can lead to lack of skilled workers in construction sector

***Funding Instruments (Energiesprong 2017)***

It is highlighted that chances for (deep) refurbishment usually only appear once in several decades. The authors therefore emphasise the **need that policymakers address what is needed and not only what is thought to be possible** in order to achieve the long-term climate protection targets at EU level. As key, the authors see energy **performance guarantees** at least for refurbishments. Furthermore, net zero energy buildings should be marketed as desirable (and achievable) instead of aiming at minimum standards like EPC B-ratings (**B-ratings are not in line with the long-term goals of the EU**).

Concerning EU funding, the authors recommend **focusing on ambitious and higher risk projects**. Furthermore, **funding should focus on outcomes** (e.g. through **energy performance guarantees**). The shift in the focus could benefit the ERDF (European Regional Development Fund) and European Social Fund projects. In order to pave the road for new ideas, it is recommended to **accept higher failure rates** for H2020 projects comparable to experienced failure rates from entrepreneurs developing new products and ideas. Instead of predefining the calls for proposals it could be asked "Who has a good idea to solve the challenge of energy efficiency performance in buildings in Europe?" (Energiesprong 2017, p. 5). Furthermore, more radical/market-changing ideas should be accepted.

The following recommendations are for the whole EU. For new buildings, an **efficiency standard of <30 kWh/m²a (thermal)** is recommended. This **should be introduced as a binding standard as soon as possible** and **accompanied by efficiency standards for lighting and appliances**. For refurbishments, it is also recommended to support deep renovation to achieve a net zero standard also in existing buildings as soon as possible, because buildings are seldom refurbished more often than every 30 years. In order to achieve the efficiency standard, it is highlighted that **prices for refurbishments must drop dramatically** in order to ensure that energy cost savings cover the refurbishment costs. The refurbishment itself needs to be **delivered within a shorter period** and **improve the look of a building**. In addition, energy performance guarantees are needed for **convincing financiers** of the investment in refurbishments is profitable and secure. It is recommended to **focus on whole refurbishments rather than a sequential patchwork of measures** as a good quality can only be assured when all measures are combined and focusing on single measures will not lead to the "right" solutions.

Concerning legislation, the authors recommend that the EU should not legislate on refurbishments even though the topic is important. The main reason is that legislation like a minimum refurbishment rate could lead to the situation that billions are spent for half-measures not compatible with the long-term goals. Instead, the authors recommend that the EU institutions support the development of refurbishment activities by **wisely spending EU funds** and – even more important – **support refurbishments by $CO_2$ prices, energy taxation and full unbundling of demand side obligations (DSO)**. **Funding should be focused on process support of market development** for deep, net zero energy refurbishments to increase the impact rather than subsidising refurbishment works itself. For the ERDF it is recommended to at least ask for energy performance guarantees.

Besides recommendations at EU level, (Energiesprong 2017) also includes recommendations for the countries addressed, which are the UK, France and the Netherlands. The recommendations address country-specific challenges and situations and are only available in the respective national languages.

## Low-carbon heating of homes and businesses and the Renewable Heat Incentive (National Audit Office 2018)

***Overview***

With the Renewable Heat Incentive (RHI), Great Britain was the first country in the world to use a financial incentive for renewable heating linked to the production of heat rather than to the upfront costs of installation. It has been followed by Northern Ireland and the Netherlands. The objectives of the RHI are:

- To increase the amount of heat produced from renewable sources;

- to reduce carbon emissions from heating homes and business premises;
- to help to grow supply chains which can support a national transition from fossil fuel to low-carbon heating technology from the 2020s.

***Policy design and implementation***

Technologies supported by the RHI include biomass boilers, heat pumps and anaerobic digestion plants, which produce biomethane injected into the gas grid. The scheme is funded directly by taxpayers, unlike subsidies for low-carbon electricity, which are funded through higher energy bills.

The RHI consists of two parts:

- Non-domestic RHI: launched in November 2011 for industry, businesses and public sector organisations; participants receive payments over 20 years.
- Domestic RHI: launched in April 2014 for homeowners, self-builders, private and social landlords; participants receive payments over seven years.

In the non-domestic scheme, payments to participants are based on the amount of renewable heat they produce. This is measured through meter readings participants submit in order to receive payments. In the domestic scheme, payments are based on a specified heat demand as set out in the applicant's Energy Performance Certificate.

The RHI includes strong cost control measures:

- tiered tariffs: included in the Non-domestic scheme when it was launched, this involves switching participants' tariff from a higher to a lower rate once their heat production reaches a pre-defined limit. This reduces the incentive for participants to produce excessive heat solely for the purposes of financial gains;
- deemed payments: included in the Domestic scheme when it was launched, for most participants payments are based on the annual heat demand figure listed in the property's Energy Performance Certificate. This is known as 'deemed payments' and predetermines the amount of money participants will receive;
- tariff degression: introduced to the Non-domestic scheme in 2012 and the Domestic scheme when it was launched in 2014. It provides the possibility to reduce tariffs for new applicants when total forecast spending on a technology exceeds its pre-defined limit. This measure has led to significant reductions in the biomass boiler tariff since the scheme started;
- budget cap: notwithstanding the intention to provide confidence to the supply chain, this control measure was introduced in 2016. It enables the Department to reserve the right to close the scheme to new applicants with little or no notice when forecast spend exceeds a pre-defined limit.

***Policy performance***

The RHI is on track to reduce carbon emissions from heating by 7 $MtCO_2e$ per year from 2020-21. The cost-effectiveness of the RHI, measured as the amount of taxpayers' money spent to achieve each one megawatt hour (MWh) of renewable heat and to reduce carbon emissions by one tonne ($t/CO_2e$), is estimated to 49 £/MWh and 142 £/$tCO_2e$. This estimate assumes that none of the accredited installations would have occurred had the RHI not been launched.

Surveys found that 25 % of participants in the Non-domestic scheme and 24 % of participants in the Domestic scheme stated that they would have installed a renewable heating technology anyway, even if the RHI had not existed.

Using this data to form a less optimistic assumption about the additionality of the scheme, our heat cost-effectiveness estimate deteriorates from £49 to £65 per MWh and carbon cost-effectiveness from £142 to £189 per tonne of $CO_2e$ saved.

***Monitoring and lesson learning***

The programme uses the following items for monitoring and updating:

- tracking of progress – on renewable heat produced, carbon emissions saved and installations supported – through an internal 'benefits realisation tracker';
- improving its understanding of the user experience and the market through surveys, interviews with different scheme participants and industry stakeholders;
- reviewing the scheme following the problems experienced with the devolved Northern Ireland RHI scheme;
- monitoring the uptake of individual technologies, which it uses to manage the budget and enable cost control measures as and when needed

***Experience from the (suspended) Non-domestic Renewable Heat Incentive (RHI) scheme in Northern Ireland***

The scheme was launched in 2012 based on a similar design to the Great Britain RHI but with significant differences, in particular as it did not include cost control measures until 2015. In 2015, following an increase in the number of applications as a result of the higher tariffs, it announced that it would introduce the tiering of tariffs, which led to a spike in applications before it was able to implement the cost control reform. This led to the scheme running out of money and being suspended to new applicants in February 2016.

**Evaluating the renewable heating and efficiency obligation for existing buildings – insights into the mechanisms of mandatory building requirements (Pehnt et al. 2019)**

***Overview***

Germany's largest federal state, Baden-Württemberg, introduced a law (EWärmeG) mandating a minimum share of renewable energy in existing buildings when the heating system is replaced. The law was first introduced in 2008 covering residential buildings and requiring a minimum share of renewable energy of 10% of heat demand; and was amended in 2015, widening the scope to including most types of non-residential buildings and increasing the requirement to 15%.

The EWärmeG covers most residential buildings (exemptions are holiday homes that are used infrequently as well as very small houses with less than $50m^2$ living space) and more than 70% of non-residential buildings. The law covers buildings with central heating systems, such that multi-family buildings with individual heating systems per apartment are not covered. With an annual exchange rate of heating systems of aroung 2.5% in Baden-Württemberg, around 38 000 buildings are covered by the regulation each year.

***Compliance options and evolution of compliance mix***

The EWärmeG includes several renewable heat technologies as well as some alternative measures as compliance options:

- **Solar-thermal collectors** (at least 0.07 m² collector area per m² living space for one- and two-family dwellings and 0.06 m² for multi-family dwellings) accounted for 30% of the compliance mix for residential buildings in 2010, with the share gradually decreasing to 8% in 2017. For non-residential buildings the share has been between 2% and 4%.
- **Heat pumps** (minimum seasonal performance factor 3.5) have a fluctuating share between 4 % and 15 % over the entire period for residential buildings, with no clear upward or downward trend. For non-residential buildings, a low share of 1%-4% use heat pumps as a compliance option. The diffusion of heat pumps is limited by the fact that many buildings subject to the EWärmeG are unsuitable for heat pumps, due to low heat insulation standards and high temperature levels in the heating system.
- **Solid biomass boilers** have a fluctuating share between 15% and 27% for residential buildings, with no clear upward or downward trend and 10%-16% for non-residential buildings.
- **Purchasing gas products with a 10 % share of biogas or heating oil with 10 % bio-oil** accounted for 16%-35% (biogas) and 7%-11% (bio-oil) until the amendment in 2015, after which the share decreased considerably. The decrease is attributed to the fact that the maximum accountable share of this option is limited to 10% in the amendment, such that for fulfilling the 15% requirement additional 5 %-points must be fulfilled through other measures, such as a renovation roadmap (see below).
- Building owners may opt to connect to a **district heating system or an efficient CHP device** with requirements on the efficiency (CHP) and the share of CHP, waste heat or renewable energies (district heating). The connection to district heating makes up for 4%-8% of the compliance mix throughout the evaluation period (2010-2017), whereas the option of connecting to CHP makes up for at most 1%.
- **PV installations** (at least 0.02 kWp per m² of living space) have become a popular compliance option since the amendment in 2015, making up for 9-11 % for residential buildings and 17-24% for non-residential buildings. However, the evaluation team finds that a large number of PV systems were already present on the buildings or would have been installed anyway.
- **Efficiency measures:** Instead of employing a renewable heating system, the building owner can opt for efficiency measures (insulation of the whole building, the external wall, the roof or the basement ceiling). This compliance option's share increased substantially after the law's amendment (from 4-6% before 2015 to 14-15% after 2015).
- **Energy audits:** Since the amendment in 2015, a part of the obligation (in residential buildings: 5 %-points) can be fulfilled by carrying out an energy audit of the building based on an individual building roadmap. In 2016 and 2017, the building renovation roadmap contributed to about 17 % of the compliance mix for residential buildings, in combination with other measures. For non-residential buildings, building owners may comply with the EWärmeG with the renovation roadmap as the only measure, making the renovation roadmap the most popular compliance option (22%-30%).
- Since the amendment in 2015, building owners may choose a **combination of measures**, where the most common combination for residential buildings is the renovation roadmap and a share of 10% biogas or bio-oil.

***Impact of the law on the deployment of renewable energies and on carbon emissions***

The evaluation team assesses the impact of the law on the deployment of the various options included in the compliance mix and finds that, while slight positive impulses are observed for other measures, the most important impact is found in the following measures:

**Biogas and bio-oil:** The range of blended products for both natural gas with biomethane content and heating oil with a share of bio-oil is much broader in Baden-Württemberg than in the rest of Germany. Gas suppliers began to introduce special biogas tariffs after the introduction of the EWärmeG in 2008. Furthermore, since the amendment in 2015, utilities offer and advertise biomethane products as a package with a renovation roadmap to comply with the EWärmeG. In Baden-Württemberg, 64 % of the examined fuel oil suppliers offer bio-oil products, while in the rest of Germany almost no products are available.

**Renovation roadmaps:** Likewise, the number of government-funded detailed energy audits per inhabitant in Baden-Württemberg has increased significantly since 2015, when the renovation roadmap was introduced. However, the building renovation roadmap is primarily an information tool and the evaluators point out that it needs to be assessed in the future if renovation roadmaps really induce additional refurbishment measures.

The combination of biogas and a renovation roadmap represents a relatively simple and (from an investment cost perspective) cheap compliance measure. The evaluation team points out that the use of these fuel-based compliance options – instead of technology-based compliance options (heat pumps, biomass boiler, solar thermal) – provide only a small contribution to long-term climate protection targets in the building stock as they support the existing infrastructure of gas and oil-based heat supply.

While the use obligation for renewable heat of the EWärmeG can be fulfilled rather easily by installing gas and fuel oil boilers with blended bio-fuels, there are few incentives for market actors (technology providers, installers) for innovations by establishing new decentralised renewable heat technologies with similar advantages.

In total, the EWärmeG has triggered additional 110,000 to 170,000 t of $CO_2$eq. savings annually since its amendment (residential buildings 50,000–70,000 t of $CO_2$eq., non-residential buildings 60,000–100,000t of $CO_2$eq.). All residential buildings under obligation of the EWärmeG have additionally saved 9 % to 16 % of emissions, compared to their emissions before the exchange of the heating system.

## ZEBRA 2020 – Nearly zero energy building strategy 2020 (TU Wien - Energy Economics Group et al. 2016)

***Overview***

In the project the market uptake of nearly zero-energy buildings (nZEBs) in Europe was analysed and monitored. Thereby, data and evidence for policy evaluation and optimisation was gathered to provide a basis for developing strategies to accelerate the market uptake of nZEBs. 17 European Member States were covered by the ZEBRA 2020 project, which are Austria, Belgium, the Czech Republic, Denmark, France, Germany, Italy, the Netherlands, Norway, Poland, Lithuania, Luxemburg, Romania, Slovakia, Spain, Sweden and the United Kingdom.

nZEBs are seen as a cornerstone for a sustainable society and economy in Europe. Furthermore, with the last recast of the Energy Performance of Buildings Directive (EPBD) nZEBs became the standard for new buildings by 2020 and Member States had to implement the directive in their national laws and define the nZEB standard taking into account national conditions and economic viability.

***Data and data availability***

In the project, information regarding market development and characteristics of nZEBs was collected. Furthermore, a new method to make available information and data comparable amongst countries / harmonise the available information was developed. A major challenge was the absence or at least difficult accessibility of key data. This especially regards non-residential and existing buildings as well as renovation activities (level as well as quantity).

The monitoring of market activities showed a substantial gap of market maturity of nZEBs at EU level, which must be closed by 2019/2021.

***Barriers and related recommendations***

- According to the study a **clear and shared long-term vision for a building stock** is essential for the definition of suitable and target compatible nZEB definitions at national level.
- Different **system boundaries, calculation methodologies, applied factors** (e.g. primary energy factors) etc. make a quantitative comparison of nZEB definitions in different Member States very difficult. Nevertheless, the study found that **many (or most) nZEB definitions in Member States do not meet the intention of the EPBD**, which says that a building should only consume “nearly zero or very low amount” of energy. The remaining amount “should be covered to a very significant extent by energy from renewable sources” (i.e. at least 50 %). The definitions are vague and leave a lot of space for interpretations. Therefore, it is recommended that the new EPBD contains clear definitions of terms and goals. It is furthermore emphasised that new buildings and renovations are distinguished.
- **nZEB compliance monitoring** as well as sanctions regimes need to be improved. Only about 50 % of the assessed Member States monitor the compliance of new constructions with energetic requirements.
- **Insufficient professional skills** are still an important barrier. This should remain a focus in policies at EU and national levels.
- The **reliability and credibility of Energy Performance Certificates (EPC) is questioned** in many Member States by different stakeholders in the building sector. A transformation of EPCs into Building Certificates or “Building Passes” considering the whole lifetime of a building could increase their credibility. Thereby, they could serve as a key measure to encourage building renovations towards nZEB standards. In addition, saving building data from EPCs in a central electronic database, which is accessible for all stakeholders could significantly improve data availability.
- **Energy poverty and vulnerable consumers** can be found in each Member State. A shift from fuel subsidies to energy efficiency support schemes could help tackling the issue.
- **Future-proof buildings** are described as buildings which are highly efficient energy hubs consuming, producing, storing and supplying energy. The smartness of buildings and their readiness to interact with other buildings at district level should be part of a revised nZEB definition.

***Scenarios until 2050***

The project develops two scenarios describing the transition towards low/ zero emission building stocks. In the centre of the analyses are the assessment of the effect of current building standards and other policy settings on the energy demand in 2050. The scenarios are “current policy scenario” and “ambitious policy scenario”.

- **Current policy scenario**: Existing policies like energy performance requirements, financial instruments and obligations for the use of renewable energies.
- **Ambitious policy scenario**: more ambitious policies fostering higher renovation rates and depths, higher efficiency of new buildings and a higher share of renewables used in buildings leading to lower energy demands and $CO_2$ emisisons; the scenario is not a “maximum intensity scenario”

In the scenarios, the following instruments were implemented in a model (TU Wien - Energy Economics Group et al. 2016, p. 24):

- “*Building codes for new buildings and building renovation;*
- *Financial and fiscal support policies/programmes;*
- *Increase of renovation rate in public buildings;*

- *Obligation to install renewable heating systems;*
- *Compliance with regulatory policies;*
- *Other instruments like $CO_2$ taxes, mandatory thermal retrofitting in case of façade maintenance or/and during real estate transaction, prohibition of oil boilers or in general all fossil fuel boilers.*"

Major results of the **current policy scenario** are:

- Reduction of $CO_2$ emissions: 27 % - 70 %
- Reduction of primary energy demand: 27 % - 61 %
- Reduction of final energy demand: 11 % - 48 %

Major results of the **ambitious policy scenario** are:

- Reduction of $CO_2$ emissions: 36 % - 81 %
- Reduction of primary energy demand: 37 % - 70 %
- Reduction of final energy demand: 17 % - 60

The results show that even the **ambitious policy scenario is not in line with the long-term climate mitigation targets**, which indicate that the emissions reduction should be beyond 80-90 % in the building sector. Furthermore, the different reduction potentials in the analysed countries are highlighted. Reasons for the different potentials are the **current energy performance of buildings** (the higher it already is, the more difficult and more expensive are additional savings), the **role of different energy carriers** (current and future role of fossil fuels in buildings), the **share of renewable energies in buildings today** (in countries which already have a high share an increase is more difficult and more expensive), increasing demand of **electricity for cooling** especially in southern European countries and the **renovation rate and depth** (key driver for energy savings).

## Building sector Efficiency: A crucial Component of the Energy Transition (Agora Energiewende 2019)

***Overview***

The study analyses the role of energy efficiency in buildings for the cost-optimal achievement of climate targets and what role buildings play in the overall energy system of Germany. Furthermore, alternative measures to be taken if energy saving measures in buildings are not taken. For the compensation of less energy savings in buildings, more renewable energy must be generated, more heat pumps are needed, and more synthetic fuels must be supplied. The need for action (in the building sector) is highlighted. In the study, five scenarios meeting the climate targets in 2030 and 2050 are analysed:

- Efficiency$^2$: Baseline scenario; reduction of final energy consumption of buildings by 44 %
- Efficiency + EE: reduction of final energy consumption of buildings by 34 %; additional energy demand supplied by conventional renewable energies (mainly solar thermal and district heat)
- Efficiency + WP: reduction of final energy consumption of buildings by 34 %; additional energy demand supplied by heat pumps
- Efficiency + PtG: reduction of final energy consumption of buildings by 34 %; additional energy demand supplied by Power-to-Gas (PtG)
- BAU + PtG: efficiency efforts kept at today's level; reduction of final energy consumption of buildings by 27 %

***Key findings***

Energy efficiency in buildings **reduces overall economic costs**. It reduces the expenditures for energy generation and distribution. When the additional energy demand compared to the baseline scenario (Efficiency²) is supplied by renewables, the additional annual costs sum up to 2.5 billion euros and if it is supplied by PtG to 3.7 billion euros. If efficiency measures are not increased (business as usual), and the remaining energy demand is supplied by PtG, the additional annual costs are the highest (8.2 billion euros). However, less efficiency in buildings than in the Efficiency² scenario also reduces maintenance expenditures by 4.5 to 7.3 billion euros.

**Increased multiple benefits** from efficiency measures: Efficient and high-quality buildings prevent damage from moisture and mold. They furthermore increase thermal comfort. Both effects have positive impacts on the health and performance of occupants. In addition, the import dependency is reduced, and renewable energy sources are relieved. Added value from building renovations stays in the country and increases the GDP.

**Efficiency is a door-opener** for all kinds of technology: Energy-efficient buildings pave the way for low-temperature applications, which are inefficient and expensive in non-efficient buildings.

**Reduced risk**: An energy-efficient building stock reduces risks associated with changes to existing energy sources.

**Purposeful action**: It is essential that the long-term goals for the building stock are in the centre of today's decisions and actions to avoid lock-in effects and the need of changes outside the usual investment cycles in the sector, which are associated with high additional costs.

***Policy recommendations***

**Efficiency roadmap:**

Due to the long investment cycles and in the same time high efficiency potentials in the building sector goal-oriented policy guidelines must be established. They must be adopted in the Energy Performance of Buildings Directive (EPBD) at the European level and in the Building Energy Law (GEG) and Energy Economic Law (EnEG) at the national level. This has to be done as soon as possible to avoid that new buildings or buildings renovated today have to be renovated (again) before 2050 in order to meet the long-term targets.

**Improve efficiency's image:**

A clear, long-term commitment by the government is needed to win back trust of the diverse stakeholders in the building sector. Furthermore, convincing arguments for insulation must be developed and communicated to build trust. This must be accompanied by advice, explanation, standards and technical solutions.

**Targeted incentives for deep renovations:**

Highly efficient buildings are usually connected to high initial investment costs (new buildings, but also refurbishments). Therefore, information on economic benefits of such buildings must be available to decision makers. Existing incentive programmes already address this issue. However, they must be adjusted in a way that buildings that are not compatible with a climate-neutral building stock are no longer supported. Furthermore, also refurbishment standards and respective incentives must be in line with a climate-neutral building stock in 2050 as e.g. defined in a renovation roadmap.

**Prepare consultants and architects for higher efficiency:**

Energy efficiency of buildings must play a greater role in planning and consulting. Therefore, consultants and planners must receive training.

**$CO_2$ steering components in energy tax law:**

It is essential to internalise $CO_2$ damage costs in energy prices in order to achieve a climate-neutral building stock and make energy efficiency measures more economically feasible.

**Promote skilled labour and training:**

Skilled workers are of high importance for achieving the long-term goal and realise the desired refurbishment rates and qualities. Therefore, working conditions and wages must be improved in the sector. This can be accompanied by measures to elevate the social status of employees in the building sector.

**Improve the heating infrastructure:**

In areas suited for the integration of renewable heating (renewable/ decarbonised district heating supply, thermal storage), funding for new heating infrastructure should be increased. Furthermore, funding should be increased for transforming and decarbonising existing district heating systems. In addition, it is suggested to improve the calculation of primary energy factors to improve the allocation of environmental impacts to the ones causing them.

**Increase development and research:**

Manufacturers and research institutes should increase their efforts to develop efficient and renewable energy technologies as well as to improve existing ones.

## Building energy renovation for decarbonisation and Covid-19 recovery (Zangheri et al. 2020)

***Overview***

Energy efficiency in general and particularly in the buildings sector has the potential to support economic recovery and decarbonisation. Despite the introduction of various incentives and regulatory mechanisms in recent years, the European buildings sector still has a very high energy and emission saving potential, especially in residential buildings. However, there are regional differences. The report analyses the European buildings stock at local level and identifies the most critical regions. The analysis considers buildings' age, climate conditions, structural barriers, and key economic indicators. Energy saving potentials of extensive renovations of residential buildings, associated investment costs and the impact on employment are calculated. The calculation results can guide decision-makers to define programmes for the refurbishment of residential buildings at the European and national level.

***Approach***

Key indicators of the analysis are gathered at NUTS2 and NUTS3 level. These include climate conditions, the age of buildings, the type of buildings and ownership structures, and the economic well-being over the period of 2018 – 2021:

**Climate conditions:** Heating and cooling degree days on NUTS2 and NUTS3 levels

**Building age, building type and ownership:** the analysis is based on EUROSTATs Census Hub published in 2011, which was updated by down-scaling national constructions after 2011 based on the Building Stock Observatory of the EC.

**Economic well-being:** The Spring 2020 Economic Forecast of the Commission is taken as the reference. The regional breakdown on NUTS2 level is based on EUROSTAT data. The following indicators are considered for the period 2018 – 2021:

- Average GDP per inhabitant in Purchasing Power Standard (PPS)
- Variation of GDP per inhabitant in PPS
- Average unemployment rate
- Average net disposable income of households per inhabitant in PPS

- Average net disposable income of households per inhabitant in PPS for 20 % of the population with the lowest income

Based on this data, a **synthetic indicator** of economic well-being is calculated to compare the EU regions and identify the most critical areas.

**Composite index:** the index combines all the information mentioned above. Therefore, weighing factors had to be defined and weights had to be normalised. The prioritisation is as follows: 35 % building age, 30 % economic well-being, 25 % heating degree days and 10 % non-ownership.

***Main results***

**Age of the buildings stock:** The lowest average age of existing buildings can be found in north-eastern Germany, south of Belgium, central France, and north-western Italy. The share of historical buildings is the highest in central Europe: Belgium, France, and Germany.

**Rented buildings:** The highest share of non-owner-occupied dwellings and rented multi-family buildings can be found in urban areas of north-central Europe, e.g. in Stockholm, Berlin, Hamburg, Prague, and Vienna.

**GDP between 2018 and 2021 and unemployment:** the lowest average GDP per inhabitant is observed in rural regions of southern and eastern Europe. Regions in the north of Italy had the greatest negative variation of GDP per inhabitant. In the southern regions of Spain and Italy, and in Greece the average unemployment rates are amongst the highest in Europe (over 20%). The average net disposable household income (per inhabitant) is very low in all southern and eastern regions. Based on this, the study identifies the south of Spain and Italy, as well as Greece and Bulgaria as the most critical regions in Europe.

**Renovation of residential buildings:** It is seen as a key strategic choice for the recovery of regional economies and to build a zero-emission society. According to the study, deep renovations to nearly zero-energy buildings (nZEBs) and/or to cost-optimal levels can lead to (primary) energy savings of 2,251 TWh, which is equivalent to 57 % of the current energy consumption of residential buildings. To exploit the potential, an increase of the annual renovation rate to approx. 3 %/a within the next decade is needed. The rate must be kept at this level thereafter. Renovation depths must be ambitious. Thereby 79 % of existing buildings can be renovated until 2050 leading to primary energy savings of 1,517 TWh in the EU. Thereby, 55 million full-time equivalent jobs could be created.

**Regional energy benefits and economic expenditures:** The ratio between energy benefits and economic expenditures is calculated on a regional level and can be described as the efficiency of buildings renovation. The efficiency is calculated from regional energy saving potentials, investment needs and impacts on occupants. The highest values are detected in eastern Europe, especially in Poland, the Czech Republic and Romania.

## Digitalisation: Opportunities for heating and cooling (JRC 2019)

***Overview***

Digitalisation and the innovative use of information and communication technologies create opportunities for energy saving and energy efficiency in buildings. This study provides a literature overview on technologies, opportunities and challenges of digitalisation in the field of heating and cooling. Practical examples are analysed and existing initiatives and research projects are presented. Compared to other sectors, such as transport, digitalisation in the heating and cooling sector has received less attention, even though this sector accounts for about half of final energy consumption. The study shows that digitalisation offers various opportunities for energy savings in buildings and as well as additional benefits beyond energy savings. However, due to the energy consumption of digital technologies, the energy savings may not be as large as expected. Other risks, such as data protection and cyber security, also need to be considered. New policies are needed to mitigate the above risks and ensure that the best technologies and business models prevail.

**Smart buildings**

There are various applications of digitalisation for heating and cooling in buildings. Simulation tools are useful in the planning phase. Through the building data modelling approach, the entire building with all systems is replicated on a computer and then simulated, tested and corrected. Regular feedback, e.g. via smart meters, is a cost-effective first step. Overall, there are fewer systems that go beyond basic information and visualisation to perform advanced analysis. Building energy management systems combine software with smart thermostats and sensors to detect behaviour and use weather forecasts and energy prices to predict energy demand and control heating and cooling. A cost-effective first step is to provide regular feedback (e.g. via smart meters, in-house displays, energy bills or emails). However, several studies show that it is difficult to engage households on energy issues, especially if the information received is not clear, actionable and timely or frequent enough. With new developments in artificial intelligence, systems can also increasingly be interconnected and controlled on smartphones. Thus, artificial intelligence offers the opportunity to significantly increase the balance between energy savings and user-defined comfort.

Examples:

- Solutions for temperature monitoring and heating control
- Voice-controlled assistants such as Amazon’s Echo or Google Home
- LeanHeat from Finland offers smart building control and maintenance based on IoT and AI in around 80,000 homes so far. 10-20% energy costs are expected to be saved through the smart heating control and up to 30% savings in technical maintenance costs
- WattTime integrates software into smart thermostats
- Fourdeg from Sweden: Smart heating service that takes into account the local weather forecast, the number of open windows, the number of occupants and the characteristics of the rooms

**Heat pumps and electrification**

Digitised heat pumps use sensors that provide data on temperature, weather and electricity prices, as well as smart controllers that understand the thermal behaviour of the building and the user and can provide this data to optimise the application. Heat pumps are expected to play a leading role in future energy consumption (see Section 2). The decarbonisation of H&C via electrification requires that electricity generation is further decarbonised, power is increased and adapted to the consumption patterns of buildings, and that distribution networks are strengthened and digitalised. In the EU, currently only 37% of consumers on average are equipped with smart meters, which is why the non-binding target of 80% could not be reached. Smart meters and digitalisation enable the automation of controllable thermal loads such as air conditioners, heat pumps or electric water heaters.

Examples:

- European Project “Real Value” analyses the potential to electrify a large part of the heating load in aggregated, small-scale residential uses by introducing power-to-heat storage
- BrenmillerEnergy: Offer of heat storage systems for district heating and industrial power-to-heat

- The DR-ROB project Will demonstrate the benefits of demand response for buildings at universities, hospitals and a technology park
- The Horizon 2020 project SABINA aims to improve the use of synergies between electricity and heating networks by optimising the use of electricity for cooling and heating purposes.

**District heating and cooling**

DHC systems can make a significant contribution to reduce emissions and save primary energy. There are more than 6000 district heating systems in Europe. These are increasingly playing an important role in the energy plans of cities and regions. District cooling is much less common than district heating due to a more complex system. Currently, fossil fuels dominate district heating, but systems can use any fuel. From 12% today, district heating is expected to cover at least half of the heat demand in a cost-effective way by 2050, with heat supplied from renewable sources. The advantages lie in its simplicity and ease of installation. In addition, district heating can also help stabilise the electricity grid. Digital technologies can make DHC more efficient, intelligent and cost-effective through digital technologies that enable data management in terms of temperatures, flow, leak detection or pressure. New district heating technologies improve energy efficiency and make it easier to integrate renewable energy.

Examples

- Indeal offers a platform for real-time collection of energy consumption data via smart meters, identification of building heating and cooling needs depending on energy efficiency, energy consumption and building type, forecasting short- and long-term weather conditions and upcoming heating and cooling needs, and monitoring and controlling the level of energy storage.
- TEMPO offers a monitoring platform to detect and diagnose faults in district heating substations, visualisation tools and a smart grid controller to balance supply and demand and minimise return temperature.
- Other examples of intelligent platforms are CELSIUS, COOL DH, RELaTED, THERMOS or FLEXYNETS.

**Smart energy systems**

In smart energy systems, electricity, heating and gas networks are coordinated to highlight synergies and achieve optimal solutions for the system. Data generated by smart meters and other digital technologies could be used to predict heating and cooling flows, detect inconsistencies and check for losses. In the process, AI has the potential to control production facilities to optimise resources and reduce costs.

Example:

The EU Project “HEAT4COOL” demonstrates integrated heating and cooling solutions complemented by heat pumps and renewable energy sources at building and district scales.

**Communities, cities and regions**

By 2050, around 84% of EU citizens are expected to live in cities. The decarbonisation of urban energy supply focuses on heat. In cities, DHC can be a cost-effective and efficient solution to reduce emissions and energy demand by capturing surplus heat. Long-term planning is essential to engage stakeholders and enable investment planning. Digitalisation can also be an important part of smart region concepts - especially for coal- and carbon-intensive regions in transition. In addition, an approach with local communities is increasingly being pursued. There are around 3000 such energy communities in Europe, of which around 1000 are in Germany. The number is increasing because more and more local communities are getting involved locally. Digitalisation enables community energy storage (CES), which stores surplus local heat and makes it available later when it is needed.

Examples:

- Aspern Seestadt: New urban centre in Vienna due for completion in 2028. It includes whole system research, three smart buildings with solar thermal, heat pumps and heat storage. The 111 households are equipped with a smart home app.
- The Kalasatama district in Helsinki: Smart district connected to district heating and cooling. It also hosts TeleCityGroup's data centre which uses seawater to cool and heat houses in Helsinki.
- Schoonschip in Amsterdam: Floating residential quarter with 47 households that aims to become the quarter with the most sustainable urban development in Europe. In addition to an implemented smart grid, all houses are equipped with local photovoltaic production, battery storage, solar collectors, thermal storage, a smart heat pump and other smart grid-enabled devices.
- The European Innovation Partnership for Smart Cities and Communities aims to find common solutions for cities with its 4600 partners in 31 countries. The focus is on energy, transport and ICT.
- Another example of the European Commission supporting cities in implementing digital solutions is the Digital Cities Challenge, where experts offer advice to 15 European cities.

**Opportunities and challenges**

Most digitalisation trends will lead to an increase in total energy consumption - especially electricity consumption. The digitalisation of the energy sector itself could be an exception, as digital technologies have a great potential to deliver energy savings through better efficiency and create convenience and financial savings for the user.

There are many advantages and opportunities that result from digitalisation: energy savings, reduced operating costs, greater resilience, new markets for local heat sources, local job creation, improved industrial competitiveness, and mitigated environmental impacts including improved air quality. However, there are also challenges for the economic and social life that should be considered: Up-front costs, privacy and data protection, fairness and impact on vulnerable groups are some of the negative effects that can accompany digitalisation.

## 3.3. Financing

**De financiële gevolgen van de warmtetransitie: Een onderzoek naar de investeringsuitdaging, effecten op energie-betaalbaarheid en het potentieel van (nieuwe) financieringsvormen (ECORYS 2019)**

**Overview**

The Dutch Climate agreement requires 2.3 M households to have switched from natural gas to decarbonised energy sources by 2020 and this report investigates the costs of this ambition as well as the means by which this transition can be financed. The 2.3 M to be decarbonised consist of 1.5 existing buildings and 0.7 M of new buildings. The segment of privately-owned houses is most challenging to decarbonise as individual solutions are more capital intensive than collective ones. For the 0.7 M privately-owned houses that need to switch from gas to sustainable heating systems it is estimated that an average investment of € 23,500 is needed per household, where € 13,000 needs to be financed by the homeowners themselves and the remainder is expected to be financed by the government. In total this market segment represents an investment requirement of €66.4 bn between now and 2030. In terms of technologies, the largest contribution to the overall decarbonisation of the heat demand is expected from heat pumps, followed by district heating fed by CHP installations or waste heat.

**New forms of financing**

For more than a third of the private homeowners targeted by the government objective, it is possible to extend their mortgage and get additional finance through a green mortgage, using their house as a collateral. For almost half of the homeowners a building-connected form of financing, which is transferable from one owner to the next could be a means for financing the required investments. Around 15% of the homeowners will need a public loan to finance the required investments. Lastly, a very limited share (0.2%) of homeowners can finance the required investments themselves, potentially in combination with commercial loans, based on an increase in the value of the house and a reduced energy bill.

**Impacts of the decarbonisation of the heat demand of houses on the household energy bill**

The anticipated changes in the energy systems of the households, in case of an unchanged policy and taxation framework, would lead to an increase in the overall energy bill, with an average of € 258 per household per year. As a consequence, a growing number of households would suffer from energy poverty as reflected by the fact that they would spend more than 10% of their income on the payment of their energy bill. It would require an annual subsidy of € 440 M to compensate for this effect.

## Financial Incentives for Renewable Heating and Cooling (EREC 2007)

***Overview***

The report is the output of task 4 of the K4RES-H project, which ran between 2005 and 2007 and was funded by the EU's Intelligent Energy Europe programme. The project focused on

- Verifiable targets and statistics for RES-H (renewable heating technologies)
- Quantifying the energy delivery of individual RES-H installations
- Regulations at a local, regional, national and European level
- Financial incentives
- Innovative RES-H applications

***Barriers for the deployment of H&C***

The decarbonisation of the heating and cooling sector requires significant investments and there are multiple market barriers hindering the diffusion of renewable H&C technologies, such as high upfront costs, split-incentives and the lack of knowledge/professional capacity. Decarbonisation of H&C applications often involves the involvement of a high number of stakeholders (constructors, installers, H&C technology suppliers, financiers, etc.), who need to act in a concerted manner. Furthermore, in the built environment, there are often short windows of opportunity for sustainable refurbishment, especially in the case of replacement of heating equipment (e.g. broken old boiler). Lastly, there is often a lack of skills and expertise among construction and installation companies, which hampers demand for RES-H technologies and vice versa (chicken and egg problem).

Although a variety of policy instruments will be needed to remove the barriers for the uptake of RES-H technologies, financial incentive schemes (FIS) can play an important role to speed up the transition process in the H&C sector, through a variety of ways. Financial incentive schemes can:

- Reduce the (high) upfront investment costs
- Act as a marketing tool;
- Stimulate market development and availability of RES-H technologies;
- Provide a positive stimulatory signal from public authorities.

***Best practices for financial incentive schemes***

FIS exist in many different forms (e.g. grants, concessional loans, guarantees, etc.), but the type of FIS seems to be less important for the effectiveness than the continuity of and long-term certainty around such an instrument as uncertainties around future adaptations can lead to postponement of investments. Furthermore, FIS should always go hand in hand with flanking measures, such as awareness raising campaigns targeting specific consumer groups or heating sector professionals, large-scale demonstration projects etc.

Best-practice financial instruments have the following characteristics:

- They avoid investment uncertainty and guarantee continuity;
- They can be adjusted when implemented, but this should be carefully consulted with experts and minimise market interference;
- They have detailed criteria regarding the eligible applications and technologies and flanking measures are aligned with this;
- The financial support should be proportional to the amount of renewable energy generated and requirements for measuring this should be proportional to the magnitude of the investment and benefits;
- Industrial RE applications might require additional support, because of the presence of other co-benefits;
- They keep administrative burden at a minimum;
- They prevent interference with EU trade rules and the creation of isolated markets.

## Identification of EU funding sources for the regional heating and cooling sector (PNO Consultants 2019)

***Overview***

The document provides information for regions on how to access European funding sources for energy efficiency projects and projects aiming to deploy renewable energy in the heating and cooling sector. The EU does not have dedicated funding instruments for heating and cooling. EU funding for H&C projects is channeled through the five European Structural and Investment Funds (European Regional Development Fund (ERDF), European Social Fund (ESF), Cohesion Fund (CF), European Agricultural Fund for Rural Development (EAFRD), European Maritime and Fisheries Fund (EMFF)) and dedicated grants and financial instruments. There are a few dedicated calls within these EU funding programmes for the H&C sector. A number of the EU funding instruments require cross-border cooperation.

***Scope***

The study focuses on public funding instruments including grants, soft loans and guarantees. EU energy subsidies are mostly funded via the structural investment funds (ESIF), Horizon2020, LIFE NER300/ETS Innovation Fund. The study provides information on the EU programming period 2014-2020. Where information is available, an outlook into the next programming period (2021-2027) is provided.

The scope of activities covered focuses on but is not limited to:

- District heating and cooling[94]
- Renewable heating and cooling sources
- House renovation
- Support to R&I on energy efficiency in H&C
- Support to local SMEs

The report covers sources of funding for Technology Readiness Levels (TRLs) across the spectrum: TRL1 to TRL9. The report also covers some information on the regulatory framework and guidelines for combining different EU funding sources.

***Conclusions***

- Investments in H&C projects, energy efficiency and renewable energy still have relatively long payback periods or/and are perceived as high risk. In order to have a convincing business case such investments often require the maximisation of public funding.
- Although there are currently no specific funding instruments for heating and cooling at EU level, H&C projects can access a large number of generic energy subsidies and other more general innovation subsidies and support instruments.
- Many of the EU funding sources in the report are large, well-known and established funding programmes. The report finds that generally, the more popular funding programmes have lower chances to be awarded. Thus, it is recommended to also examine alternative, lesser-known funding instruments. To identify relevant subsidies for a project it can help to look at the project from a different perspective. This approach can bring different funding instruments into view. For example, looking at a project from the employment perspective may help to identify subsidies that support social inclusion, e.g. through the European Social Fund.
- There are many opportunities for combining EU funding with local, national or other EU funding instruments. An option is to use several funding instruments for the different phases of project development. However, familiarity with rules and guidelines is advised especially with regard to non-cumulation and state aid regulations. Managing authorities have the primary responsibility to verify compliance with regulations, however, the report finds instances where this did not occur correctly and where beneficiaries hat to repay parts of the funding.
- Results from several surveys supporting this report identified previous experience in drafting project applications as one of the key factors determining whether an application is successful or not.

**Matching money with green ideas (Agora Energiewende 2021)**

[94] Based on the definition of efficient district heating and cooling as specified in Article 24(6) of Directive 2012/27/EU.

***Overview***

The study provides an overview of the various EU funding schemes in the context of the Multiannual Financial Framework and the Next Generation EU programme (NGEU) and links these schemes to the investment needs in various sectors (industry, buildings, transport and energy). This summary focuses on the results concerning the buildings sector.

***EU funding and climate mainstreaming***

Across the EU budget, 30 per cent of expenditures must be directed to climate action (the so-called "climate mainstreaming" obligation), and various programmes also earmark and/or specifically focus on green transition activities. In addition, the recovery fund and several other EU programmes have to respect the do no significant harm principle that was established in the EU Taxonomy.

***Funding opportunities at EU level***

The *Recovery and Resilience Facility (RRF)* entered into force in February 2021 as the largest instrument of the Next Generation EU Fund (with €312.5 billion in grants and €360 billion in loans). It is introduced as a temporary instrument with the objective to help Member States repair the immediate economic and social harm caused by the coronavirus pandemic. The RRF has a climate earmarking of 37 per cent and a digital target of 20 per cent.

*Cohesion and structural funds* are part of European Structural and Investment Funds (ESIF) and apply low-carbon spending earmarking. Cohesion spending was increased for 2021–2022 with REACT-EU (€47.5 bn), which does not have the same low carbon conditions, however MS are "expected" to contribute 25 per cent to climate objectives. The European Regional Development Fund (ERDF) aims at reducing regional disparities in economic development and includes the net-zero-carbon economy as one of the main themes. At least 30 per cent of all funds are reserved for projects that contribute to the larger objective of climate neutrality. Cohesion Funding provides financing for Member States whose Gross National Income per inhabitant is less than 90 per cent of the EU average and funds multi-annual national programmes aligned to EU objectives (climate earmarking of 37 per cent).

The *European Social Fund* (€88 bn) is the main fund for developing the human capital needed as the labour market transitions to a digital and green economy. There is no specific amount earmarked for activities related to decarbonisation, but upskilling in sectors related to the environment, climate, circular economy and bio-economy is encouraged.

The Just Transition Fund (JTF, €17.5 bn), which is part of the broader Just Transition Mechanism (JTM), is allocated through both the NGEU (€10 bn) and the MFF (€7.5 bn) and addresses Member States in regions that are heavily reliant on fossil fuels and other carbon-intensive industries. The fund focuses on creating a fair job market for workers who are forced to leave the fossil fuel industry through reskilling & upskilling programmes, R&D, job seeking assistance, digitalisation, the circular economy and technical assistance. The fund excludes fossil fuels and nuclear power. Moreover, the JTF includes climate policy incentives by a green rewarding system and conditional access to 50 per cent of national funding allocations for Member States based on the adoption of national objectives for climate neutrality by 2050. The JTF will be co-financed by MS and complemented with other MFF funds.

Horizon Europe and the EU ETS Innovation Fund are funding instruments geared to early development stages, whilst the recovery funds are targeted more at market ready technologies that need to be upscaled for the revised 2030 ambition. The new LIFE budget features a new Clean Energy Transition sub-programme of approx. €1 billion that comes in addition to another €1 billion of climate mitigation and adaption funding. The LIFE programme is the successor of the Intelligent Energy Europe programme.

## Innovative financing schemes (Covenant of Mayors 2019)

***Overview***

The report presents the lessons learned by cities and regions across Europe regarding innovative financing schemes to fund locally-owned projects.

***Lessons learned***

**Green municipal bonds** provide the bond issuer (borrower) with external funds to finance long-term investments that have positive environmental and/or climate benefits, while providing the bond holder (lender) a return on the investment. They can provide a low-cost source of capital and have been introduced successfully in several cities and regions, e.g. Gothenburg, Malmö, Stockholm and Örebro (Sweden), Oslo (Norway), Hannover (Germany), Paris and Region Ile de France.

**Earmarking local environmental or energy taxes**, fees or congestion charges for projects and campaigns on sustainable energy has been implemented in several cities, e.g. Lausanne (Switzerland), Oslo (Norway), Milan (Italy), Nis (Serbia), London (UK). The revenues are partly distributed through grants, loans or subsidies to citizens, research institutions or businesses to support sustainable practices.

**Energy Performance Contracting (EPC)** refers to the implementation of energy efficiency or renewable energy projects by external organisation (Energy Service Company – ESCO), which then uses the stream of income from the energy savings achieved or the renewable energy produced to repay the costs of the project. The approach is based on a performance guarantee given by the ESCO, which transfers the technical risks from the client to the ESCO. Consequently, ESCO remuneration is based on demonstrated performance.

**Energy cooperative** offers citizens the possibility to jointly own and/or participate in renewable energy and energy efficiency projects on municipal sites and infrastructures. Municipalities can support and promote citizens' cooperatives and can also own part of the shares.

**Soft loans** provide homeowners with money at lower-than-market interest rates, providing an incentive to carry out energy-efficient renovation works.

**On-tax financing** can be used to recover payments from citizens and companies for energy efficiency measures financed by private investors. These investors lend the money for retrofits up-front and then get repaid over a timescale of up to 20 years through an additional charge on a property-related tax bill. The scheme is being deployed in Europe based on the experience of the "PACE scheme" established in the US.

**Third-party investment** is a scheme where the investment on the renovation of a building is not paid by the homeowner but by a third-party investor. Thus the homeowner does not take on a debt but pays a service fee to the investor instead. The investment can be done via an Energy Performance Contract. In this case the costs are repaid through the guaranteed energy savings.

**A revolving fund** is a reserve of money used to finance a particular set of activities by lending to one or more borrowers. Over a given period of time, the borrower is expected to repay the original sum that restocks the fund. Usually, an interest is charged to the borrower as a fee for administrative costs but also to protect the fund from being depleted.

**Policy developments in the EU and strategies for P4P business models (SENSEI 2021)**

***Overview***

The H2020-funded project SENSEI aims at designing and testing innovative transaction models building on pay-for-performance (P4P) schemes. In these schemes, payments for energy efficiency are based on proven and measured savings (using pre-agreed measurement and verification methods).

***Strategies for rolling out P4P schemes in the EU***

The report proposes ten integrated strategies for rolling out P4P schemes in the EU :

1. Exploiting economic stimulus packages
2. Establishment of demanding energy performance requirements
3. Strengthening the role of energy efficiency market players
4. Recognising and valuing energy efficiency as a resource
5. Promoting metered methodologies to increase accuracy and transparency
6. Increasing ambition on public buildings
7. Increasing ambition on Small and Medium Enterprises
8. Ensuring stakeholders’ involvement
9. Establishing standards and promoting capacity building activities
10. Raising awareness and empowering citizens

## 3.4. National strategies

**Climate Agreement (Netherlands) (Ministerie van Economische Zaken en Klimaat 2019)**

***Overview***

The Dutch Climate Agreement was developed though a participative approach in 2018/2019 and covers the built environment, mobility, industry, agriculture and land use and electricity, as well as cross-sectoral issues. Regarding the built environment, aside from climate change mitigation, the aim of the Dutch government to cease natural gas extraction in Groningen as soon as possible is a further reason for reducing transforming the heating sector.

***Targets and objectives***

- Reduction target of 3.4 Mt of $CO_2$ in the built environment by 2030, compared to the reference scenario.

- Enhancing energy performance of 7 million homes and 1 million utility buildings
- New buildings will no longer be heated with natural gas
- Improvement of existing buildings to enable fossil-free heating: 1.5 million by 2030; from 2021 onwards 50,000 buildings per year; increase to 200,000 buildings per year before 2030
- Growth in district heating, increasing up to approximately 80,000 home equivalents per year by 2025 and holding that level up to 2030. This will result in a heating demand of 40 PJ by 2030.
- Municipalities are in the lead, using a neighbourhood/district approach: -2019: 27 pilots -2021: 100 pilots
- Reduction efforts of 1 Mt of carbon dioxide are required for existing non-residential buildings

***District-oriented approach***

The Dutch plan takes a district-oriented approach, covering the following elements:

- ***Transition vision:*** Municipalities are obliged to have adopted a transition vision for heat by 31 December 2021, in which they will establish the timetable for a step-by-step approach to phasing out natural gas. This includes an assessment of alternative energy infrastructures, of social costs and benefits and integral costs for the users. A review of the transition visions after five years is foreseen.
- ***Development of a monitoring tool*** in which the municipalities communicate their progress on achieving their transition vision for heat.
- ***Setting up an independent regional energy information platform***
- ***Explore whether energy information platforms or a digital platform can contribute to pooling the demand of owner-residents***
- ***Setting up a knowledge and learning programme for municipalities***
- ***Adaption of laws and regulations in the field of electricity, gas, heating and mining activities and environmental law to make them suitable for the district-oriented approach (by January 2021)***
- ***Additional funds*** (150 million euro) for the period 2019 to 2021

***Natural gas phase-out in new construction***

The Gas Act (Gaswet) was amended as of 1 July 2018, such that new buildings are no longer fitted with gas connections. The change in the law affects new buildings for which the building permit was requested on or after 1 July 2018. The change applies to all small-scale users (<40 $m^3$ gas/hour), such as homes and small commercial buildings.

***Non-residential buildings***

- Emissions target for 2030 of 1 Mt of carbon dioxide for existing non-residential buildings and development of standard for non-residential buildings.
- Roadmaps for social real estate to be developed by twelve social real estate sectors to set out the starting points of the relevant sectors and outline according to which plan and timetable the sector will be working toward the 2030 target and toward achieving a low-carbon property portfolio by 2050 in a cost-effective manner.
- Development of benchmarks
- Development of a data system for energy consumption data, building data and building usage data

***Sustainable gases***

- Objective to realise 70 PJ of green gas by 2030 (3.6 Mt of carbon dioxide reduction), of which a substantial percentage can then be used for the built environment (direct injection into the gas grid, hybrid heat pump or through the heating grid).
- The green gas sector aims to achieve additional carbon dioxide reduction worth 1 to 2 Mt by 2030 through CCS and CCU (negative emissions).
- The green gas sector aims to arrive at a cost level of 100 – 150 euros per avoided tonne of carbon dioxide by 2030. The means to achieve this include a decrease of production, the combination of green gas production with carbon dioxide storage or reuse (CCS and CCU) and further improvement of the yields through multiple improved returns.
- Elaboration whether the expanded financial support scheme SDE+ can stimulate green gas.

## Heat Transition 2030 (Agora Energiewende 2017)

***Overview***

The study examines the diffusion pathways until 2030 for key technologies required in the heat sector in order to meet the German decarbonisation targets for 2050 (80-95% reduction of greenhouse gases with respect to 1990 levels). The study identifies building efficiency, district heating and heat pumps as key pillars of the decarbonisation of heating and discusses the required diffusion pathways of these technologies until 2030.

***Key technologies and diffusion pathways***

**Energy efficiency:** Based on an analysis of existing projections, the study concludes that the final energy demand for heating needs to be reduced by around 40% in 2030 (as compared to 2008 levels) and around 60% by 2050 through energy efficiency measures. With a final energy consumption for heat in buildings of 869 TWh in 2008, this corresponds to a remaining final energy demand of 521 kWh (2030) and 348 kWh in 2050. The increase in energy efficiency is highlighted as a key requirement in order to facilitate the accelerated diffusion of heat pumps in existing buildings. The study assumes an increase of the retrofit rate to 2% (from currently around 1%) and an increase in the depth of renovations.

**Decentralised renewable energy:** The study estimates that the potential for decentralised renewable energy for heating is 197 to 447 TWh per year (solar thermal: 53–69 TWh; biomass: 69–139 TWh; ambient heat: 58–186 TWh; electricity for heat pumps:17–53 TWh per year).

**District heating:** The study states that the share of district heating needs to increase from around 10% of final energy consumption in 2014 to around 23% in 2050 and indicates a range of 15-21% of final energy consumption as a milestone for 2030. Due to the strong decrease in final energy demand, the increase in the share of district heating does not correspond to an increase of heat supply from district heating in absolute terms. For the long-term decarbonisation of district heating, the study concludes that it is essential that temperatures are reduced and deep geothermal energy, large-scale solar thermal installations and/or ambient heat/waste heat utilisation (drain water, industry, rivers, sewage water, etc.) with large-scale heat pumps are expanded.

**Heat pumps:** The study states that by 2030 a range between 6 and 8 million heat pumps need to be installed in order to meet a -95 % decarbonisation target by 2050. In 2018, the total number of installed heat pumps was

877,000 and the annual sales in 2019 reached around 86,000[95]. In order to meet the milestone of 6-8 million heat pumps in 2030, the annual sales would need to increase at least fivefold. With regard to the increase in peak demand due to the electricity consumption of heat pumps, the study concludes that by 2030, the additional 21 GW needed for heat pumps do not cause any serious challenges for the electricity system, as currently 35 GW are needed for electric resistive heating (of which demand is assumed to decrease). By 2050, the study differentiates between a -80% decarbonisation target (total emissions in Germany) and a -95% target: While peak demand could be covered with electricity generated using efficient gas turbines in a -80% scenario, in a -95% target the electricity system needs to be fully decarbonised, such that PtG technologies would be necessary to cover peak demand from heat pumps. The study concludes that peak demand is not a serious challenge for heat pumps. The study considers that the main challenge for the increased diffusion of heat pumps is the requirement of ambitious progress in increasing the energy efficiency of buildings in order to ensure an efficient and economically feasible use of heat pumps.

**Green gas**: The study discusses renewable gas as an alternative to the ambitious expansion of heat pumps. As the potential or biomass is limited, the study focuses on power-to-gas (PtG) technologies. The study points out the advantages of heat pumps as compared to PtG in terms of efficiency (heat pumps produce around 3 to 4.5 kWh of thermal heat per kWh of electricity and power-to-gas only produces between 0.24 and 0.84 kWh of heat per kWh due to conversion losses).

## Energy Efficiency Strategy for Buildings (BMWi 2015)

***Overview***

The Energy Efficiency Strategy for Buildings published by the German Ministry for Economic Affairs and Energy is based on the goal of reducing primary energy demand of buildings by 80 per cent against the 2008 level through a combination of energy savings and the use of renewable energy. The strategy labels this 80% reduction goal “virtually climate-neutral building stock” and indicates pathways to reach the goal. The pathways are presented as a target corridor, spanned by maximum energy efficiency combined with a slightly less ambitious expansion of renewable energies on the one hand, and maximum use of renewable energies combined with a lower ambition in energy efficiency on the other hand.

The strategy is based on a reference scenario and two target scenarios:

1. The “energy efficiency” target scenario relies on an increase in energy efficiency up to the estimated maximum value of -54 per cent final energy consumption and covers the remaining target achievement gap by using renewable energies with a share of at least 57 per cent.
2. The “renewable energies” target scenario primarily relies on the development of renewable energies up to the estimated maximum potential limit of 69 per cent in final energy consumption, covering the remaining target achievement gap by energy savings of at least -36 per cent.

***Key policies and measures***

**Building-specific renovation roadmaps** offer building owners a reliable strategy for a holistic assessment and an energy-efficient renovation programme for their buildings spanning a period of several years. Besides purely

[95] https://www.waermepumpe.de/presse/zahlen-daten/

energy-related issues, the determination of the renovation concept is to focus on the specific building owner's options and to identify possible funding and/or support offers.

**Further development of consulting and information**, in particular through regional renovation networks involving local stakeholders such as skilled craftsmen, consultants, planners/designers, consumer protection associations, etc. The tasks of these networks include regional networking and dissemination, qualification of craftsmen, planners/designers and other stakeholders as well as quality assurance through further training and feedback on quality on conclusion of a project.

**Public funding for investment in ambitious building renovation and new building project**: Integration and further development of existing support schemes for energy efficiency in buildings and renewable heating.

**Public funding for energy-efficient urban and neighbourhood renovation**: Improvement and better coordination of the "Energy efficient urban refurbishment" KfW programme, supporting the development of energy concepts for urban and neighbourhood renovation.

**Energy-saving legislation for buildings**: Further development of the standards of the Energy Saving Act (EnEG) / Energy Saving Ordinance (EnEV) and the Renewable Energies Heat Act (EEWärmeG) as are key elements for achieving the Federal Government's energy efficiency and climate targets.

**Targeted technology support and accelerated transfer to practical applications**: launch of the promotional initiative on "Innovative Projects for a virtually Climate-neutral Building Stock 2050 ("EnEff.Gebäude2050"), aiming to show how innovations which are already available today but not yet very widespread can significantly reduce primary energy consumption in buildings.

## Systemic challenges of Germany's heat transition (Fraunhofer ISE et al. 2020)

***Overview***

The study addresses two targets for the transition of H&C in buildings in Germany until 2050, which are (i) an almost climate-neutral building stock (target 1) in accordance with the Energy Efficiency Strategy for Buildings (BMWi 2015) (reduction of the non-renewable primary energy demand by 80 % compared with 2008) and (ii) an overall greenhouse gas reduction of 95 % in Germany, which means that the whole energy sector including heating and cooling has to be completely climate neutral by 2050 (target 2). The basis of the study is a meta-analysis of existing scenarios and studies analysing the transformation of the German energy system until 2050, from which different pathways, as well as central measures and technologies for achieving the goals are derived. Furthermore, different policy instruments are assessed and an in-depth analysis of the district heating sector in Germany is conducted including the identification of decarbonisation possibilities. For both targets a deficit and risk assessment is conducted and compensation possibilities for achieving the goals are identified and quantified. All results are combined in measure and policy roadmaps for both targets. Especially for target 2 it is necessary that the electricity and gas sectors are completely decarbonised until 2050.

***Key measures***

**Electricity generation:** The electricity generation must be almost completely decarbonised for target 1 and completely emission-free for target 2. Furthermore, the electricity system has to be adjusted and retrofitted due to new demands from heat pumps and other new electrical consumers.

**Allocation of biomass:** Even though biomass is a renewable energy source, its potentials are limited and are needed in other sectors than the supply of low temperature heat in buildings. In both target pictures, biomass only plays a minor role in buildings. In order to direct the biomass to sectors in which its application has the highest benefits, an allocation strategy should be developed until 2050.

**Energy demand reduction in buildings:**

The energetic standard for new buildings in both target scenarios ís increased to KfW-Efficiency House 55 by 2025 and KfW-Efficiency House 40[96] for the period 2025-2050. Furthermore, the refurbishment rate and depth is strongly increased compared to the past decades and current status (from approx. 1 %/a to 1.75 – 2.3 %/a between 2020 and 2030 and to 2.0 – 2.6 %/a between 2030 and 2050). The average energy standard of a refurbished building is increased to KfW-55 standard from 2025 onwards. For supporting this development, the improvement and market acceleration of serial/industrialised refurbishment (e.g. Energiesprong) until latest 2030 is suggested. It is furthermore required that with each refurbishment the supply temperature of the heating system is reduced in order to support the integration of renewable energies in the heating system.

**HVAC systems:**

All generally usable roof / building envelope areas must be used for the installation of PV and solar thermal systems from now on (new and refurbished buildings). Heat pumps will be the dominating heating technology for buildings with decentralised heat supply. The installation of monovalent oil and gas boilers has to be forbidden after 2020 and 2025 respectively (in the target 1 scenario five years later). For achieving target two also bivalent oil boilers will not be installed after 2025 and as biomass is needed in other sectors than the low temperature heat supply in buildings, no new biomass boilers will be installed in buildings after 2030. Besides that, boilers and (small) CHP must be developed, which can generally use hydrogen in the future.

**District heating:**

District heating provides the possibility of large-scale integration of renewables and especially in densely populated areas it might often be the only possibility for the decarbonisation of the heat supply of buildings as not enough areas for decentralised application of renewables are available. Therefore, system expansion and densification accompanied by a reduction of the grid temperatures is needed. Coal must be replaced by renewable sources latest by 2025 and natural gas latest by 2050.

***Key policies***

Different policies supporting the strategic dimension of the heat transition are required. These are (amongst others):

- obligation of a strategic municipal heat planning from now on**:** It is essential that municipalities plan the development of infrastructure and technologies in advance to avoid parallel expensive infrastructure and conflicts. This is of major importance for the gas and district heating infrastructure, but also for the use of ambient heat from the ground or ground water with heat pumps.
- the adjustment of taxes and fees to support the overall energy transformation
- integration of efficient monitoring

[96] KfW is a bank providing loans on behalf of the Federal Government of Germany to support e.g. efficient buildings. The KfW-Efficiency House standard refers to the currently applicable Energy Conservation Ordinance (soon Building Energy Law). The primary energy demand of a KfW-55 house is only 55 % of the primary energy demand of a reference building, the demand of a KfW-40 house only 40 % of the primary energy demand of the reference building.

- increase of information for all stakeholders in the building sector, especially for refurbishment measures
- clearly defining how and in which sectors biomass and synthetic gases and fuels will be applied in the future
- As the heat transition requires skilled work force, policies to ensure that enough skilled workers are available.
- In the frame of the energy demand reduction and HVAC systems policies and laws have to follow the long-term targets with respect to greenhouse gas emission and energy demand reductions;
- the long-term targets have to be integrated in laws even today with increasing energy requirements for buildings
- a roadmap for phasing out fossil fuel burning boilers (including prohibitions to install these boilers) as well as a reduction/ elimination of existing exceptions.
- The obligation to install PV and/ or solar thermal systems at each building must be integrated in the building energy law as soon as possible.
- Besides obligations in the regulative law, support schemes are needed (i) to accelerate the heat transition and investments in refurbishments and renewable heating technologies and (ii) to ensure socially acceptable heat transition and too high burdens especially for low- and medium-income households.
- As investment cycles in the district heating sector are long and the transition and expansion of district heating systems needs time, the frame must be defined now. This includes a clear quota for renewable energies and waste heat in district heating systems until 2050, an improvement of the regulatory frame of the systems (currently single systems can be considered as local monopolies) and an adjustment of support schemes in order to ensure the needed grid expansion, densification, temperature adjustments and integration of renewables.

**French strategy for energy and climate (Ministière de la transition écologique et solidaire 2018)**

***Overview***

The French Multi-Annual Energy Plan (MAEP) establishes the priorities for government action regarding energy policy for Metropolitan France in the next decade, shared in two 5-year periods (2019-2023 and 2024-2028). It addresses, among other things, heating and cooling in buildings and industry, the development of heat networks using renewable energy and waste (recovered) heat as the main instruments of heat/cold decarbonisation.

***Targets related to H&C for 2030:***

- 38 % of RES in final heating consumption (RES-H&C share in 2018 according to SHARES data: 22 %)
- Multiply the amount of RES-H&C and recovery in heat networks by five as compared to 2012 (in 2012: 7.9 TWh of RES-H&C and recovery heat in DH in France)
- Reduction of final energy consumption in buildings by 28 % (as compared to 2010)

***Objectives for renovation rates***

- Thermal retrofit (building envelope) of 1,200,000 homes in the decade 2021-2030 (i.e. average of 120,000 per year)
- Energy efficiency improvements (heating and cooling equipment) in 300,000 homes per year on average

***Strategies for the decarbonisation of H&C***

Besides increasing energy efficiency, the decarbonisation of H&C is mainly driven by direct use of renewable energies, by the systematic use of recovered (waste) heat for heating and to a lesser extent by the injection of green gases into the gas grid.

The French Strategy for Energy and Climate provides an outline of the policies and programmes that are implemented and planned in order to support building renovation and the use of renewable energies in H&C.

For building retrofit, the strategy outlines key measures included in the plan for energy renovation of buildings:

- Creation of a guarantee fund of more than 50 million euros for 35,000 low-income households each year;
- Simplification of the existing incentive scheme, switching from a tax refund to a bonus;
- Adaption of the 0% green loan programme;
- Reliable energy labeling of houses
- To train professionals and control the quality of works with a reform of the labeling RGE (validated for environment), with an investment of 30 million euros in the professional training and 40 million euros in innovation;
- Promotion of a large renovation programme in public buildings (state and local authorities) with a budget of 4.8 billion euros.
- The government will dedicate 200 million euros to implement the renovation plan with the white certificate scheme.

Addressing professionals in the building retrofit sector, the strategy outlines the following measures:

- Work with building and real estate professionals, NGOs, local authorities and energy companies, under the FAIRE banner to better identify the relevant renovation solutions for households, to trigger more action by enhancing household knowledge and confidence, and to better coordinate the existing grants and financing;
- Finalisation of the implementation of the new environmental regulations for buildings, including: A RES quota for new buildings (individual, collective, tertiary) by 2020; updating the conversion factors in primary energy for electricity used in the regulation of new buildings according to the revised EED; Adopting criteria on greenhouse gas emissions on the life cycle of the building, being careful not to have a negative impact on electricity peak demand
- Energy efficiency obligations for tertiary buildings (expected to cover 40 % of existing tertiary buildings in 2030 by targeting all business sectors and limiting exemptions to buildings of less than 1,000m²).

Addressing private individuals, the strategy covers the following measures:

- Several improvements to the Energy Transition Tax Credit (Crédit d’impôt pour la transition énergétique, CITE): Increase efficiency of the programme via a new fixed rate scale in 2020, which will take into account the energy efficiency of the actions and will be defined after wide consultation with stakeholders in the sector; extension to landlords in 2020; from 2019, extend the CITE for lower income households to cover the installation of renewable heat equipment and the disposal of oil tanks; make the CITE payments through the French National Housing Agency (Agence nationale de l'habitat, ANAH) at the time of the work, for the households in the first four deciles (current scope of ANAH aid).

- Maintaining the VAT rate at 5.5% for energy renovation works eligible for the CITE and related works;
- Enable the ecoPTZ (interest-free loan) to be applied at a fixed rate for single initiative work, without a work package (e.g.: installation of central heating powered by renewable energies);
- 100% funding of an energy audit for lower income households who own buildings with performance certificates F or G. Make this audit mandatory prior to letting a private category F or G dwelling and during transfer of a dwelling classified F or G between now and 2021, to encourage homeowners to initiate building work.

Addressing the industry sector, the following measures are included:

- Testing a managed release of the first energy saving certificates for energy saving operations carried out in facilities covered by the European carbon trading system;
- Including a technical-economic evaluation of solar or geothermal heat production in the energy audits of large and medium-sized companies;
- Continuing to increase applications for the eco-energy loans (PEE) made available by BPI France, for SMEs and micro-companies engaged in work qualifying for energy saving certificates. Prolonging the PEE scheme until 2025;
- Promoting the deployment of energy management systems (ISO 50 001 type) and energy benchmarks in industry.

***Direct use of renewables***

Main source of RES heat is solid biomass (wood), followed by heat pumps and to lesser extents solar thermal and geothermal heat.

***District heating***

Objective of five-fold increase in the amount of renewable and recovered (R&R) heat and cold delivered by district heating networks by 2030 (baseline 2012: 7.9 TWh), which represents a target of 39.5 TWh.

The following key measures to support RES-H in district heating are mentioned in the strategy:

- Increasing the ratio of R&R Heat Fund projects.
- Requirement for cities with more than 10,000 inhabitants to carry out feasibility studies into heating and cooling networks;
- Keeping VAT at 5.5% for heat deliveries from networks that are more than 50% supplied by R&R energy (and incorporate solar thermal energy to eligible R&R energies);
- Supporting the development of the most efficient R&R cooling networks through the Heat Fund;
- Establishing a recognised definition of renewable cold when delivered by network, at European level;
- Encouraging social landlords to develop R&R energy and anti-fuel poverty targets.
- Ensuring the integration of R&R energy in territorial policies and plans and planning documents;
- Promoting strategies for ranking networks when the master plans are submitted by the end of 2018.

***Green gases & New energy carriers & gas grid***

Biomethane: The French objective for injecting biomethane into gas grids is 8 TWh in 2023, starting from 0.4 TWh in 2017.

Hydrogen: The strategy does not mention hydrogen in the context of heating and cooling but only for the use in industry, transport and storage (power-to-gas). While the plan foresees support for R&D and demonstrators, it states that it is unlikely that there is a need to implement power-to-gas on a large scale before 2035 in France.

# 4. References: Part I


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# Policy Support for Heating and Cooling Decarbonisation

## Meta-study

## Part 2: Decarbonising industrial heating and cooling

# 5. Introduction to Part II

This section presents part II of the meta-study, reviewing recent works addressing the decarbonisation of heating and cooling in industry. The meta-study was conducted between January 2020 and September 2021. Table 1 provides an overview of the studies contained in this part of the meta-study.

Chapter 2 presents the key findings from the meta-study and provides a synthesis of the analysis of the studies. Chapter 3 includes summaries of the individual studies.

**Table 1**

*Overview of studies*

| No. | |
|---|---|
| 1 | **Error! Reference source not found.** (Bataille et al. 2018) |
| 2 | *A review of cross-sector decarbonisation potentials in the European energy intensive industry***Error! Reference source not found.** (Gerres et al. 2019) |
| 3 | *Deep decarbonisation of the German industry via electricity or gas? A scenario-based comparison of pathways (Fleiter et al. 2020)* |
| 4 | A review of the emission reduction potential of fuel switch towards biomass and electricity in European basic materials industry until 2030 (Rehfeldt et al. 2020) |
| 5 | Breakthrough Strategies for Climate-Neutral Industry in Europe *(Agora Energiewende 2020)* |
| 6 | Enabling European industry to invest into a climate-neutral future before 2030 (Agora Energiewende 2021) |
| 7 | Industrial Innovation: Pathways to deep decarbonisation of Industry (ICF Consulting und Fraunhofer ISI 2019) |
| 8 | Sustainably Heating Heavy Industry (Sutherland 2020) |
| 9 | Decarbonizing Industrial Thermal Energy Usage (Gardiner 2020) |
| 10 | Decarbonising industry in Sweden an assessment of possibilities and policy needs (Åhman et al. 2012) |
| 11 | *The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat), Environmental Research* letters 15 (Madeddu et al. 2020) |
| 12 | *Industrial Transformation 2050: Towards an Industrial strategy for a climate neutral Europe, Institute for European Studies: Brussels.* (Institute for European Studies 2019) |
| 13 | *Pathways to Net-Zero Emissions from EU Heavy Industry, University of Cambridge:* Cambridge (University of Cambridge 2019) |
| 14 | Decarbonisation of the Steel Industry: the Role of State Economic Policy (Glushchenko 2020) |

| | |
|---|---|
| 15 | *Low carbon energy and feedstock for the European chemical industry, study commissioned by the European Chemical Industry Council (DECHEMA 2017b)* |
| 16 | *DECHEMA and FutureCamp (2019), Roadmap Chemistry 2050 – On the way to a greenhouse gas* neutral chemical industry in Germany (DECHEMA; FutureCamp Climate 2019) |

# 6. Synthesis of Findings: Part II

This part of the meta-study analyses several studies presenting the technological options and policy instruments for the decarbonisation of heating and cooling in the industry. The studies included in the review analyse decarbonisation technologies and policy strategies for process heat in different industrial sectors (e.g., steel, cement, petrochemical, etc.). Although most of these studies analyse industry process heat decarbonisation from a general perspective, some provide a geographical perspective at the European (Gerres et al. 2019; Rehfeldt et al. 2020) and national levels (Åhman et al. 2012; Fleiter et al. 2020), focusing on the specific policies for the chosen geographical scope. The opportunities, implementation barriers, needed policies and suggested technologies for the decarbonisation of industry are discussed.

## 6.1. Industry decarbonisation opportunities and barriers

The opportunities for the decarbonisation of industrial process heating and cooling are essentially based on the substitution of fossil energy sources with renewable electricity, green hydrogen and, to a certain extent, biomass, solar thermal and geothermal energy. For heat demand up to a temperature level of 200°C, there are several technology options, such as industrial heat pumps in combination with waste heat, environmental heat or solar thermal energy.

The analysed studies agree that the main barriers for energy-intensive industry decarbonisation are the high capital investments needed for the transition, and some studies point out the lack of market-ready alternative technologies for high-temperature process heat. While investment costs are also a common barrier for the decarbonisation of other sectors, they are more crucial in the industrial sector given the expected long lifetime of their facilities (Institute for European Studies 2019), their intimate ties with regional economies and their impact on productivity and competitiveness.

Regarding the availability of decarbonisation technologies, the studies differ on whether available technologies only lack commercial maturity (Bataille et al. 2018; Rehfeldt et al. 2020; Fleiter et al. 2020) or if they still need further technical development to be effective (Gerres et al. 2019). In this sense, the worst scenarios indicate that the required breakthrough technologies may not be ready before 2030. By contrast, other studies estimate high technical potentials for reducing emissions by switching from fossil fuels to biomass and electricity across a variety of industrial processes, however fuel switching is not economically feasible under current pricing structures in the EU (Rehfeldt et al. 2020). This experience is shared in the USA, where even for well-known technologies, the implementation is just below a tenth of what it could be, due to a lack of a comprehensive policy for renewable heat (Gardiner 2019).

Economic barriers due to low fossil fuel prices are a key barrier for low-carbon technologies (Institute for European Studies 2019), especially in the existing fiscal and policy context where support for the use of fossil fuels still exists. The environmental and climate impact of fossil energy carriers is as of yet not depicted sufficiently in their pricing. $CO_2$ pricing is therefore a key element to achieve cost-competitive of low-carbon technologies.

As of yet industrial businesses do not face a political framework towards carbon neutrality that creates sufficient security for low-$CO_2$ investments (Skoczkowski et al. 2020). This leads to insecurity regarding investment decisions. Although political plans focus on reducing emissions, a clear pathway towards carbon neutrality is lacking. This creates uncertainty regarding the long-term ambition level of climate policy frameworks and thus insecurity regarding investments that might lead to sunk costs or competitive disadvantages in international markets.

If global competition does not face as strict environmental and climate policies as the European industry does, companies face a disadvantage. Without policies that address this risk, investments in low-$CO_2$ technologies lead to losses for European businesses (University of Cambridge 2019), highlighting the importance of policies that aim to mitigate such risks, like the Carbon Border Adjustment Mechanism.

## 6.2. Policies for a decarbonised industrial sector

With regard to suggested policies for the promotion of decarbonisation in industry, there is an agreement on the need for stronger support of research and development (R&D) activities, innovation, and commercialisation, promoting pilot projects and product development. Moreover, the necessity of decarbonising energy-intensive industry is emphasised, since the main energy-intensive sectors (e.g., production of cement, steel, petrochemicals, glass) account for nearly 21 % of global $CO_2$ emissions (Sutherland 2020).

Several studies point out that due to the long investment cycles, it is important that the policy framework avoids lock-in by focussing not only on achieving the 2030 targets but taking into account the transition to climate neutrality by 2050 (Rehfeldt et al. 2020; Agora Energiewende 2021; 2020).

All studies confirm that additional policy efforts are needed. At the upstream level, this includes financial support instruments for low-$CO_2$ technologies and for green hydrogen, the creation of a sustainability framework for hydrogen as well as strategic planning for pan-European infrastructures (Agora Energiewende 2020). At the midstream level, carbon contracts-for-difference are seen as a key instrument, along with de-risking instruments for capital expenditure in first-of-a-kind, large-scale investments and the introduction and adaption of standards for production processes to ensure compatibility with climate neutrality.

At the downstream level, material efficiency can be addressed by introducing material efficiency in green public procurement approaches, by introducing a climate surcharge on material-intensive final products containing large amounts of basic materials, requirements to improve recycled material quality and material efficiency in manufacturing and construction and climate-neutral product labelling and eco-design requirements for embedded carbon in final products (Agora Energiewende 2020). The introduction of these instruments will lead to demand for low-$CO_2$ products, which is the basis for continuous business operation when switching from $CO_2$ intensive to low-$CO_2$ production processes. Businesses can orient themselves by these new markets and plan their investment in innovative technologies and production processes. However, studies emphasise that it is necessary to protect European industry from international competition that does not face as high environmental standards as European businesses (Institute for European Studies 2019).

Policies should be flexible and be revised and updated regularly as implementation targets evolve (Sutherland 2020). In addition to this, more comprehensive and in-depth roadmaps for specific technologies and industrial subsectors are necessary (Åhman et al. 2012).

## 6.3. Technologies for decarbonisation

The best-case scenarios within the studies considered in the review show that up to 95 % of industry emissions could be mitigated by 2050, but for that a strong policy support and a smart integration and combination of different technologies would be necessary (ICF Consulting and Fraunhofer ISI 2019). The high integration of different processes within industry makes it difficult to make individual technology changes and in most of the cases a full production chain re-design is needed (Glushchenko 2020).

In the decarbonisation of the highest temperature processes (>500°C), only biofuels and hydrogen can compete with fossil fuels, as nuclear power or electricity cannot reach those temperatures (Sutherland 2020). If these processes are not substituted by other production processes, energy carriers from carbon neutral sources play a key role. However, the supply of sustainable biomass is limited. As an example, it is seen that even in countries with high availability of biomass like Sweden, there is no clear strategy for its sustainable use (Åhman et al. 2012). In addition, the clean production of hydrogen requires the development of the required infrastructure. Since hydrogen may be an important alternative for some industrial processes (e.g., iron furnaces, metal production and chemical industry), it is envisioned that industry may become the main actor in the development of hydrogen infrastructures.

Although carbon capture and storage (CCS) is mentioned in many studies to also play a key role in the decarbonisation of industry, its development and reliability are not yet proven, it faces concerns on the $CO_2$ storage and transport, and its use may prevent the prioritisation of greener alternatives against fossil fuels (Sutherland 2020).

Furthermore, studies for the decarbonisation of the basic material industry indicate that the most effective alternatives may be based on material substitution for cement (e.g., wood, hemp), use of alternative chemistries or replacement of charcoal with bio charcoal. These alternatives may introduce important changes in the production chain, for which the entire process may need to be redesigned.

Studies suggest that strong R&D efforts are necessary to spark innovations that lead to new technology routes. For example, new technologies discussed are plasma technologies, micro wave and induction heating that can be applied in different industrial sectors (University of Cambridge 2019). However, as these processes require large amounts of electricity, the decarbonisation of electricity generation is necessary as well as a strong scale-up of electricity generation capacity (University of Cambridge 2019). This also entails sufficient grid expansion and the use of flexibility options that guarantee security of supply. Flexibility options like electricity storage (e.g. batteries) as well as demand response technologies are needed to facilitate a larger share of electricity use in the industrial energy mix (Madeddu et al. 2020).

A key element for the decarbonisation of the chemical industry is low-$CO_2$ electricity generation from renewable energies. An important example of this are electrically heated steam crackers that split naphtha into olefins and aromatics (DECHEMA; FutureCamp Climate 2019). Another key component is green hydrogen from electrolysers powered by renewable electricity. Green hydrogen can replace the fossil-based hydrogen produced through steam reforming of natural gas and can be used in the synthesis of both ammonia, methanol, and potentially more complex hydrocarbons (provided that a climate neutral CO2 source is available).

For the synthesis of methanol and other basic chemicals, a non-fossil carbon source is also needed. Biomass is one possibility, however its availability is limited. Biomass can be used either as feedstock directly (e.g., in the form of biomethane) or $CO_2$ originating from biomass combustion can be used as a “climate neutral” carbon source for the synthesis of synthetic hydrocarbons with renewable hydrogen. $CO_2$ as carbon source could also be captured from the atmosphere (direct air capture), which would then lead to increasing demand of renewable electricity (DECHEMA; FutureCamp Climate 2019). In addition, the recycling of polymers and other synthetic materials is another possibility for the decarbonisation of the feedstock in the chemical industry (DECHEMA 2017a).

# 7. Summary of Studies: Part II

## 7.1. Industry in general

**A review of technology and policy deep decarbonisation pathway options for making energy-intensive industry production consistent with the Paris Agreement (Bataille et al. 2018)**

***Summary and main findings***

The article provides a review of grey climate policy and engineering literature to identify technological and process abatement options as well as policy solutions for the decarbonisation of energy intensive industry production. The main findings are:

- Industry is hard to decarbonise due to conversion costs, trade sensitivity, and long facility life.
- Technologies exist to decarbonise all industrial commodity production, but their maturity needs to be developed.
- Knowledge of industry mitigation options is low, leading to skewed policy & effort.
- Policies combining R&D, commercialisation support and GHG pricing are needed.
- Since the average economic lifetime of industrial facilities is 20 years or more, all new investment must be net-zero emitting by 2035 - 2060 or compensated by negative emissions to guarantee GHG-neutrality
- Reducing energy intensive industrial GHG emissions to Paris Agreement compatible levels is technically possible with sufficient prioritisation and policy effort
- A database demonstrative of emerging and near-commercial technologies for decarbonisation of industry is provided
- Electrification technologies provide a solution for decarbonisation in the short term. However, in the longer term, the re-design of industrial processes and carbon capture strategies will be needed to achieve the decarbonisation goals.

***Main decarbonisation strategies***

The article identifies strategies for the key processes including the following aspects:

- dematerialise or recycle/reuse
- keep the core existing process or make fundamental changes
- carbon capture and storage or GHG free process heating

*Pulp and paper*

- dissolved lignin as biofuel to heat and power using recovery boilers
- decarbonised electricity for milling motors
- production of wood pellets from waste and biomass

*Renewable fuels*

- low temperature fermentation
- anaerobic biochemical digestion

- medium temperature thermochemical gasification

*Energy carriers*

- use of bulk excess renewable electricity
- renewable hydrogen
- gasified or digested biomass
- post-combustion or direct capture to make synthetic renewable fuels and key chemicals

*Iron and steel*

- replace coking coal with bio charcoal
- use renewable hydrogen in a DRI-EAF as the reductant
- decarbonised electricity for electrowinning

*Metallurgy*

- use renewable hydrogen, synthetic methane or biofuels for pyrometallurgy
- refocus where possible on hydrometallurgy or electrometallurgy

*Glass industry*

- oxycombustion with CCUS
- direct electric melting

*Cement*

- reduce clinker ratio in cementous materials
- material substitution by adding wood, hemp, carbon fibre and other
- use of CCUS for process emissions
- alternative chemistries for cement

***Decarbonisation policies***

- make decarbonisation of energy intensive industry a priority and the international, national, and regional level
- develop regional roadmaps
- gradual phase out of free allowances in EU ETS to increase carbon costs
- end-use based consumption carbon pricing
- Industrial R&D
- piloting of net-zero technologies
- multinational institution to fund portfolio of decarbonisation pilot projects

**A review of cross-sector decarbonisation potentials in the European energy intensive industry (Gerres et al. 2019)**

***Summary and main findings***

This study presents a review of public and private sector publications and scientific literature on pathways and roadmaps for the decarbonisation of different industries. It aims at identifying the key areas for emission abatement across all subsectors in order to comply with the European Union emission targets by 2050. The key strategies for this process include the decarbonisation of low temperature heat by cross-sector technologies, the use of membranes in the (petro)-chemical industry, carbon neutral steelmaking, alternative feedstock for the cement production, and carbon capture & storage (CCS).

***Main decarbonisation strategies***

The industries analysed include iron & steel, (petro-)chemicals, cement, ceramics, glass, paper & pulp and food & beverages, which represent 64 % of EU industrial carbon footprint. Little consensus can be found on how deep decarbonisation of energy intensive industries will be achieved.

***Heat recovery:*** Heat recovery may offer high reduction potentials, but numbers are not clear. It is estimated that the emissions among all subsectors may be reduced around 5 %, for which full redesign is required.

***Furnaces:*** minimizing $CO_2$ emissions from furnaces requires new designs and technologies in all subsectors. Partial or full electrification solutions of the furnaces are proposed, but since they are not commercially available, other technologies with lower emission reduction potential are suggested as transitory technologies.

***Carbon capture & storage (CCS):*** CCS technology has been extensively investigated, but its high cost and storage technical issues hinder its commercialisation. CCS is feasible only in the cement and pulp & paper industry.

***Biomass & bio-based waste:*** besides the potential limits imposed by biomass availability, the use of internal bio-based waste streams can play an important role in decarbonising subsectors such as food and pulp & paper industry

***Process heat provision:*** a high share of energy is required for boilers providing process heat up to 200°C. The most discussed solution are heat pumps, which may provide an incremental or full electrification of heat provision.

***Alternative feedstock:*** clinker substitutes can significantly reduce emissions from the cement industry provided novel process designs. Additives are expected to bring only minor improvements.

***Electrolysis:*** electrolysis with zero-emission electricity can be an alternative to furnaces and kilns for different metal production and also produce hydrogen as a renewable energy carrier.

***Combined heat & power (CHP):*** CHP is a viable option for heat and electricity intensive industries, like ceramic and food & drinks. Its potential depends on the level of penetration today, being minimal for (petro)chemical sector.

***Industrial ovens:*** Electrification of heat below 500°C will target the main $CO_2$ emitters in the pulp & paper and food industry. Electrification options for food industry are closer to commercialization.

***Catalyst processes & membrane separation:*** advancements in membrane technology can reduce heat and energy intensity of the (petro-)chemical and food-processing subsector, but their potential is difficult to quantify.

***Decarbonisation policies***

Current technologies for decarbonisation will not be enough to lower industrial $CO_2$ emissions. Breakthrough technologies are required, but none of them is market ready (and this is not expected before 2030).
Policies to foster and accelerate the development and implementation of the key mentioned technologies are essential for reaching $CO_2$ reduction targets. However, a previous better understanding of their expected decarbonisation potential and their status is essential, making further research necessary. It is important that models and simulations for policymaking account for cross-sectorial interactions.

## Deep decarbonisation of the German industry via electricity or gas? A scenario-based comparison of pathways (Fleiter et al. 2020)

***Summary and main findings***

The article presents the results of a scenario analysis of different pathways for the decarbonisation of the industry sector in Germany. A variety of measures may contribute to the decarbonisation, including energy efficiency, biomass, electrification, green hydrogen, power to gas (PtG), circularity, material efficiency, process switch and carbon capture and storage. However, their individual contributions are debated controversially. The analysis compares two scenarios, one based on electrification as the main decarbonisation option and the other based on a broad availability of green gas. The results show that both scenarios reach a GHG reduction of about 93 % in 2050 without using carbon-capture and storage, with the remaining emissions being mostly process-related. Common elements are substantial improvement in energy efficiency and material efficiency along the value chain for $CO_2$-intensive products as well as a strong shift to a circular economy. The increase of direct use of electricity in the electrification scenario is about 100 TWh or 50 % by 2050 compared to 2015 plus additional 146 TWh green hydrogen. In the gas-focused scenario, a demand for 337 TWh of green gas emerges by 2050 while electricity demand remains stable. While the analysis does not include a detailed analysis of the costs of each pathway, the study concludes that in the electrification scenario a stronger conversion of process heat generation and the construction of new industrial furnaces is required. In the scenario focusing on green gas, production can largely be continued in current gas-fired plants, however, the running costs increase more strongly, since synthetic gas as an energy source will be more expensive than renewable electricity.

## A review of the emission reduction potential of fuel switch towards biomass and electricity in European basic materials industry until 2030 (Rehfeldt et al. 2020)

***Summary and main findings***

The article provides a review of the potential for reducing green-house gas emissions in the industrial sector by switching from fossil fuels to biomass and electricity. The analysis covers the European basic materials industry including the production of clinker, lime and ammonia, blast furnace operations, refineries and others. The process is currently largely based on fossil fuels and the emission intensity of these installations is closely tied to the type of fuel used. The potentials for reducing emissions by fuel-switching are assessed for the year 2030 and are compared to the required emissions pathways in order to meet a 1.5° target. The article focuses on the technical potential to use biomass and electricity with existing or available technologies in important industrial processes including steam systems and other furnaces, non-metallic minerals, iron and steel and refineries. The industries covered in the analysis account for 95 % of the total verified emissions in the EU ETS industrial sector in 2015 and 64 % of total industrial emissions of the EU28. The analysis finds that 34 % (184 Mt) of these emissions could be avoided from a technical perspective until 2030 with fuel switch measures towards biomass and electricity. However, while the technical potential is compatible with pathways towards the 1.5° target, the options lack economic competitiveness under present conditions, e.g., due to high electricity prices. In view of full decarbonisation of the sector, the study concludes that deep decarbonisation in line with climate targets requires innovative production processes only available in the long term.

## Breakthrough Strategies for Climate-Neutral Industry in Europe (Agora Energiewende 2020)

***Overview***

The study aims at identifying strategies and investments that meet the EU 2030 target and achieve climate neutrality by 2050. The latter requires a rapid introduction of low-carbon break-through technologies, as reinvestment in traditional production processes, even if the best available technologies are used, is not an option so long as those processes are not easily convertible to zero-carbon or carbon-negative operation**.** The study presents strategies and pathways for deploying breakthrough technologies for industrial capacities in need of reinvestment, while allowing industrial assets with traditional processes to continue operation until they are scheduled for replacement.

***Breakthrough technologies***

The study identifies breakthrough technologies supporting the reduction of greenhouse gas emissions to meet the target for 2030 as well as the climate neutrality target by 2050:
In **steelmaking**, the study assumes that around 48 per cent of the primary steel capacity requires relining or reinvestment before 2030. Key technologies are the direct reduced iron with clean, providing reductions by up to -97 % relative to the blast furnace route. Another low-carbon option in the steel sector is to increase the share of secondary steel produced by electric arc furnaces.
In the **chemicals industry,** power-to-heat, clean hydrogen and chemical recycling are named as key technologies.
In the **cement sector**, demand-side measures, efficient application and packing of granules, partial substituting of the clinker and material circularity and are named alongside with Oxyfuel CCS for clinker production.

***Policy instruments***

Upstream policies:
**Support instruments for clean hydrogen:** 1) A feed-in premium for clean hydrogen to close the price gap with respect to conventional hydrogen; 2) carbon contracts-for-difference (CCfD) for the production, transport, and use of clean hydrogen; 3) A clean hydrogen quota can be applied on sellers of maritime and aviation fuels.

**Robust sustainability framework for clean hydrogen**, including the governance of guarantees of origin for clean hydrogen and the “additionality” of renewable or decarbonised energy for clean hydrogen production; ensuring that clean hydrogen is allocated to the most appropriate “no-regret” options (e.g., steel, chemicals, maritime, and aviation); and governance of the safety of hydrogen production, transport, and use.

**Strategic planning for pan-European infrastructures** for hydrogen, electricity, and CCS infrastructure.

Midstream policies:
Creating an **EU policy framework for carbon contracts-for-difference** to make investments viable.
**De-risking instruments** for capital expenditure in first-of-a-kind, large-scale investments in addition to existing funds such as the EU Innovation Fund and InvestEU.

Setting **standards for production processes** compatible with climate neutrality and facilitate the creation of lead markets for climate-neutral materials (e.g., through green public procurement).

**Reforming the anti-carbon leakage system**, including the introduction of output-based allocation and a reform of state-aid guidelines.

Downstream policies:
Introducing a **climate surcharge on material-intensive final products** containing large amounts of basic materials (cars, plastic bottles, houses).

Requirements to **improve recycled material quality and material efficiency** in manufacturing and construction.

Climate-neutral **product labelling and eco-design requirements** for embedded carbon in final products.

**Green public procurement** requirements for basic materials.

### Enabling European industry to invest into a climate-neutral future before 2030 (Agora Energiewende 2021)

***Summary and main findings***

The study provides suggestions for key elements of an EU strategy for reaching climate-neutrality in the EU industry sector. It proposes milestones for the year 2030 for the deployment of key technologies for decarbonising heating and cooling:

- 40 Mt of primary steel produced from “climate neutrality-compatible” technologies
- 16 Mt of EU cement production linked to offshore carbon capture and storage sites

- large-scale demonstrators for innovative bio-mass-to-chemicals technology
- critical, innovative recycling technologies are established for chemicals and cement
- 50 % industrial steam demand at up to 200°C supplied by power-to-heat technologies

Furthermore, the study proposes elements of a legislative roadmap to decarbonise the EU industry sector:

- creation of an enabling framework for Carbon Contracts-for-Difference for climate-neutral technologies
- standardised $CO_2$ and environmental performance labelling for intermediate basic material products
- lifecycle assessments (LCAs) for embedded $CO_2$ emissions and resource use requirements for a) new construction, b) public works and c) vehicles
- enhanced recycling targets and end-of-life sorting and tracking requirements for basic materials
- priorisation of access to clean hydrogen, power and biomass in “no regrets” industrial applications

## Industrial Innovation: Pathways to deep decarbonisation of Industry (ICF Consulting und Fraunhofer ISI 2019)

***Summary and main findings***

This second report uses the findings from its first part 1 on technology uptake pathways through 2050 in order to evaluate the extent to which key EU industrial sectors can benefit and contribute to a climate-neutral future. The ability of industries to implement existing technologies and the development and commercialisation of new products and breakthrough technologies are evaluated. Current policies and trends will only result in a slow reduction of GHG emissions in industry, so a fundamental change in the policy and regulatory framework is needed. Significant emissions reductions of up to 95 % can be achieved by combining several mitigation options, but for this, additional costs are expected in all scenarios and a strong policy and regulatory support will be needed.

***Modelling approach***

- A number of scenarios have been developed for the future evolution of energy demand and greenhouse gas emissions of the EU's industry sector by using the bottom-up simulation model FORECAST.
- The input data include technology assumptions and economic framework.

***Scenarios***

- Four groups of scenarios are defined, including: i) reference scenarios; ii) scenarios with focus on clean gases (hydrogen and synthetic methane); iii) scenarios with focus on bioeconomy & circular economy; and iv) scenarios with focus on electrification.
- The main result of the simulation are the annual GHG emissions of the scenarios, analysed by subsector, source, country, timeline and scenario.
- The considered subsectors are: iron & steel, chemical industry, cement and lime, glass & ceramics, pulp & paper, non-ferrous metals, and refineries.
- Considered mitigation options: process integration improvement, fuel switch, CCS, recycling and re-use, material efficiency and substitution.

***Decarbonisation strategies and policies***

- Applying best available technologies in energy efficiency, recycling and fuel switch may achieve 59 % emission reduction by 2050, with reference to 1990, but does not result in a deeper decarbonisation beyond 2050.
- Deep decarbonisation needs innovative low-carbon production technologies, circular economy, material use efficiency, $CO_2$-free energy carriers, biomass and CCS.
- Clean gas may result in high costs, while biomass may be a cheaper solution but dependent on availability. CCS has reasonable costs, but its introduction poses a lot of uncertainty. Electrification requires significant changes in the production system and may compromise the electricity sector.
- A reduction of up to 95 % emissions can be achieved by combining several mitigation options, however it has to be pointed out that all scenarios imply additional costs and high energy expenditures.
- A new policy and regulatory framework should support R&D, revise economic incentives and include new incentives for sustainable value down to the final consumer, support the transition of construction sector to be less GHG-intensive, develop infrastructure for energy carriers, and promote the demand on low-carbon basic materials. This should be done while keeping the EU industry competitive.
- Further research should:

- Assess the role of re-investment cycles, age of the capital stock and impact on transition speeds and costs.
- Explore uncertainties regarding energy price and technology development interactions with other sectors where there is a high degree of coupling (clean gas, electricity).
- Explore the supply side of resources (e.g., clean gas, electricity, $CO_2$).

## Sustainable Heating Heavy Industry (Sutherland, 2020)

***Summary and main findings***

This article reviews the state-of-the-art available technologies for low-carbon heating for heavy industry. Heavy industry requires high-temperature heat for which the only feasible alternatives are biofuels, nuclear power, hydrogen, or carbon capture and storage. These options have each their own barriers, mostly concerning cost or inadequacy. Policy instruments to decarbonise this sector and technology innovation are urgently needed.

***Heating for heavy industry***

- Heavy industrial processes such as the production of cement, steel, petrochemicals, glass, ceramics, petroleum refining, and others contribute, together, approximately 21 % of global $CO_2$ emissions.
- Heavy industry is a key sector that needs rapid decarbonisation, but it has intimate ties to regional economies that need to be considered and their processes require flux heat at high temperatures (300°C - 1800°C)
- This high-grade heat required for heavy industry, as for example that for the production of cement, steel, petrochemicals, and glass, accounts for nearly 10 % of global $CO_2$ emissions.
- There are multiple proposed approaches to reduce greenhouse-gas emissions from this sector. However, the proposed pathways are unclear, and existing options are costly, inadequate, or both. It is concluded that there are no quick wins when it comes to decarbonising heavy industry.
- The most inexpensive way to produce high-grade heat is the combustion of fossil fuels, which is why it is the main source for industrial heat. As a result, roughly half the $CO_2$ emissions of heavy industry (therefore about 11 % of global emissions) come from heat production.

***Proposed low-carbon technologies***

- Nuclear power, while low-carbon and cost-competitive, does not provide heat at sufficiently high temperatures.
- Biofuels can provide sufficiently high temperature heat during combustion, but they have a highly variable carbon footprint and are significantly more expensive.
- Electricity can be used for high-grade heat generation through resistive heating, but its carbon footprint is tied to the electricity source, which today is highly variable.
- Hydrogen can produce high-grade heat by combustion and is suitable for almost all heavy industrial applications. Blue hydrogen made by reforming natural gas, may offer the lowest wholesale production costs for fossil fuel alternative high-grade heat if combined with CCUS. Green hydrogen based on renewable energy is a near ideal solution, except for the fact that present technology is prohibitively expensive.
- The least disruptive option in the short term would be to continue business as usual and introduce a carbon capture, utilisation, and storage (CCUS) scheme.
- The cost associated with CCUS is high, and without policy intervention, will be levied on consumers or the producing industry.

***Policies and strategies***

- Increased efforts to decarbonise this sector through policy instruments and technology innovation are urgently needed.
- Policy instruments should be reflective of the fragmented character, uncertainty, cost, and inadequacy of current technology.
- Policies should remain ‘technology-neutral’, have limited time frames for their implementation, be replaced regularly, incentivise private investment and ensure that innovation is rewarded.

## Decarbonising Industrial Thermal Energy Usage (Gardiner 2020)

***Summary and main findings***

This article presents an overview on technologies to reduce emissions of industrial heating, with a focus on combined heat and power (CHP) and integration of renewable resources including biomass, and hydrogen. The overview presents the benefits and potential of these technologies in the North American industrial sector and suggests policies that may improve expansion of their use in the USA.

***Industrial heating in the USA***

- Industrial heat makes up two-thirds of industrial energy demand and almost one-fifth of total energy consumption, rising the interest in the industrial sector to reduce GHG emissions through energy efficiency or reduction goals.
- CHP and WHP can make manufacturers more competitive by reducing energy costs and cutting emissions.
- Industrial heating can run on renewable fuels such as biomass, biogas, or renewable hydrogen.
- Most of the emissions are concentrated in six energy-intensive sectors: steel, chemicals, cement, pulp and paper, aluminum, and oil refining.

***Combined heat and power (CHP)***

- CHP can bring significant advantage for the chemicals and petroleum refining industries, and other critical infrastructures by providing resiliency against extreme weather conditions and power outages.
- CHP could produce 20 % of all USA electricity by 2030, but it requires a significant capital investment.

- Depending on the marginal fuel mix of the electric grid, CHP can provide overall energy and $CO_2$ savings comparable to solar photovoltaics, wind, and natural gas combined cycle (NGCC), at a lower capital cost.
- The chemicals, petroleum refining, food, paper, and primary metals industrial sectors have the greatest potential for CHP installation.

***Renewable resources for heating***

- Only 10 % of global heat production is powered with renewable energy.
- The Energy Transmission Commission recommends using three renewable technologies to address industrial emissions for heat production: biomass, electrification, and hydrogen.
- Renewable thermal technologies face supply, market, and policy barriers compared to renewable electricity.

***Current barriers***

- CHP produces only 9 % of US electricity, as it faces economic, financial, regulatory, and informational barriers.
- The United States do not have specific targets, nor a clear policy, for renewable heat at the federal level, although some states have adopted renewable heating and cooling plans.

***Decarbonisation strategies and policies***

- Include approaches to reduce emissions from heat production in the industry, considering thermal energy process and non-process heating and cooling, as well as building space heating and cooling.
- Implement policies that make it easier for potential users and developers to obtain information about CHP, and provide financial incentives or loan and grant programs to support deployment of CHP and WHP.
- For renewable resources, the best approach is to advance a broad range of renewable thermal technologies and let the markets determine the best outcomes.
- Support, by the national government, the development of new technologies, innovation and efficiency improvements in existing technologies, and research and deployment
- Follow the European model on setting ambitious targets for renewable heat deployment and providing financial support for projects.

## Decarbonising industry in Sweden an assessment of possibilities and policy needs (Åhman et al. 2012)

***Summary and main findings***

This report analyses the technical opportunities for a complete decarbonisation by 2050 of the basic material industry in Sweden (i.e. production of steel, cement, basic chemicals, aluminium, and pulp). Policy implications for the industry sector are discussed. It is concluded that the complete phase-out of greenhouse gas emission in the industrial sector by 2050 is very challenging and relying on current production systems and applying “end-of-pipe” solutions will be insufficient to decarbonise industry. Instead of decarbonising industry while maintaining production volumes a major effort to develop, introducing and investing in novel technologies and process designs will be needed. A set of broad technology platforms and infrastructure needs are identified (i.e. electro-thermal processes, black liquor gasification, bio-based chemicals, magnesium based cement, and application of industrial CCS).

***Methodological Approach***

Review of the results of climate-economic modelling studies and technology assessment of the long-term opportunities not included in climate economic models.

***Barriers***

- There is a need to develop the capacity to be "zero emission technology ready". Technologies should be developed, demonstrated and commercially available between 2040 and 2050, and even though, it may take many years before they are widespread and common practice.
- Decarbonisation will have to rely on energy carriers availability from carbon neutral sources (i.e. renewable or nuclear energy) and electricity is expected to be the backbone of future sustainable energy systems. In turn, the electrification of some industrial processes is dependent on a major supply of $CO_2$-free electricity.
- Sweden and the Nordic system already have high shares of renewable electricity (i.e. wind) and may support industry to deploy a mix of electricity and "stored electricity" as hydrogen or other fuels.
- There are no clear strategies for the use of sustainable biomass, despite the high availability in Sweden.
- Industry will become an integral part of future energy system, serving as an important source of low-grade heat for district heating system and even a main actor in the development of hydrogen infrastructures.
- For CCS to play a role, its legal situation, development and reliability need to be proven and transport of $CO_2$ needs to be solved. The legal responsibility and scientific knowledge of storage sites need development.

***Policies and strategies***

- There is a need to complete the current main climate policy approach of pricing the emissions with a stronger policy for technical change, including funding for R&D and market development support. This approach has worked well in the renewable energy sector.
- A policy strategy towards decarbonisation needs to clarify the long term reduction target of the EU ETS and how to deal with the risk of carbon leakage.
- There is a necessity to widen the scope of climate policy to include trade policy in the longer-term.
- A technology strategy for industry's decarbonisation is needed, identifying combinations of new technical systems, possible multi-purposes technology areas and infrastructure needs.
- More comprehensive and in-depth roadmaps for specific technologies in different subsectors are necessary.
- Energy efficient processes and technologies need continued development.
- The wide scale deployment of new basic industry process technologies is likely to require high carbon prices (through taxes or trading schemes).
- Policy strategies must consider other options such as regulatory approaches and permitting procedures, investment grants and subsidies, border adjustment taxes, and sectoral agreements.

**The $CO_2$ reduction potential for the European industry via direct electrification of heat supply (power-to-heat), Environmental Research letters 15. (Madeddu et al. 2020)**

***Summary and main findings***

Madeddu et al. analyze the potential for decarbonisation of the European industry through electrification of processes. The focus lies on the generation of heat through existing and potential technologies, which are discussed in the paper. Policy recommendations are given in chapter 6 of the paper. These focus on possible instruments in the scope of the European Green Deal.

***Strategy to realise decarbonisation***

Industry stakeholders and the policy makers should jointly work out a transformation strategy that direct investments to technologies with lower emissions.

In sectors with only small amounts of emissions (e.g. paper, wood, textiles) the retrofit of technologies (e.g. substituting boilers with heat pumps) can introduce a gradual transition. Businesses can get used to new technologies maintain a stable production.

High barriers exist in the steel, chemicals and cement sectors.

As the industrial electrification will increase the electricity demand significantly the industrial electrification of heating and cooling needs to be accompanied by sufficient renewable extension.

The industry will need to implement demand flexibility measures, e.g. load shifting and the implementation to hedge against price spikes.

Electric processes and technologies are often more cost intensive than their fossil counterparts. This is due to different taxes that are raised on the energy carriers.

***Policy for industrial electrification and decarbonisation***

Taxation and levies on electricity prices need to be reduced to a reasonable level. This is the prerequisite for the cost competitiveness of the energy carrier electricity. The goal should not be to support electricity prices but to create a level playing field between energy carriers.

A clear carbon price needs to be introduced that reduces investment uncertainties for industrial businesses. The authors suggest the introduction of a EU ETS minimum price in combination with instruments against carbon leakage.

Third complementing policies such as technology support schemes and market introduction programs in areas where the carbon price doesn`t have an effect.

Based on these policy changes industrial businesses can orient themselves towards emissions reduction.

## Industrial Transformation 2050: Towards an Industrial strategy for a climate neutral Europe, Institute for European Studies: Brussels. (Wyns et al. 2019)

***Summary and main findings***

This study is the result of the joint work of scientific organizations and industrial businesses. The goal is to find pathways and policy options that reach the goal of carbon-neutrality in 2050. While reaching this goal the European Industry should stay on a competitive level. This report seeks to enhance understanding of the implications and opportunities of moving to industrial climate neutrality and shed light on the near term decisions to be made.

***Main challenges towards a climate-neutral industry***

This report considers six major challenges:

- innovation gaps from basic R&D towards the deployment of new technologies
- an insufficient circular and materials efficient economy
- barriers to market entry for low-$CO_2$ solutions:
  - low $CO_2$ price
  - existing standards that exclude low carbon products
  - lack of information on LCA
  - unused opportunities in procurement
- lack of streamlining between the energy and industrial transition to climate neutrality and infrastructure needs for the transition

- possible bottlenecks in scaling up investments and the risk of high-carbon lock-ins

- regulatory framework needs to ensure that investments can be made with an acceptable amount of risk.

- The complexity of integrating different types of policy instruments, policy areas and competences into a cohesive (industrial) strategy

***Strategy to realise decarbonisation connected to heating and cooling***

The study suggests different policy approaches. However, not all deal with heating and cooling and the connected electrification. The ones that deal with this topic are:

*Innovation framework for a climate neutral industry*

- Enhance innovation governance: Coordinate national industrial R&D programmes under Horizon Europe. Focus on supply side (process technologies) and demand side (materials efficiency, energy storage)

- Accelerate technology market readiness: Introduce one-stop-shops that help businesses to get access to funding quickly. Support should be introduced for systems that do not mitigate emissions on their own. Elimination of regulatory barriers that hinder upscaling of low carbon technologies. Consider low regulatory zones for technology demonstration and testing. This could include timely well-defined exemptions under the ETS.

*Create competitive lead markets for low-$CO_2$ solutions*

The EC should introduce

6. Instruments that make low $CO_2$-solutions competitive through pricing support, this entails:
   a. Subsidies for low-$CO_2$ production technologies through premiums, tax reductions or CCFD
   b. Extensions of EU ETS scope with low-$CO_2$ processes
   c. Inclusion of consumption in the EU ETS to secure carbon price pass through
2. Standards that facilitate access to the market (among others)
   a. Introduce flexibility in the standardisation process
   b. Redesign existing standards that hamper market access for low-$CO_2$ products
   c. Promotion of voluntary standards, labelling and certification
3. Use public procurement to gain market entry (among others)
   a. Linking public procurement to low $CO_2$ standardisation
   b. Introducing EU wide procurement task force
   c. Sustainability quota in EU funding schemes
4. Global trade environment (among others)
   a. Greenhouse gas standards for materials used in construction or assembly of domestically and imported materials
   b. Introduce carbon standards on imported final goods
   c. Carbon border adjustment
5. Scaling up of investments and avoiding carbon lock in
   a. Support investment in low-$CO_2$ technologies
   b. Test for carbon intensity of new investments to avoid high carbon lock-in effects.

**Pathways to Net-Zero Emissions from EU Heavy Industry, University of Cambridge: Cambridge. (Institute for European Studies, Wuppertal Institut 2019)**

***Summary and main findings***

The study explores multiple ways to achieve net-zero emissions from EU steel, plastics, ammonia and cement production while keeping that production in the EU. Any strategy to reduce emissions needs to address the main sources of $CO_2$. For the sectors in scope here, three issues are particularly important: high-temperature heat, process emissions and end-of-life emissions.

The basis for decarbonisation is that companies remain profitable and competitive. Policy needs to ensure that there is a business case for low-$CO_2$ production routes. This is the base line. On this basis, new technologies need to be found and made economically viable.

***Barriers and measures for the decarbonisation of these sectors are:***

Technological options are not economically feasible or not even found yet. Innovation must be speed up and the application and economic feasibility of new technologies must be reached. Further development, deployment and associated cost reductions are necessary to make a decarbonisation in these areas viable.

Industrial businesses face high costs when it comes to the implementation of new processes. Therefore, a support policy is necessary to make their quick adoption feasible. Businesses will only engage in low-carbon investments when the long-term profitability is secured. This makes strong political support and a regulatory framework necessary that ensures this long-term prospects.

The necessary political framework needs to be established as soon as possible. As life cycles are long and investments are long term decisions, the decision towards a conventional technology may lead to a costly carbon lock-in. These processes then will be in place for the next decades.

Large amount of RES-E is needed for direct and indirect use in industrial processes. Also, the electricity costs need to low to guarantee the competitiveness of production of goods. Infrastructure related to RES-E will be necessary to enable a continuous and secure electricity supply. That entails grid expansion and installation of storage capacities.

***Policy***

The first step to transition will require major policy innovation, but also changes in the strategy of businesses themselves.

The EU ETS is one instrument that can have an effect on the reduction of $CO_2$ emissions. However, actors doubt that it will spark innovation and does not correct market failures that hinder new technological options. Also, this instrument does not ensure the protection of the European industry in the international competition.

A policy agenda that enables a low-carbon industry consists of different instruments:

- Launch of major mechanisms for innovation. This entails early support of research and piloting. On the other hand, support until fully commercial viability. Parts of this are among others an innovation agenda and also public finance for demonstration.
- Create lead-markets for low carbon products. A business case is needed for businesses to make a decision towards low-carbon processes and products. The EU ETS is one instrument that should be complemented by carbon contracts for differences and carbon boarder adjustments.

- Remove existing regulatory hurdles, e.g., product standards that hinder low-carbon solutions
- Subsidies for low carbon solutions: similar to the support in the electricity sector, an instrument should support low-carbon solutions.
- Product quotas and standards: Defining a minimum of necessary low-carbon ingredients in products creates a market for industrial products.
- Public procurement can directly create demand for low carbon products.

- Border adjustment: Raising taxes on products form emission intensive regions. To allay fears of revenue-raising protectionism, the taxes could be refunded to the countries of origin.

- Financing mechanisms should hedge the risk for businesses. As many technologies are not completely economically viable an investment needs to be supported financially. Different options can be thought of: public financing, risk-sharing models, tax reduction, concessional finance or early direct public investments. Investment inertia caused by permitting rules could be addressed through “low regulatory zones”.

- The risk of stranded assets needs to be addressed. Redundancy will most likely be inevitable and $CO_2$ intensive technologies will be written off before the end of their lifetime. This will hit companies balances and influences their ability to invest.

***High temperature processes***

In many industrial processes heat is essential. Due to product quality standards as of yet only certain technologies can applied. To reduce emissions from fossil fuels in high temperature processes new technologies need to be found and made economically viable. Today heating technologies can be applied in lower temperature ranges. Therefore, emissions from high temperature processes are rather hard to abate.

Hight temperature processes that need to be electrified are: steam crackers, cement kilns, iron ore sintering, steel reheating furnaces, and high temperature steam production. Potential technologies are plasma, induction and microwave heating

## 7.2. Iron and steel industry

**Decarbonisation of the Steel Industry: the Role of State Economic Policy (Glushchenko 2020)**

***Summary and main findings***

This study analyses the potential areas of decarbonisation of steel production in order to propose government policy measures for reducing $CO_2$ emissions. The key measures are carbon capture and storage, carbon capture and utilisation and prevention of emissions. Decarbonisation measures including melting steel in electric arc furnaces, replacing coke with charcoal, using hydrogen in a blast furnace and for direct reduction of iron and employing electrolysis of iron are analysed. Instruments of economic policy for accelerating the decarbonisation of the steel industry are identified. It is concluded that decarbonisation without state participation is impossible, due to the lack of competitive advantages for the companies.

***Decarbonisation strategy***

Most scientific publications study decarbonisation of the electric power industry, but there are also studies of decarbonisation of industry (especially the steel industry). The main focus is on the effectiveness of various instruments of economic policy. Most studies focus on restrictive measures (e.g., taxes, emission limits).

***Current policies in EU and China***

- EU launched the Emissions Trading System (ETS), setting a limit on greenhouse gas emissions for enterprises.
- China closed obsolete facilities and reduced levels of activity proportionally to the industry emissions.

***Barriers for decarbonisation of steel industry***

- $CO_2$ emissions occur at different process stages, each of them requiring different decarbonisation methods.
- High process temperatures (over 500 °C) are required, which reduces the number of alternative technologies.
- The process stages are highly integrated with each other, requiring changes in the full production chain.
- High capital investments are needed to implement new decarbonisation technologies.
- Using low-carbon technologies leads to an increase in production costs and a reduction in competitivity.

***Decarbonisation strategies for the steel industry***

- carbon capture and storage (CCS) or carbon capture and use (CCU)
- melting reduction using one production unit and thus concentrating $CO_2$ emissions
- using electric arc furnaces can reduce $CO_2$ emissions to zero if renewable electricity is used
- replacing coke by charcoal, provided biomass availability
- use of hydrogen for direct reduction of iron ore, where natural gas is often used as reducing agent
- Iron electrolysis, requiring high temperatures (1600 °C). This is still at the stage of laboratory research.

The most promising methods to prevent $CO_2$ emissions are electric arc and hydrogen-based direct reduction.

***Decarbonisation policies***

An active state policy to accelerate the decarbonisation of the steel industry should include the following measures:

- Develop long-term inter-sectorial plans for decarbonisation and required infrastructure.
- Reduce import tariffs on equipment needed for decarbonisation to reduce capital expenses and increase import restrictions for highly $CO_2$ -intensive products.
- Limit exports of raw materials for low-carbon technologies, to cover domestic demand and avoid price surge.
- Increase carbon dioxide emission charges and develop product standards that allow only low CO2 emissions.
- Simplify patent procedures for decarbonisation technologies, and state-fund decarbonisation projects (e.g., grants, loans, interest rate compensation).
- Build qualified staff capacity and find jobs for employees dismissed during the “green transition”.

## Technology innovation system analysis of decarbonisation in the EU steel industry (Skoczkowski et al. 2020)

***Summary and main findings***

This paper analyses the development of technology in the EU I&S industry and identifies potential avenues of its decarbonisation. They argue that it is not possible to decarbonise this sector without new breakthrough technologies. Therefore, research and development “play a key role”.

The focus lies on the barriers and drivers to find innovative new technologies that enable the sectors decarbonisation. The authors name challenges and drivers for innovations in the EU steel industry.

***Decarbonisation strategy & instruments***

Research and development are necessary to find green-steel technologies. This needs to be financed as it is very cost intensive. Without government support businesses cannot produce steel in a competitive manner.

As there is little demand for green steel businesses that produce green steel would face losses as the production costs are higher. Therefore, demand for green steel needs to be created by setting up a green steel market and introducing a quota or material requirements for large consumers.

When instruments address the pollution limits of businesses they need to be set at a realistic height. Otherwise, businesses could not reach these limits.

Guarantee suitable energy prices and an emission free electricity is necessary to reduce emissions and also guarantee the competitiveness of the European steel industry.

As green-steel prices are above the ones for conventional steel unfair import of non-green steel products needs to be hindered.

***Barriers***

Businesses need certainty about political support of the decarbonisation path. If the policy framework bears a risk of change, incentives are not sufficient and support is lacking, businesses will not engage in R&D and the change of their production processes.

The same can be said for the uncertainty of the EUs climate policy. Businesses are insecure about the future development of climate policies, e.g. if they will continue ambitiously or only moderately. The level of ambitions also has an effect on the potential decarbonisation.

Businesses depend on their sales. Currently there is only little demand for green steel. A change in technology would lead to losses as production could only be sold partly.

Industrial infrastructure shows high capital costs and long lifetimes. New investments in green technologies therefore are only possible when the existing infrastructure has reached the end of its life.

Research and development are connected to high costs and not all businesses may have access to capital for investment in green technologies.

## 7.3. Chemical industry

**Low carbon energy and feedstock for the European chemical industry, study commissioned by the European Chemical Industry Council (DECHEMA 2017b)**

***Scope and methodology of the study***

"The objective of this study is to explore options towards a carbon-neutral European chemical industry. This entails the description of pathways for a transition of production processes towards low-carbon production, by further exploiting energy and resource efficiency measures, increasingly by using alternative carbon feedstocks i.e. renewable raw materials (biomass) and CO2, which can replace fossil feedstocks and leverage a lower overall carbon footprint, and by exploring possibilities to use electricity-based processes that can benefit from a progressive decarbonisation of the power sector." *(DECHEMA 2017a)*

The potential impacts of new technical options to produce ammonia and urea, methanol, ethylene, propylene, chlorine and the aromatics benzene, toluene and xylene are described based on four deployment scenarios with different ambition levels:

- business-as-usual (BAU), assuming no implementation of new technology options and no further advancement of efficiency measures,
- intermediate (Interm), describing a moderate level of ambition and slow but continuous deployment of low-carbon technologies,
- ambitious (Amb), depicting a high level of ambition and strong support of all stakeholders to overcome any constraints,
- maximum (Max), describing the theoretical potential, i.e. upper limit of possible CO2 reductions.

***Summary and main findings***

Implementation of the technologies investigated in this study allow for a reduction of $CO_2$ emissions up to 210 Mt annually (max) in 2050. In the considered range of ambitions, between 70 Mt (Interm) and 101 Mt (Amb) CO2 can be mitigated, corresponding to 59 % to 84 % of the anticipated emissions in 2050.

20 to 30 Mt CO2 of these emission savings can be achieved by further efficiency measures and plant retrofits, transition to a power-based heat and steam generation and recuperation of waste heat. The main share of the additional savings is enabled by chemical production of ammonia using hydrogen from low-carbon electricity and production of methanol, olefins and BTX from hydrogen and carbon dioxide. These processes benefit from avoided fossil emissions and a considerable amount of carbon from CO2 built into the products, thereby enabling a CO2 recycling and avoidance of fossil feedstocks.

***Barriers for the decarbonisation of the chemical industry***

"A main hurdle to overcome is the relatively high production cost of the target building blocks in case of the low-carbon technologies. While power-based steam generation and heat recuperation by steam recompression are technologies that already seem competitive in terms of costs, the production costs for ammonia, methanol, olefins and BTX are currently 2 - 5 times higher than the fossil alternatives. This is related to high feedstock cost (in the case of biomass) and high cost of electricity (in the case of hydrogen based processes)." *(DECHEMA 2017a)*

***Policy and measures for the decarbonisation of the chemical industry***

Based on the main findings, the following key actions are recommended:

- Realisation of a large and ambitious R&I program to further investigate the potential of new technologies, including low-carbon hydrogen production, CO2 utilisation, lignocellulosic biomass use for chemical and biochemical synthesis and advanced concepts for waste heat recovery;

- Public-Private-Partnerships (PPPs) to focus RD&I efforts and to enable risk sharing for investments for demonstration of innovative technologies; fast realisation of demonstration plants at scales beyond 5kt/a with lighthouse character are a prerequisite;
- Enhanced cross-sectorial collaboration and exploration of industrial symbiosis opportunities creating synergies and improving energy and resource efficiency beyond sectorial boundaries;
- A dialogue with policy makers to point out the barriers and constraints and to facilitate market-uptake.
- Generation of a central European database of CO2 sources and infrastructures that would provide potential for industrial symbiosis, including e.g., emitters below the threshold for reporting to the European Pollutant Release and Transfer Register; likewise, a database on the available sustainable biomass and a central database for lifecycle data.

***High temperature processes***

Power-to-Heat technologies (electrical heat pumps) should be further developed to extend operating window to temperatures > 250 °C.

**DECHEMA and FutureCamp (2019), Roadmap Chemistry 2050 – On the way to a greenhouse gas neutral chemical industry in Germany (German title “Roadmap Chemie 2050 – Auf dem Weg zu einer treibhausgasneutralen chemischen Industrie in Deutschland”) (DECHEMA; FutureCamp Climate 2019)**

***Scope and methodology of the study***

The study commissioned by the German Association of the Chemical Industry describes a possible path for the transformation of the German Chemical Industry towards industry towards greenhouse gas neutrality. The production processes and raw materials of the Chemical Industry, which are particularly energy- and emission-intensive, are examined in detail. In the study, both the greenhouse gas emissions, that occur in the production process itself, as well as the emissions resulting from the purchase of electricity and heat (steam) are taken into account. As an important novelty, the roadmap also includes the carbon content of chemical products as a source of CO2 for the first time. In addition to the emissions, the costs for reduction of greenhouse gas emissions are also considered.

The roadmap describes the path to greenhouse gas neutrality from 2020 to 2050 in three paths with different levels of ambition:

- Reference path (path 1): The companies continue to produce exclusively with today's technologies.
- Technology pathway (pathway 2): It is shown how far the chemistry can achieve climate protection, if it also invests in new production technologies for basic chemicals such as ammonia and methanol.
- Greenhouse gas neutrality pathway (pathway 3): All conventional basic chemical processes are completely replaced by alternative processes to achieve greenhouse gas neutrality. It is determined which technologies and investments are required and how much electricity is needed to achieve zero emissions in 2050.

***Summary and main findings***

**Reference path (path 1): By 2050, reduction of greenhouse gases by 27 % compared to 2020 through coal phase-out and increased efficiency.**

Electricity demand in the chemical industry will decrease by around 10 % by 2050 compared to 2020.

**Technology path (path 2): By 2050, reduction of greenhouse gases by 61 % compared to 2020 through higher investments for new processes and a significant increase of electricity demand in 2050.**

The electricity demand in the German Chemical Industry will increase to around 220TWh/a from 2040. This corresponds roughly to the current electricity consumption of the entire German industry.

**Greenhouse gas neutrality path (path 3): Nearly zero greenhouse gas emissions through maximum investments for alternative processes and a dramatic increase of electricity demand in 2050.**

New methods of recycling, CO2-free hydrogen production and the use of CO2 as a raw material make climate neutrality in the chemical industry possible. The new electricity-based processes will increase the electricity demand of the chemical industry to 685 TWh/a from the mid-2030s, which is more than the total electricity production of Germany in 2018.

***Barriers for the decarbonisation of the Chemical Industry***

High additional costs for alternative processes compared to older and already depreciated assets; given the prices for basic chemicals on the world market, it is currently hardly possible to pass them on to the customer.

***Policy and measures for the decarbonisation of the Chemical Industry***

An important prerequisite for almost all new technologies is the availability of renewable electricity in very large quantities from today's perspective and at low costs of 4 cents per kilowatt hour.

The current relief and carbon leakage rules alone will not be sufficient to ensure internationally competitive electricity prices for the chemical industry and further measures will be necessary to curb the cost of electricity for industry.

Government funding and support for research and development of new electricity-based processes.

There is a need for rules to protect European production sites if global competitor regions do not make comparable climate policy efforts.

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# Policy Support for Heating and Cooling Decarbonisation

Meta study

Part 3: Technologies and infrastructures

# 9. Introduction to Part III

This section presents part III of the meta study, reviewing recent works addressing energy carriers and infrastructure for the decarbonisation of heating and cooling. The meta-study was conducted between January 2020 and September 2021. **Error! Reference source not found.** 1 provides an overview of the studies contained in this part of the meta-study.

Chapter 2. provides a synthesis of the analysis of the studies. Chapter 3 includes summaries of the individual studies.

**Table 3**

*Overview of studies*

| **RES technologies** | |
|---|---|
| 1 | Support to key activities on the European Technology Platform on Renewable Heating and Cooling (Mazzucchelli et al. 2019) |
| 2 | Renewable power-to-heat: Innovation landscape brief (IRENA 2019) |
| 3 | Heat Pumps – Integrating technologies to decarbonise heating and cooling(European Copper Institute 2018) |
| 4 | METIS Studies - Study S6: Decentralised heat pumps: system benefits under different technical configurations (Artelys 2018) |
| 5 | Power-to-heat for renewable energy integration: Technologies, modeling approaches, and flexibility potentials (Bloess et al. 2017) |
| 6 | Heat pumps in existing residential buildings – results from the research project "WPsmart im Bestand" (Fraunhofer Institut für Solare Energiesysteme 2020) |
| 7 | The decarbonisation of the EU heating sector through electrification: A parametric analysis (Thomaßen et al. 2021) |
| 8 | Heating without the hot air: Principles for smart heat electrification (Rosenow and Lowes 2020) |
| 9 | Advancing District Heating & Cooling Solutions and Uptake in European Cities - Overview of Support Activities and Projects of the European Commission on District Heating & Cooling (Celsius 2021) |
| 10 | The Future Role of Thermal Energy Storage in the UK Energy System (UKERC 2014) |
| 11 | A new perspective on global renewable energy systems: why trade in energy carriers matters (Schmidt et al. 2019) |
| 12 | Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)<br>Work package 1: Final energy consumption for the year 2012 (Fraunhofer ISI et al. 2016b) (Fraunhofer ISI et al. 2016b) |

| | |
|---|---|
| | Work package 2: Assessment of the technologies for the year 2012 (Fraunhofer ISI et al. 2016a) (Fraunhofer ISI et al. 2016a) |
| 13 | Vision for deep geothermal |
| 14 | *EU biomass use in a net-zero economy (Material Economics 2021)* |
| 15 | The role of biomass gasification and methanisation in the decarbonisation strategies (Mantulet et al. 2020) |
| 16 | *ReuseHeat – WP 2: Market and stakeholder analysis (Reuseheat 2019)* |
| **New fuels for heating** | |
| 17 | The National Hydrogen Strategy [Germany] (BMWi 2020) |
| 18 | Hydrogen: a renewable energy perspective (International Renewable Energy Agency 2019) |
| 19 | Spatially Resolved Optimisation for Studying the Role of Hydrogen for Heat Decarbonisation Pathways (Jalil-Vega and Hawkes 2018) |
| 20 | Potential for hydrogen and Power-to-Liquid in a low-carbon EU energy system using cost optimization (Blanco et al. 2018) |
| 21 | A review of four case studies assessing the potential for hydrogen penetration of the future energy system (Chapman et al. 2019) |
| 22 | Trends in design of distributed energy systems using hydrogen as energy vector: A systematic literature review (Fonseca et al. 2019) |
| 23 | *Handbook of Climate Change Mitigation and Adaptation, Second Edition. Ch. Power-to-gas (Chen et al. 2017)* |
| **Sector integration and infrastructure** | |
| 24 | Sector Coupling in Europe: Powering Decarbonisation(Bloomberg Finance L.P. 2020) |
| 25 | Sector coupling: how can it be enhanced in the EU to foster grid stability and decarbonise?(Trinomics 2018a) |
| 26 | Decarbonising the EU heating sector: Integration of the power and heating sector (Kavvadias et al. 2019) |
| 27 | Influence of heat pumps on renewable electricity integration: Germany in a European Context (Bernath et al. 2019) |
| **Gas infrastructure** | |
| 28 | *The role of trans-European gas infrastructure in the light of the 2050 decarbonisation targets (Trinomics 2018b)* |
| 29 | *Impact of the use of the biomethane and hydrogen potential on trans-European infrastructure (European Commission 2019)* |

| | |
|---|---|
| 30 | *The future of gas in Europe: Review of recent studies on the future of gas* (CEPS 2019) |
| 31 | *The optimal role for gas in a net zero emissions energy system (Navigant 2019b)* |
| 32 | *Gas Decarbonisation Pathways 2020–2050* (Gas for Climate and Guidehouse 2020) |
| 33 | *Decarbonisation of heat in Europe - Implications for natural gas demand* (Honoré 2018) |
| 34 | *Demystifying natural gas distribution grid decommissioning: An open-source approach to local deep decarbonization of urban neighborhoods (Zwickl-Bernhard and Auer 2022)* |

# 10. Synthesis of findings

This part of the meta-study covers studies addressing key technologies for renewable heating as well as the corresponding infrastructures.

## 10.1. Heat pumps

Heat pumps can provide efficient heating and cooling and can improve energy efficiency of both the residential sector and district H&C, where multiple heat and cold sources can be linked (European Copper Institute 2018). Moreover, waste heat (including low temperatures) or underground sources can enhance the application of heat pumps (Bernath et al., 2019). However, the extension of their use to some high-temperature industrial processes may require further development.

Recent studies show that heat pumps can be used and operated efficiently in existing buildings even if they are not fully refurbished to an ambitious level (Fraunhofer Institut für Solare Energiesysteme 2020): the monitoring study shows that air-source heat pumps achieved a seasonal performance factor of 2.5 – 3.8 (average 3.1) and ground source heat pumps had a seasonal performance factor of 3.3 – 4.7 with an average of 4.1. The key factor for applying heat pumps in existing buildings is the required heating circuit temperature (depends on specific heat demand and installed heat transmission system). The results show that deep renovation is not necessarily needed for an efficient and emission saving operation of heat pumps in existing buildings. Temperatures in the heat transmission systems can often be reduced due to over-dimensioning in the past. For efficient operation, good planning covering the heat source, the system integration of the heat pump and the whole heat transmission system in the building especially in old buildings is essential.

Together with thermal storage, heat pumps can play a crucial role in the flexibility of the electricity system through smart operation (Fraunhofer Institut für Solare Energiesysteme 2020; Artelys 2018; Thomaßen et al. 2021). A field test with 450 heat pumps finds that the most suited shifting intervals are 15 – 50 minutes and the losses are below 17 % as back-up heaters are not used. Smart operation and demand shifting measures can help to reduce peak demand and increase the heat pump capacity that can be deployed without further changes to the electricity system.

The impact of a large-scale deployment of heat pumps on the electricity system is discussed in several contributions. A large-scale deployment is favoured in countries with mild climate, large shares of low-carbon heat as well as a high level of installed firm capacity. According to the modelling work by (Thomaßen et al. 2021), additional heat pump capacity of around 1.1 – 1.6 $TW_{th}$ can be deployed based on the existing firm power capacity, which would correspond to a heat pump share of 29 – 45 % in space heating.

A key barrier for the deployment of heat pumps is the fact that heat pumps are more expensive than other heating and cooling technologies, due to the lack of carbon pricing on fossil fuel use and comparatively lower investment costs for combustion-based technologies (UKERC, 2014). However, it is indicated that the higher the achieved levels of decarbonisation and renewable electricity, the more competitive heat pumps may become in heating grids (Bernath et al., 2019). Moreover, incentives for deployment of heat pumps and a change in taxation levels may reduce the costs of heat pumps and spread their use for simultaneous heating and cooling (IRENA 2019).

## 10.2. District heating

Several studies highlight the important role of district heating in the transition of the heating and cooling sector and for sector integration (Celsius 2021; Mazzucchelli et al. 2019; UKERC 2016; Fraunhofer ISI et al. 2016a; ETIP-DG 2018; Reuseheat 2019).

While several successful examples for positive energy districts based on efficient district heating and cooling systems have been implemented, key priorities for research and development to support large-scale deployment remain. This includes novel approaches for low-temperature district heating, the integration of renewable energies, and waste heat in district heating and cooling, scaling up the use of large-scale heat pumps for district heating and cooling, the development and deployment of digital technologies as well as the introduction of local planning.

Heat storage may allow for bridging the temporal gap between the existence of sufficient generation load and the moment when consumption loads needs to operate (the moment of heat demand), thus facilitating the integration of renewables (UKERC, 2014).

## 10.3. New fuels and gases for heating

In today's energy system, natural gas is the most important fuel for heating. Given the presence of extensive natural gas infrastructure and a large number of buildings with gas-based heating systems, the future use of these assets combined with the use of renewable or low-carbon gases is a fiercely discussed and highly controversial topic in the literature.

The most important types of 'clean' gases are hydrogen and non-fossil methane, where the former can be low-carbon hydrogen produced from Steam Methane Reforming combined with CCS or renewable hydrogen produced through electrolysis of water using renewable electricity and the latter is mostly produced from biogas (through upgrading) or through the methanation of hydrogen (power-to-methane). In many cases, biogas can also be used locally in CHP installations or in boilers to satisfy local heat demand (without the need for transport via public gas grids), where upgrading to biomethane is not necessary.

There is a wide range of estimates on the production potential for biogas and its availability for the heating sector. Biogas and biomethane are biobased fuels which are in principle well-suitable for heating purposes. Biogas is usually derived from anaerobic digestion of wet biomass, which results in a mixture of methane and $CO_2$. This biogas can be used locally for heating purposes, but if it is to be transported over larger distances to end-users further away from the production source, the biomass first needs to be upgraded into biomethane, which complies with the gas quality criteria applicable in the gas grid. This also means that biomethane can be used directly in conventional gas boilers.

Lastly, there might be a (niche) role for the use of liquid biofuels for heating. This can especially be a solution in remote areas that are not connected to the gas grid. However, liquid biofuels are relatively expensive and therefore these are more likely to be used in transport. Also, in most cases other stand-alone heating solutions such as heat pumps or biomass stoves/gasifiers are likely to be a more cost-efficient solution than boilers using liquid biofuels.

Electricity-based hydrogen produced with renewable electricity is not dependent on the constrained supply of sustainable biomass and could therefore potentially be produced in much higher quantities. Important advantages of hydrogen are that electrolysers can be used as a solution to balance the electricity system and hydrogen offers one of the few solutions to the seasonal energy storage challenge, as it can be stored in large volumes in salt caverns and potentially in depleted gas fields.

There are, however, several challenges related to electricity-based hydrogen, where the high costs are amongst the most important barriers. These high costs are related to the high capital cost of electrolysers, but also to the relatively high variable costs related to the use of electricity as an energy input. Another disadvantage from an energy efficiency point of view is that the electrolysis comes with an energy loss of 20 – 40 % and as such it is leads to a loss of energy efficiency when compared to the direct use of electricity. However, from an energy systems point of view it is also important to mention that given the intermittent character of renewable electricity sources, the storage properties of hydrogen are also important to take into account when assessing system efficiency. In other words, even though when it is most efficient to use electricity for heating directly, excess electricity may be available in some moments when it cannot be used directly. In those moments, conversion of electricity into hydrogen at a limited energy loss can still be considered energy efficient from a systems point of view. Furthermore, putting the electrolysers in smart locations also enables the recovery of the lost heat to utilise it for heating purposes. It should be noted though that the intermittent use of electrolysers (so only operating with a limited load factor over the year) poses additional challenges to the cost-effectiveness of $H_2$ production.

Considering that hydrogen is still a rather expensive energy carrier and given the availability of more cost-effective alternatives for space heating, hydrogen decarbonisation of heat demand is most likely to focus on decarbonisation of industrial process heat. It is unlikely that renewable hydrogen will be used on a large scale for space heating applications, although it might be used in some specific locations, where local conditions make it the most attractive decarbonised energy source. In most cases, however, the deployment of individual heat pump systems or district heating networks based on renewable engergies will be a more cost-efficient solution for decarbonising space heating. Hydrogen can be introduced in low concentrations in the existing natural gas network without the need to adapt the equipment. When higher concentrations are to be transported, changes to the gas infrastructure are needed and this would also require adaptations to the end-use equipment.

While a range of carbon-free heating solutions is available for the space heating sector, the options are much more limited when it comes to the decarbonisation of industrial process heat, especially for high-temperature processes, the number of decarbonisation options available is more limited and hydrogen is one of those options. In steelmaking, hydrogen is one of the energy carriers that could be used to replace the existing coal-based production process and the first pilot projects to experiment with this are ongoing in Sweden and Austria. Furthermore, renewable hydrogen can also play a role as a renewable energy-based feedstock, for example in fertilizer industry. The prioritisation of the use of hydrogen to decarbonise industrial processes is also reflected in Germany's national hydrogen strategy.

Instead of using renewable hydrogen directly, it is also possible to convert it into methane through the incorporation of carbon derived from $CO_2$ – a process called methanation, producing synthetic methane. Conversion into methane has the advantage that it can be directly used in existing natural gas-based processes and it can serve as a renewable feedstock for organic chemistry. However, the conversion of electricity-based hydrogen into synthetic methane involves some additional energy losses and also adds to the overall costs. To be sustainable, it is important here that this CO2 is derived from a biogenic source or captured from the atmosphere. The latter process is still very costly and as such this is a barrier to the production of hydrogen-derived synthetic methane (or other synthetic fuels). Similar to the production of synthetic methane, hydrogen can also be used to produce a wide variety of other carbohydrate fuels (methanol, butanol, synthetic kerosine etc.), but the same barriers apply as with the need for a non-fossil CO2-source. Furthermore, since the entire goal of energy system decarbonisation is to decouple it from CO2 emissions, it only makes sense to turn hydrogen into synthetic carbohydrate fuels when the carbon is really needed in the process (e.g., in the synthesis of organic chemicals).

Even though hydrogen production using renewable electricity is the preferred production process, producing hydrogen from natural gas using the conventional steam methane reforming process, combined with carbon capture and storage could serve as a steppingstone to promote hydrogen demand in different end-use sectors and develop the market, while keeping the production costs manageable. The disadvantage of this fossil-based hydrogen with carbon capture is that it is not completely free of $CO_2$ emissions, as the $CO_2$ capture efficiency is not 100 %. Self-evidently, fossil-based hydrogen with carbon capture should not replace or postpone the deployment of electrolysers, but could rather be deployed in parallel to scale-up hydrogen production faster, without being restrained to installed electrolyser capacity or the required renewable electricity generation capacity. On the long term, fossil-based hydrogen with carbon capture hydrogen production needs to be fully phased out in order to achieve the GHG targets

The implications of the use of new gaseous fuels for heating on the future of the gas grid are discussed controversially. There are numerous studies addressing potential pathways for the future use of gas for heating (Trinomics 2018a; European Commission 2019; Gas for Climate and Guidehouse 2020; CEPS 2019), however the projected use of gas differs largely in the different scenarios. While the demand for gas is expected to decrease due to improvements of the efficiency of buildings and the use of renewable heating, the technological, economic, and regulatory implications for the future of the gas grid are discussed controversially.

# 11. Summary of studies

## 11.1. RES-H&C technologies

**Support to key activities on the European Technology Platform on Renewable Heating and Cooling (Mazzucchelli et al. 2019)**

***Overview***

This document provides an overview of a study awarded to the secretariat of the European Technology and Innovation Platform on Renewable Heating and Cooling (RHC-ETIP) based on the following tasks:

- The **monitoring of the implementation of five technology roadmaps** (biomass, solar thermal, geothermal, cross-cutting technologies and common implementation roadmap) published by the RHC - ETIP in 2014 in order to see how the technologies have advances with respect to the Key Performance Indicators (KPIs) proposed in the roadmaps. The 2020 KPIs for each technology differ, thus a separate analysis per technology was undertaken.[97] These generally were based on cost, improved efficiency, increased production, longer lifetimes and improved use or design of materials for specific sub-technologies within each roadmap.

- The **analysis of the H&C industry** at EU-level with a focus on the potential of RHC technologies in comparison to incumbent, fossil fuel-based technologies.

- The **analysis of the consumers in the H&C sector** at EU-level with an emphasis on factors that can encourage the uptake of H&C technologies and proposing policies to address barriers for adoption.

***Monitoring of the implementation of technology roadmaps***

The report finds that for some technologies (geothermal, biomass) the KPIs proposed in 2014 are adequate and the sectors are on track to fulfill them. However, in other cases the research and innovation priorities and KPIs should be updated to better reflect the new information gathered during the analysis and the new priorities and needs of the sectors. In the case of heat pumps, the R&I priorities set in the roadmap have not yet been taken into proper consideration by research programmes at either national of EU level. This is the case for both direct calls and dedicated funding schemes. Likewise, the indicative budget for R&I in solar thermal technologies set in the roadmap turned out to be much higher than the amount of finance actually allocated to the technology so far. With regard to district heating, the report suggests that more attention needs to be paid to intelligent planning and operation of DHC networks through smart metering and load management systems. Furthermore, more applied research should be carried out on smart thermal grids connecting diverse types of buildings and industrial processes. More R&D is needed on low-temperature substations. In the case of thermal energy storage, it was found that some KPIs for e.g. underground thermal energy storage are difficult to verify as, for example, energy storage efficiency (a KPI) is based on parameters that depend on specific conditions. The analysis also concludes that since hybrid system structures and their interactions differ, new KPIs must be proposed to allow for uniform comparison.

***Analysis of the EU H&C industry***

The key results from the analysis of the EU H&C industry are summaries in the table below.

*Key performance figure for the EU H&C industry in 2014. Information taken from RHC ETIP.*

| Industry Sector | Stock installed TWh/y | Stock installed GW | Sale GW/y | Industry turnover EUR bn/y | Employment in industry FTE/y | Turnover from heat distribution of fuel sourcing EUR b/y | Employment in heat distribution or fuel sourcing FTE/y |
|---|---|---|---|---|---|---|---|
| **Solar Thermal** | 23 | 35 | 2.1 | 3.2 | 37, 000 | | |

[97] See the technology roadmaps for details on the KPIs: https://www.rhc-platform.org/publications/

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Heat Pumps** | 70 | 74 | 11 | 6.5 | 55,000 | | |
| **Geothermal** | 23 | 19 | 1.1 | 1.6 | 25,000 | | |
| **District Heating** | 400 | 327 | 0.6 | 2.4 | 19,000 | 26.0 | 195,000 |
| **Biomass** | 578 | 436 | 20 | 4.2 | 23,000 | 10.8 | 174,000 |
| **Fossil fuels** | 4,050 | 3,300 | 132 | 21.3 | 223,000 | 305 | |

***Consumers in the H&C sector***

The two major aspects identified in the decision-making of consumers were economic savings and reliability of performance. Other important factors identified included social factors, technological usability factors and ecological factors. Building-ownership needs to be considered in understanding the consumer's decision-making, as it determines who are the main intermediaries and whether split incentives will be a factor in the final purchasing choice. Installers and building professionals were identified among the most influential actors (gatekeepers) having an impact on the decisions of the consumer. However, installers were found to often have a negative opinion regarding RHC technologies, likely based on their lack of familiarity with the technology and unwillingness to reskill. Thus, current practices among installers were deemed to constitute a major barrier to RHC adoption. Other barriers identified included: high investment costs, lack of adequate awareness among consumers and the disruption of routines associated with installing a new technology. Furthermore, the window of opportunity for RHC installation was found to be an obstacle based on the short decision time available after the breakdown of an existing system.

## Renewable power-to-heat: Innovation landscape brief (IRENA 2019)

***Summary and main findings***

- Converting solar and wind power to heat can help transform the power sector, increasing its flexibility
- A regulatory support, incentives for renewable energy use in buildings and industry, and a specific market design that allows revenue stacking are needed
- Heat pumps, electric boilers and thermal storage serve to convert electric power into efficient heating or cooling in a flexible way.
- Electrification of the heating sector is feasible in the short term as most of the required infrastructure is already in place and the electrical grid already reaches most demand points: buildings, houses, commercial sites, and industrial factories.
- The transmission and distribution network would probably need additional investments to increase its capacity.
- Centralized heating systems use large boilers or heat pumps consuming electricity from the grid, and providing heat to several buildings
- Decentralised heating systems use small scale boilers and heat pumps using electricity from the grid or local generator, and providing heat locally (e.g. industry)
- Power-to-heat systems can help integrate greater shares of renewable energy, and use the excess electricity supplied from these sources to address heating needs
- In decentralized systems, consumption can be switched from high-demand time intervals to low-demand time intervals, thus reducing peak load
- Thermal storage can store energy for days or months to help address seasonal variability in supply and demand, thus decoupling heat and cold generation from consumption and allowing use of surplus renewable heat

- The thermal inertia of well-insulated buildings can be used as the storage

***Key policies and measures:***

- Incentives for deployment of heat pumps, support additional storage that helps lowering heat pumps cost, and spread the use of heat pumps for simultaneous heating and cooling
- Limiting the use of fossil fuel boilers and introducing requirements for new buildings to include renewable energy sources for supplying heat
- Change in taxation levels, reducing the burden of using electricity, increasing the levy on fossil energy, eliminating the “right to be connected to the gas grids” for new buildings, ending subsidies on fossil fuels
- Incentivising energy efficiency
- Policies that enable the interconnection of heating and electricity markets should be implemented.
- Targets for more renewable energy-based heating and cooling.

## Heat Pumps – Integrating technologies to decarbonise heating and cooling (European Copper Institute 2018)

***Overview***
The study discusses the potential of heat pumps to contribute to the decarbonisation of the heating and cooling sector. Heat pumps can be operated to provide heating by using ambient heat, waste heat or heat in the soil. Some heat pumps are reversable and are able to operate in cooling mode or heating mode. Another aspect in which heat pumps can differ is in their means of heat distribution, which can be done through hydronic or air-based distribution system or a mix of both.

The fact that heat pumps produce heating and cooling simultaneously means that there is also an opportunity to combine the two and thus further increase energy efficiency. As an example, the heat extracted from buildings by air conditioners in summertime can be used for the hot water supply, thereby removing the need for a separate water heater. Such linkages can also be achieved at a larger scale where multiple heat and cold sources are linked via heat and cold distribution grids.

***Heat pumps as flexibility options***
Heat pumps can also play an important role in balancing the electricity system through load shifting and the realisation of smart grids. By combining heat pumps with a well-insulated building envelope, thermal storage and potentially also battery storage, heat pumps can optimise the time of energy consumption. In well-insulated houses, superheating can be done before people get home and when the electricity demand is still low, decreasing the energy demand during peak hours. Similarly, thermal storage can be used for heat grids or in buildings. This flexibility can also be used in demand side flexibility-based service models: the end-user uses the heat pump as part of a heating/cooling as a service model, where a private company owns the heat pump and is responsible for its optimal operation. In this model the heat pump is used by a grid operator as a flexibility tool.

***Heat pumps in industry***
Heat pumps can also be used in industry, including heating, cooling, and dehumidification. When it comes to heating, commercially available heat pumps can only provide heating up to temperatures of around 100°C, heat pumps in the temperature range of 120 - 140°C are currently in the pilot/demonstration phase, but heat pumps achieving temperatures above 150°C are still in the research and development stage. There is, however, a significant share of industrial processes in the temperature range that can be provided by heat pumps.

***Market uptake***
Up to now, market uptake of heat pumps has been very heterogeneous across different European countries, with the Scandinavian countries being frontrunners, together with France. In general, the study considers that a positive attitude to electricity as an energy source for heating and a limited availability of natural gas (including gas infrastructure) are factors that are contributing positively to a high uptake of heat pumps. The same holds for countries that have stimulatory policies in place, such as financial support schemes, institutional support via the provision of information, clear decarbonisation policies and targets for the H&C sector or support for the development of required infrastructure (e.g., heat grids). For financial support mechanisms to be effective it is important that these

are transparent regarding the total amount of funding available and the duration of the funding program. Furthermore, it is essential that the availability of funds is budget-independent, to ensure continuity and long-term availability, it should support various applications and the support levels should be high enough to substantially affect total cost of ownership.

In order to facilitate market development for heat pumps it is important that the total cost of ownership is taken into account, including system design, installation costs, maintenance and fuel costs. Comparison with other heating technologies is crucial in this respect. In many markets, heat pumps are still a more expensive option due to the lack of carbon pricing for fossil fuel use and the comparatively lower investment costs for combustion-based technologies.

## METIS Studies - Study S6: Decentralised heat pumps: system benefits under different technical configurations (Artelys 2018)

***Summary and approach***

Space heating has a share of approx. 70 % in the total final energy demand and is mainly generated by technologies using/ burning fossil fuels like gas, oil or coal. With an increasing share of fluctuating renewable electricity generation in the power mix, electric heat generation could play an important role in the decarbonisation of the space heating sector. The most commonly known power-to-heat technology are electric radiators. However, their efficiency is comparably low (close to 100 %). Heat pumps can provide the heat with a much higher efficiency (coefficient of performance (COP) of 3 – 4 (state of the art ground source heat pumps up to 5). They are usually combined with a back-up heater to avoid over-dimensioning. The goal of the study is the evaluation of system benefits of decentralised heat pumps in the EU under different technical configurations. Technical information for different power-to-heat technologies was gathered and more technical and economic parameters were collected for heat pumps. Different topics were furthermore addressed:

- Assess benefits of heat pumps over conventional boilers
- Estimate the flexibility offered by heat pumps with thermal storages
- Analysis of profitability of heat pumps with gas-fired back-up boilers

These options were assessed for two EU power system scenarios, a business-as-usual scenario and a more ambitious, further decarbonised 2050 scenario with a renewable share of 65 % in power production and high CO2 prices (522 €/tCO2). In order to perform the analysis, the EU power system model METIS was extended in order to be able to model the hourly functioning of heat pumps (varying temperature profiles, heat production of heat pumps coupled with electric or gas back-up heater) adequately.

***Main findings***

The results show that heat pumps are an efficient technology to decarbonise the heating sector. The effect is higher with an increasing share of renewables in the electricity mix. A challenge is still the profitability of mono-energetic heat pumps at least in 2030 in the business-as-usual scenario due to the high investment costs and the need for additional peak power generation. In 2050, monetary savings from avoided $CO_2$ emissions from gas boilers offset the needed additional investment leading to a high profitability from a system's point of view. The main advantage of heat pumps in combination with thermal storage in combination with real-time pricing is the flexibility they offer for the electricity system. Gas-boilers as back-up heaters are seen as a promising compromise to curb potential peak loads in the electricity system and thus reducing the need (and cost) for peak generation units. Furthermore, a smart operation of heat pumps helps to integrate more fluctuating renewable electricity generation and thus reduce the overall $CO_2$ emissions in both scenarios assessed by several million tons per year. The monetary savings achieved by smart operation sum up to approx. 6bn€/year, which is about 3 % if the whole power production costs in the EU28.

## Power-to-heat for renewable energy integration: Technologies, modeling approaches, and flexibility potentials (Bloess et al. 2017)

***Summary and main findings***

This study provides a literature review of model-based analyses of the contribution of flexibly coupling the electricity and heating sectors to both renewable energy integration and decarbonisation. Focusing on residential heating, the study compares the geographic and temporal areas of research and highlights the latest analytical model formulations.

In general, the results show that power-to-heat technologies can contribute cost-effectively to the integration of renewable energy, the substitution of fossil fuel and decarbonisation. In particular, heat pumps and passive thermal storage are favourable options.

***Main findings:***
A systematic literature review of 46 studies published between 2007 and 2016 is presented. The reviewed papers are analysed according to their research scope; methods and modeling approaches; and research questions and findings.

- Regarding the research scope, the study provides an overview of the time frame, spatial coverage and technologies considered. It is identified that most papers focus on European case studies. Broadening the scope of sector coupling, especially the combination of power-to-heat and power-to-X, could shed light on the comparative attractiveness of power-to-heat and provide further insights into alternative or complementary decarbonisation and flexibility potentials.

- Regarding the research methods and modeling approaches, the study provides an overview of general methods, the type of program, time resolution and endogenous investments. Additionally, explicit formulations for heat pumps and heat storage equations are presented. It is identified that most reviewed papers are based on optimisation models. Future research could broaden the focus by considering the behavior and incentives of consumers, regulators or policymakers.

- In terms of research questions and results, the study analyses cost effectiveness, integration of variable renewable electricity, decarbonisation, electricity prices and demand for power-to-heat, heat supply structure and impact of method choice. Although numerical results vary depending on location, time, and assumptions about cost, policy, and technology availability, it can be generally stated that power-to-heat applications are cost-effective in contributing to renewable energy integration and decarbonisation. Heat pumps and electric boilers in particular, have a central role in the literature. Although electricity demand increases when electricity is used for heating, electricity price spikes can be prevented if the heating sector is sufficiently flexible through the flexible operation of power-to-heat options or heat storage.

## Heat pumps in existing residential buildings – results from the research project “WPsmart im Bestand” (Fraunhofer Institut für Solare Energiesysteme 2020)

***Summary***
The project is the latest of several monitoring projects monitoring and analysing heat pumps under real operation conditions “in the field” conducted by Fraunhofer ISE. It focused on two main research questions:

- Question 1 – efficiency: “What efficiencies do electrically driven heat pumps achieve in differently retrofitted older buildings under real operating conditions in the field?"

- Question 2 – flexibility: “What is the flexibility that heat pumps can deliver to the power system?”

**Efficiency:** For answering the question a total of 56 heat pumps were monitored including 32 air source heat pumps, 9 combined systems (two heat pumps in the system using different heat sources), 13 ground source heat pumps and 2 heat pumps using an ice storage as heat source. Most heat pumps are installed in single-family buildings (42; average heated floor area 172 m²). The others are installed in buildings with up to four dwellings. The average heat floor area of all buildings was 183 m². More than half of the heat pumps were installed in buildings built before 1979 and around one-third in buildings constructed between 1980 and 1995. For most of the buildings a detailed assessment of the energetic quality of the buildings in the original and current state could be conducted. Most of the older buildings were already at least partly refurbished (replacement of windows (89 % of buildings), and/or insulation of roof (86 % of buildings), and/or significant improvement of external walls (57 % of buildings)). Not all buildings could be monitored in all project years. In the first monitoring period from July 2018 to June 2019 29 ambient air heat pumps used for space heating and domestic hot water were analysed.

**Flexibility:** The question was answered by extensive simulation studies. The simulation evaluates a heat pump pool dimensioned according to current standards and controlled by smart grid (SG)-Ready signals.

***Main results:***
**Efficiency:** Heat pumps can be used and operated efficiently in existing buildings even if they are not fully refurbished to an ambitious level. In the first monitoring period air heat pumps achieved a seasonal performance factor of 2.5 – 3.8 (average 3.1). The maximum supply temperature was 45.4 °C and the average temperature for space heating was 36.9 °C. Some air source heat pumps even achieved higher efficiencies (4.1 and 4.6). Ground source heat pumps had a seasonal performance factor of 3.3 – 4.7 with an average of 4.1. the supply temperatures were slightly higher than in the systems with air source heat pumps. The achieved $CO_2$-emission reductions in 2018 compared to a gas condensing boiler are between 19 % and 47 % (air source heat pumps) and between 39 % and 57 % (ground source heat pumps). Anticipating further decarbonisation of the electricity generation until 2030 leads to even higher emission reductions of up to 80 %. The key factor for applying heat pumps in existing buildings is the required heating circuit temperature (depends on specific heat demand and installed heat transmission system). The results show that deep renovation is not necessarily needed for an efficient and emission saving operation of heat pumps in existing buildings. Temperatures in the heat transmission systems can often be reduced due to over-dimensioning in the past. For an efficient operation, good planning covering the heat source, the system integration of the heat pump and the whole heat transmission system in the building especially in old buildings is essential.

**Flexibility:** A pool of around 250 heat pumps shows a robust response of the whole system to grid signals. Each unit has an electrical shifting potential of 0.18 – 10.68 kWh per unit and operation cycle. Depending on the SG-Ready control signal one million heat pumps can provide a shifting potential of up to 4 – 14 GWh hourly. The shifting potential decreases for shifting periods of more than one day to 3- 8 GWh. The shifting potential strongly depends on the season. During summer the potential is neglectable compared to transition periods and winter. The most suited shifting intervals are 15 – 50 minutes and the losses are below 17 % as back-up heaters are not used. Losses increase with longer shifting intervals to up to 70 %. The field test showed that only few controlled heat pumps of the first-generation SG-Ready heat pumps showed the expected behavior.

## The decarbonisation of the EU heating sector through electrification: A parametric analysis (Thomaßen et al. 2021)

***Summary***
The article analyses the electrification of the heating sector using heat pumps as a decarbonisation strategy in the EU Member States. It discusses its effectiveness and assesses its impact on the power system. As a basis, the article describes the energy mix in the heating sector in the EU Member States and decomposes the power demand for different end-use purposes including heating and cooling. The study finds that electrification can reduce the total energy-related emissions by up to 17 %, if paired with simultaneous expansion of low-carbon electricity. The article finds that most national power systems could cope with higher heat-electrification rates and identifies three main factors that are beneficial for electrification: 1) mild climate; 2) large share of low-carbon heat ; 3) high level of installed firm capacity. The study finds that an additional heat pump capacity of around 1.1–1.6 $TW_{th}$ can be deployed based on the existing firm power capacity, which would correspond to a heat pump share of 29 – 45 % in space heating. Based on their current power capacity, 12 Member States are prepared for even full electrification scenarios, whereas three Member States could get their power system stressed if 40 – 60 % of all fossil-fuelled technologies are substituted. The upper end of the capacity can be reached by introducing demand shifting measures, such as those relying on the thermal inertia of the building stock. To this end, regulators should ensure that this flexibility is available to the market. For example, transmission-system operators can contract heat pump capacity, acquiring a large portfolio of interruptible loads available. Another option on the demand side is to enable smaller consumers to react to price signals from the wholesale market, requiring the rollout of smart meters and the implementation of real-time metered electricity tariffs for households and other small consumers.

## Heating without the hot air: Principles for smart heat electrification (Rosenow and Lowes 2020)

***Overview***
Given that currently, in Europe, 31 % of the overall energy consumed is used for space and water heating, and that 75 % of this energy comes from fossil fuels, the decarbonisation of the heating sector is of paramount importance to achieve the target of net-zero emissions by 2050. Electrification of the heating system together with efficiency improvements in buildings currently represent some of the most relevant tools to achieve the desired decarbonisation of the sector. The electrification of the heating system should be planned by

considering the heating and power sectors in parallel, as part of the wider energy system, in order to maximise system flexibility and minimise costs. Furthermore, on the demand-side, energy efficiency can facilitate the lowering of heat demand and increase the performance of heating systems. Considering the interactions among the heating systems, power sector and demand-side flexibility can maximise the benefits of heat decarbonisation. The recently published (08/07/2002) EU Strategy for Energy System Integration further highlights the importance of an energy system approach. The report aims to provide smart heat policy recommendations, where "smart" is understood as an approach to optimise heat decarbonisation across sectors and maximize the benefits of the available technologies. The scope of the report includes space heating and hot water provision, it does not include industrial heat.

***Options for heat decarbonisation***

The paper argues that heat production using zero-carbon electricity sources (e.g. solar, wind, electricity) represents a key solution for heat-decarbonisation and that heat pumps can be used to maximise system efficiency. Solar thermal technologies can play an important role in particular for the provision of hot water. Options for low-carbon heat provision include combustion technologies such as bioenergy and waste. However, in many cases the potential scale of bioenergy may be limited by availability of resources and the issue of land use sustainability and GHG reduction potential. Regarding the use of hydrogen for heating, uncertainty remains about production methods, transmission, its performance as a heating fuel and costs of production. Furthermore, considerations on how to best use a high-value resource such as hydrogen need to be taken into account since low-grade heat provisions will, at least in the short and medium term, compete with applications ranging from industry to long-distance transport and power generation. Conversion efficiencies, the amount of renewable electricity required to produce one unit of usable heat, should be considered in the selection of different technologies. Many uncertainties remain regarding which technologies will be most suitable in a particular context. These include future technology costs, further innovation, power system change and consumer uptake. Nonetheless, the paper already identifies five key issues which are already clear today:

7. All technology options will require substantial improvements in the energy efficiency of the existing building stock
8. Options that combine energy efficiency with low-carbon heat supply are likely to be more economic and feasible as opposed to those that rely only on one of the two approaches.
9. Rapid progress needs to be made now.
10. It is critical to learn how different low-carbon heating technologies perform in different types of buildings with different occupants in other to make informed policy choices in the future.
11. The embodied carbon emissions of most low-carbon technologies are significantly lower to the operational emissions of heating systems based on fossil fuels.

## Advancing District Heating & Cooling Solutions and Uptake in European Cities - Overview of Support Activities and Projects of the European Commission on District Heating & Cooling (Celsius 2021)

***Summary and main findings***

The report provides an overview of the findings of a variety of projects addressing district heating and cooling solutions. It focuses on the Horizon 2020 Programme for Research and Innovation (2016 - 2020), including projects funded under the LIFE programme.

- The report provides an overview of existing lighthouse-projects, where positive energy districts have been realised using innovative district heating and cooling approaches.
- Low-temperature district heating is a key solution for efficient system integrating renewable heat sources. The report reviews projects that address such systems, including the development of innovative business models and regulatory frameworks.
- The integration of renewable energies in district heating and cooling is addressed in several projects, focussing on the one hand on advancing geothermal technologies and their market uptake and on combining different renewable sources in district heating and cooling.

- The use of waste heat in heat networks is addressed, focussing on industrial waste heat and on unconventional urban sources. In addition to technical innovations, business models, market uptake measures and support to stakeholders are addressed.
- The report further summarised projects addressing large-scale heat pumps for district heating and cooling networks.
- The digitalisation of District Heating & Cooling Networks and Smart Energy System Integration are subject to several projects, dealing with the smart connection and/or optimisation of different energy networks.
- Another priority area covered in the report are local heat planning studies and tools, reviewing several projects that provide data and reliable models for supporting heating and cooling mapping and planning.
- Finally, the report addresses project involving accompanying measures such as standardisation, awareness-raising and communication, market uptake measures or policy dialogues.

## The Future Role of Thermal Energy Storage in the UK Energy System (UKERC 2014)

***Summary and main findings***

This study aims at: (i) characterising the main areas of heat use in the UK; (ii) reviewing research on thermal energy storage systems; (iii) describe the main characteristics of available thermal energy storage technologies; (iv) identify key application areas for thermal energy storage in the UK based on a national target for an 80 % reduction in greenhouse gas emissions by 2050. Two case studies of applications are analysed: (i) domestic heating of a dwelling in Derby; ii) district heating scheme in London. The development of more effective storage technologies, balancing heat peak load with decarbonised heat pumps and low emission heating approaches will be essential to achieve the emissions targets.

***Heat use in UK***

- Just under half (45 – 47 %) of total final energy consumption in the UK is currently used for heating purposes, of which approximately 80 % comes from fossil fuels. Space and water heating account for 63 % and 14 %.
- Of the 18 % of heat supplied for industrial processes, 6 % is for high temperature process, 9 % for low temperature process and 3 % for drying and separation.

***Thermal storage technologies***

- Sensible heat storage is by far the most utilised and mature form of heat storage. Although latent heat and thermochemical heat storage systems may provide greater energy storage per volume, they are still at lower technology readiness levels.
- Store volumes range in size from domestic hot water tanks for few hours to systems with volumes up to 75,000 m3 for inter seasonal storage.
- There are four main types of large scale, low temperature, thermal energy stores available: tank thermal energy stores, pit thermal energy stores, borehole thermal energy stores and aquifer thermal energy stores. Large inter-seasonal stores are only sized for a maximum of a few hundred buildings
- Since the annual heat load profile is not constant, thermal storage can be combined with large scale deployment of electric air source heat pumps to balance peak grid load. If the heat pumps are operated with decarbonised electricity supply and district heating, large scale heat pumps may prove advantageous over combined heat and power.
- Thermal storage has not been observed to increase the society sense of community, but may have an impact on society’s behaviour, by encourage users to use energy with more flexibility or use more energy.

***Barriers and challenges***

- The provision of heat during the transition to a low carbon economy is a significant challenge as currently less than 2 % of UK's space heating is provided by heat networks.
- Wide-scale adoption of air source heat pumps for space heating will require significant investments due to the seasonal variation and magnitude of peak winter loads, as well as increased pressure on electricity grid.
- Without the development of more effective latent or thermochemical heat storage systems, the storage volumes required will be large and difficult to integrate into a domestic context.

***Key policies and measures***

- The achievement of national emission reduction targets will require low emission heating approaches.
- The introduction of a thermal store will require new skills to be developed among technicians and engineers, including specialist knowledge in maintaining the system effectively and efficiently.
- Unless the system undergoes a radical transformation improving thermal efficiency, space heating will remain the main heat user.

## A new perspective on global renewable energy systems: why trade in energy carriers matters (Schmidt et al. 2019)

***Summary and main findings***

This study identifies four drivers that facilitate trade of renewable energy carriers: (i) new land-efficient technologies for renewable fuel production; (ii) regional differences in social acceptance and land availability for energy infrastructure; (iii) economics of renewable energy systems; and (iv) reduction of stranded investments in the fossil fuel sector by switching to renewable fuel trade. Consequences derived from these drivers should be considered for a future development of global renewable fuel trade streams. Although all current modelling studies suggest a decline of long-distance trade in energy carriers in future global renewable energy systems, this conclusion may be due to the under-investigation of the impact of these drivers on trade in renewable energy carriers.

***Prediction of future global renewable energy systems***

- Current models tend to predict very high shares of electricity generation from renewable sources as the best scenario for future use of renewable energy.
- Models usually foresee highly renewable energy systems as largely regional, showing a decline in intercontinental trade of energy carriers as electricity generation from renewable sources increases.
- However, the identified drivers put into question the currently dominating view that renewables expansion will cause a decline in long-distance trade in energy commodities.

***Potential of renewable carriers' trade***

- New land-efficient ways of producing renewable fuels may become cost-competitive until 2050 and may allow long-distance trade of renewable energies.
- If renewable fuels are made compatible with the existing infrastructure for liquid and gaseous fuels, they would allow avoiding stranded costs in the fossil fuel sector.
- The costs of imported renewable fuels may be lower than local production.

***Barriers***

Several factors may hinder the advent of trade in renewable fuels:

- Deploying renewable energy generators on large scale may be incentivised only under strict greenhouse gas emission limits.

- The global community may not agree on far-reaching mitigation measures and trade in renewable fuels may be seen by the importing countries as a continuation of the current dependency on oil and gas exporters.
- Sourcing renewable fuels from the Global South may cause adverse effects on local populations.

***Future strategies***

- A major effort in the energy research community is necessary to better understand possible future trajectories of global energy systems
- Improve understanding of the scientific and technological fundamentals of renewable fuel production, its associated economics along the whole supply chain, social conflicts with energy infrastructure expansion, and preferences of actors in open or closed global energy systems.
- Global and bilateral agreements on free trade may have a strong impact on the opportunities for trade.
- Trade in renewable solar and electric fuels may become a major option in the coming decades.

**Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)**
**Work package 1: Final energy consumption for the year 2012 (Fraunhofer ISI et al. 2016b) (Fraunhofer ISI et al. 2016b)**
**Work package 2: Assessment of the technologies for the year 2012 (Fraunhofer ISI et al. 2016a) (Fraunhofer ISI et al. 2016a)**

***Overview***
The aim of the study is to provide a detailed overview of the heat and cold supply as well as use in Europe in 2012. The study covers all 28 EU Member States plus Iceland, Switzerland and Norway. It is composed of five reports and a complete dataset. The reports are:

- Report 1: Work package 1: Final energy consumption for the year 2012
- Report 2: Work package 2: Assessment of the technologies for the year 2012
- Report 3 and 4 (published in one document): Work package 3: Scenarios for heating & cooling demand and supply until 2020 and 2030; Work package 4: Economic Analysis
- Report 5: Work package 5: Barriers, Best Practices and Policy Recommendations

In the following report 1 and 2 are described in detail. The other reports can be found in the respective sub-chapters by following the link given above.

The report on work package 1 provides a full data-set on heating and cooling consumption in the base year 2012, the first ever such data set looking at final, primary and useful energy consumption in heating and cooling in buildings (space heating/cooling) and industry (process heating divided into three temperature bands of low, medium and high temperature). The study was the first also providing a full data set of district heating and cooling energy consumption by quantity and fuel types in all assessed countries. The report on work package 2 provides an overview of the heating and cooling technologies installed in the assessed countries in terms of installed numbers and capacities. The dataset distinguishes between different capacity classes and also provides the most relevant technical (efficiency, technical lifetime) and economic (investment and operation and maintenance costs) parameters.

***Results***
**Energy and fuel consumption in 2012** (Fraunhofer ISI et al. 2016b)
For gaining detailed information about the energy and fuel consumption, different statistics on European and national level are assessed. Furthermore, a method to derive useful energy demands is developed and applied. The analysis shows that the final energy for **heating and cooling accounted for about 51 % of the total final energy consumption** of approx. 12,800 TWh in 2012, which corresponds with a final energy consumption of 6,497 TWh. The **most relevant heating end-use in 2012 was space heating** (52 % of the total final energy demand for heating and cooling, which is about 3,350 TWh). With about 2,000 TWh **process**

**heating follows** (approx. 30 %). Water heating (domestic hot water;10 %), cooking in the residential sector (3 %) and cooling uses (5 %) played smaller roles in 2012. The different demand sectors (private households, tertiary sector, industry) differ strongly in the importance of the mentioned end-uses. While the **residential sector is dominated by space and water heating** (76 % and 16 % respectively; cooking (7 %) and space cooling (1 %) only play minor roles) the **industry sector is dominated by process heating** (share of approx. 81 % in total heating and cooling demand). In the **tertiary sector, space heating also has a large share** (61 %). Other end-uses with relevant shares are water heating (14 %), process cooling (10 %) and space cooling (9 %).

The **major energy carrier for heating and cooling sector is natural gas** with a share of approx. 45 % (2,660 TWh). The other end energy carriers have similar shares (electricity, fuel oil and biomass 12 % each coal 9 % and district heating 8 %). **Waste, solar energy, ambient heat and geothermal only play a minor role** with a share of 1 % or less each. **Fossil fuels had a share of about 66 %** and 20 % were supplied by secondary energy carriers (electricity and district heat). **Renewables** had a share of only **14 %**.
The **primary energy demand** of approx. 8,000 TWh in 2012 was **mainly met by natural gas (45 %) followed by coal (15 %)**, biomass and fuel oil (11 % each), nuclear (7 %) and other renewables (5 %; wind, PV and hydro). The other renewables (solar thermal, geothermal, ambient heat) together only had a share of 1.5 % in the primary energy consumption in 2012. **All renewables together had a share of 18 %, fossil fuels accounted for 75 %**. From the 6,500 TWh final energy demand approx. 5,100 TWh are used (**useful energy**). About **21 % of the final energy is dissipated/ lost** during the conversion process to useful energy.

**Installed capacities in 2012** (Fraunhofer ISI et al. 2016a)
The main heat and cooling supply technologies installed in Europe in 2012 were assessed in detail. The technology stock (installed capacities, number of installed units, age distribution) was assessed and described in detail. Furthermore, technical, and economic parameters were described (efficiency, lifetime, investment and operation and maintenance costs.

Three major end use categories were distinguished:

- Technologies in buildings,
- Technologies for industrial processes,
- Technologies for district heating and cooling.

In 2012, the **space heating and cooling sector** was **dominated by fossil fuel burning technologies** (natural gas, oil, and coal boilers). They account for **61 % of the installed thermal capacity and 50 % of the installed units** (if small CHPs and direct electric heating would be counted as “fossil”, the share would even be higher: 74 % of capacity and 62 % of units). The **proportion strongly differs amongst member states** and is highly depending on local conditions like available domestic energy carriers. In countries with natural gas resources, the share of gas boilers can be above 80 % (UK) or even above 90 % (NL) with respect to installed capacities. Countries without own sources or even without a connection to the European gas infrastructure, natural gas is not used at all and the share of oil boilers is high instead. In Sweden, Estonia, and Finland the shares of installed fossil fuel fired technologies is only 7 %, 10 % and 13 % respectively. In these countries, biomass, district heating and in Sweden also heat pumps play an important role. Heat pumps have an overall share of 7 % in the installed capacity and 12 % in the installed units in the assessed countries. However, in some national statistics cooling devices are counted as heat pumps even though they are not used for heating purposes (e.g. Italy). In total, heating technologies with a capacity of 1,747 $GW_{th}$ in more than 217 million units were installed in 2012.

**Most heating technologies in buildings were installed after 1992**: with respect to capacities 71 % and with respect to units 74 %. Especially renewable technologies are comparably new (76 %) while fossil technologies are generally older (only 69 % installed after 2012). The **oldest technologies installed are coal fired boilers** (58 % installed before 1992) and the **newest are aerial heat pumps** (99 % installed after 2002).
In the **process heating and cooling** sector technologies directly using generated heat (e.g. furnaces) and technologies indirectly using heat via e.g. steam were differentiated. The assessed technologies cover 85 % of the total process heat demand in the analyzed countries in 2012. Steam boiler statistics are only available on European level from Eco-design-pre-studies and only cover boilers with a thermal capacity between 1 and 50 $MW_{th}$. Therefore, for the country breakdown additional statistics and assumptions had to be used. The estimated steam boiler stock was approx. 68,000 units with a capacity of roughly 770 $GW_{th}$ in 2012 and most of the boilers (two-thirds) were installed in Germany, Italy, France, UK, and Spain. About **71 % of the boilers were gas-fired and approx. 17 % oil-fired**. Biomass and electricity steam generators only had a share of 4 – 5 % each (biomass predominantly in Sweden). Besides boilers, there are also CHP-plants installed for steam generation (lower temperatures than boilers). However, the data availability was found to be weak and different sources (mainly Eurostat and PLATTS database) provide different values. A large share of furnaces

was installed in the iron and steel industry in 2012, in which coal (products) are the dominant energy source used. Capacities are usually not provided in thermal units, but in production capacities (e.g. kt steel). Other sectors, in which high shares of furnaces are installed are the cement and glass industry. **Biomass, alternative fuels, and electricity were only used in a small proportion of the installed furnaces**. Besides heat generators, also cooling units in the industry were assessed. The study assumes that approx. 73,000 cooling systems were installed for process cooling in 2012.
The countries with the highest installed thermal capacities in **district heating** systems are Poland (58 GW), Germany (49 GW), Czech Republic (24 GW) and Denmark (23 GW). Most CHP units used for district heating supply were steam turbines (72 %) followed by gas turbines (13 %) and combined cycle units (11 %). In terms of installed units, internal combustion engines were the dominating technology in 2012. In 47 % of the installed CHP plants natural gas is used as a fuel and 20 % use coal. Renewable energies together have a share of 18 % in the final energy use in CHP plants.

## Vision for deep geothermal (ETIP-DG 2018)

***Overview***
Deep geothermal energy is defined as thermal energy extracted from the earth's subsurface at depths larger than 500 m. To date, the majority of deep geothermal energy plants are used for electricity generation, representing an installed capacity of 2.5$GW_{El}$[98] and the remainder functioning as heating plants, representing an installed capacity of 4.8$GW_{th}$. Up to now the investment levels in R&D for deep geothermal energy has been relatively limited compared to other renewable energy technologies.

**Geographical aspect of the geothermal energy potential**
Geothermal reservoirs are unevenly spread over Europe. Heat sources with temperatures exceeding 90°C are relatively scarce. Areas possessing such sources are the places where most of the existing geothermal energy production capacity is located. However, advancements in low-temperature heating systems, energy efficient buildings and fourth generation heat grids enable the use of heat sources with much lower temperatures (50 - 90°C), which greatly expands the use potential as such sources are geographically more abundant.

**Geothermal energy and district heating**
Geothermal sources can be used as a sustainable heat source for district heating grids. Geothermal energy plants produce heat at a continuous basis. As heat demand can fluctuate, demand-side response strategies or thermal energy storage can be applied to match supply and demand. In order to utilise low-temperature heat sources for supplying heat to high-temperature grids it is also possible to upgrade the heat to the right temperature using a large-scale heat pump. High-temperature heat sources can also be used for industrial processes requiring medium-temperature process heat. In this context, cascading heat use, where the geothermal energy is in several subsequent processes with progressively lower temperatures is an economically attractive option.

**Sector coupling and integration with other renewables**
Geothermal energy can also play a role in coupling of the electricity and district heating systems and balancing the intermittent nature of wind and solar energy. In this context, combined cooling, heating and power (CCHP) is an interesting option. The option to produce power can be utilised when electricity generation from other renewable sources is inadequate and the system can switch to heat production when other renewable electricity sources are sufficiently available. Excess heat from cooling or other processes can be used in the summer for injection into the ground for later use thereby extending the useful lifetime of the heat source.

**Breakthroughs driving deployment of deep geothermal energy**
Several breakthroughs are expected to contribute substantially to a faster deployment of deep geothermal energy, namely: high-resolution imaging and modelling techniques to assess the underground, improved borehole designs and sustainable flow enhancement, innovative technologies for efficient heat utilisation, hybrid systems and responsiveness to energy demand.

[98] Note that the electric output capacity is rather small compared to the thermal input (~10%)

## EU biomass use in a net-zero economy (Material Economics 2021)

***Overview***
The study considers biomass use in the EU across all sectors in the context of the transition to net-zero greenhouse gas emissions by 2050. It analyses the costs, resource requirements, and $CO_2$ impacts of different options for using biomass both for materials and energy uses.

***Biomass demand and supply***
The study analyses the projected demand of biomass in several net-zero scenarios and finds that the demand projections largely exceed the expected supply. While the biomass demand varies largely between the scenarios, the average demand foreseen is about 50 percent higher than can be covered by EU resources. The study lists several reasons why future biomass supply is scarce: 1) Increasing imports of biomass would likely come at the expense of environmentally damaging conversion of land; 2) The potential to increase supply from EU forests, waste and residue streams is limited, as it is expected that an increase of more than 10–15% leads to major trade-offs with environmental impacts or faces practical and economic constraints; 3) Increases in EU biomass supply from the cultivation of new energy crops would entail a major remake of EU landscapes.

***Prioritisation of end uses***
The study provides a framework for prioritising the use of biomass across different end uses and concludes that bio-based materials are typically the applications with highest value in the net-zero context. By contrast, it concludes that biomass is not competitive for low-temperature heat applications where heat pumps are suitable. The study estimates that biomass at 2–4 EUR/GJ could compete, whereas the actual supplies at scale have estimated costs of about 6–8 EUR/GJ. Regarding low-temperature heat, the study thus concludes that biomass is competitive primarily in niches where local stranded resources, co-benefits, or amortised infrastructure can compensate. Regarding high-temperature heat applications, the study finds that bioenergy can be competitive in some industrial heat applications at around 6–8 EUR/GJ and highlights the role of hybrid solutions to back up electricity or hydrogen.

***Net-zero scenario with lower biomass demand***
The study develops scenario projections for a net-zero transition by 2050 that use considerably less biomass than the existing net-zero scenarios. By comparing the “high-value” scenario (with low biomass use) with a business-as-usual scenario, the study finds that the capex and opex of meeting the required energy services and materials production are 36 billion EUR per year lower in 2050 in the high-value scenario than in the BAU scenario, with average abatement costs being 85 EUR/t $CO_2$ lower. Furthermore, the land-use requirements are 90 per cent lower in the high-value scenario. Furthermore, the study estimates that around 144 million tonnes of $CO_2$ are avoided in the high-value scenario, as the production and extraction of biomass can lead to substantial release of $CO_2$ that would otherwise be stored in vegetation and in soils. Key enablers for meeting net-zero in line with the biomass demand of the high-value scenario include a considerable reduction of costs for hydrogen as well as the transition of electricity supply to renewable sources as well as considerable increases in resource and energy efficiency.

***Policy recommendations***
The study points out that the policy framework in the EU and its Member States does not sufficiently take into account new findings regarding the limited growth potentials for biomass use. Examples include the “zero carbon” rating of biomass combustion and the $CO_2$ price in the EU ETS as well as a variety of national measures fostering the use of energy for heating and electricity generation. The study suggests that renewable energy policies both at EU as well as national level need to prioritise other renewable energy sources to avoid that the ongoing increase of biomass use in heating and electricity production continues. On the other hand, the study highlights the importance of supporting the deployment of biomass in certain niche applications (e.g. industrial heat in hybrid systems).

## The role of biomass gasification and methanisation in the decarbonisation strategies (Mantulet et al. 2020*)*

***Summary and main findings***

- The study explores the future development of biomass uses across different climate policy scenarios and under different biomass supply availability and technology performances.

- The role of green gas energy carriers (biomass gasification and methanisation) in the decarbonisation is evaluated.
- The future of bioenergy depends mostly on countries' bioenergy supply and demand.
- Most of modern uses of gas fuel will be possible with a biomass transformation through the gas vector.
- Implementing climate policies boost the deployment of biomass methanisation and gasification by 2 to 3 times, and implementation of carbon capture and storage accelerate even more their use.
- Electricity and heat valorisations are prominent in northern countries while biofuels are prominent in developing countries.
- Methanisation develops earlier than gasification because the process is more developed and profitable.

Both technologies will provide flexibility to the gas vector, and they can be transformed into heat, electricity or both or upgraded to biomethane.

***Approach***
Inputs: the projected population, Gross Domestic Product (GDP) by region, oil and gas resources, technology costs and performances.

***Decarbonisation strategies***

- High value carbon taxes that penalise fossil fuels drive biomass valorisation for electricity and fuels conversion.
- Combining bioenergy with carbon capture and sequestration is a key technology to generate the negative emissions needed for the climate commitments.
- Technology development is not enough, as field competitiveness in decreasing $CO_2$ emissions depends a lot on people's behaviour. These technologies can raise resistance (e.g. noise, smell, explosion risk, increase of traffic to fuel digesters, flies invasion).
- Better communication is key to remove concerns and launch these technologies at a bigger scale.

## ReuseHeat – WP 2: Market and stakeholder analysis (Reuseheat 2019)

**Overview**
Recovery of urban waste heat bears the potential to increase overall system efficiency and reduce dedicated heat production needs of district heating (DH) systems, but up to now the use of urban waste heat sources has been very limited. This study analyses the main barriers for increased use of urban waste heat as well as solutions to overcome these barriers, through the consultation of relevant stakeholders in eight EU Member States, namely: Sweden, Romania, Italy, Spain, Germany, Denmark, France and Belgium. The stakeholder groups consulted in the study were DH companies, owners (suppliers) of waste heat, customers, policy makers and investors.

**Barriers for urban waste heat recovery and use**
Numerous barriers for increased use of urban waste heat were identified in the study including economic, financial, technical, and cognitive barriers. The most important barriers that were identified in this study are:

- Low maturity of existing solutions (at system level);
- The absence of a legal framework;
- The absence of standardised permits and contracts;
- The absence of a common methodology to evaluate the value of waste heat;

- The low temperature of most urban waste heat sources (and hence low value);
- The competition with incentives for renewables and CHP.

From the stakeholder analysis it became clear that the utilisation of urban waste heat as a heat source for district heating is still very uncommon. The economics of heat recovery are often poor, due to a combination of the low temperature of the heat, the relatively high costs of the required technologies such as heat exchangers and heat pumps, especially compared with other heating technologies. The fact that the profitability of urban waste heat recovery (WHR) projects is often poor reflects how important it is to take non-financial benefits equally into account when evaluating an investment, which highlights the role of the public sector in making urban WHR projects feasible. Another aspect that is important for projects to succeed is that the continuity of both the heat supply and the demand are ensured, to reduce the investment risks.

**Country-specific findings on barriers and ways forward**

***Sweden*** - Limited experience, low number of suppliers, difficult to match a waste heat source with users. Lack of economic incentives. Tax incentives for data centres could be adjusted to promote the use of waste heat using heat pumps.

***Romania* –** The need for feasibility studies was emphasised, which could be combined with the introduction of economic incentives. From the consumer's point of view it is important that the continuity of the heat source is ensured contractually.

***Italy*** – For investors the complexity of urban WHR projects compared to other low-carbon technology investments, combined with the need for maintenance, often leads investors to invest in other technologies. Furthermore, the lack of a legal framework and economic incentives was mentioned as a barrier.

***Spain -*** In Spain, investments in WHR are often not profitable for existing heating networks, due to the low costs of fuels used in the existing heat supply installations. Furthermore, the relatively low heating demand makes it more difficult to earn back investments. Changes in the policy framework are required to make investments in urban WHR projects attractive, e.g. through changes in the energy taxation scheme or through the introduction of incentives.

***France*** – A lack of expertise on verification, measurement and proper estimation of the heat resource is mentioned as an important barrier, as uncertainty about the quality of the heat resource often prevents investments from taking place. The "Fond chaleur" (Heat fund) can in principle be used by project developers of WHR projects, although it does not specifically address urban WHR. Independent studies on project feasibility can be supported too. Directions for possible policies include: an obligation to assess waste heat recovery potentials, a guarantee fund for waste heat recovery projects amongst others.

***Germany* –** The required technologies often have high investment costs compared to other sustainable heating technologies. The German tax system was also perceived to be prohibitive to the investment in WHR projects. It was also mentioned that a mapping exercise to identify relevant urban waste heat sources is needed, to identify WHR opportunities. Electricity price components need to be lowered, to incentivise the use of heat pumps for low-grade heat upgrading. The recently introduced German Wärmenetz 4.0 instrument, was the only instrument identified in the study that explicitly targets low-temperature DH investments. Still, local economic incentives are needed as well.

***Denmark*** – There is already experience with several projects that implement urban WHR as a heat source for DH. The two most important barriers mentioned for implementing such projects were the fact that waste heat suppliers often want to make a profit on the heat sales, which is not always in line with the value of the heat. Secondly, the current tax system is perceived as a barrier.

***Belgium*** – Smaller projects are less attractive to invest in for banks. Project developers often do not provide the correct information to the bank, with too much focus on technical details and too little information on existing experience with comparable projects. Gas-based heating is very dominant in the country and the existing infrastructure and low gas prices are a barrier to DH development. Also, high taxes on electricity present a barrier.

## 11.2. Hydrogen and e-fuels

**The National Hydrogen Strategy [Germany] (BMWi 2020)**

***Overview***

With the National Hydrogen Strategy published in 2020, the German government aims at developing a coherent framework for the generation, transport and use of hydrogen. The strategy summarises the status quo of hydrogen use in Germany, outlines the governance for the national hydrogen strategy and develops an action plan covering the following elements:

- Hydrogen production
- Fields of application
- Infrastructure/supply
- Research, education, innovation
- Need for action at European level
- International hydrogen market and external economic partnerships

***Hydrogen production***

- In addition to the adopted carbon pricing scheme starting in 2021, the government will explore the possibility of additional reforms of the price components induced by the state in order to ensure a viable business environment for companies operating plants for the production of green hydrogen in Germany (e.g. exemption for electricity used for the production of green hydrogen from taxes, levies, and surcharges, in particular from the EEG surcharge).
- Explore possibilities for new business and cooperation models for operators of electrolysers and for grid and gas network operators in line with the principle of regulatory unbundling (results expected in 2020).
- Support the switchover to hydrogen in the industrial sector by providing funding for investments in electrolysers (implementation starts in 2020). Exploration of potential tendering schemes for the production of green hydrogen, e.g. to help decarbonise the steel and chemical industries.
- Development of framework for supporting offshore wind as a key technology for the production of green hydrogen, e.g. designation of additional areas that can be used for offshore production of hydrogen/PtX, the infrastructure necessary for this, and the potential for additional auction rounds for the production of renewables.

***Fields of application (heat)***
The German Hydrogen Strategy covers measures in the fields of transport, industry and heat, where priority is given to fields in which the use of hydrogen is close to being economically viable in the short or medium term, in which no major path dependency is being created, or in which there are no alternative options for decarbonisation. The present summary only focuses on the measures proposed in the heat sector.

- Continuation and possibly expansion of Energy Efficiency Incentive Programme for highly efficient fuel-cell heating systems (in place since 2016).
- Exploration of possibilities of providing funding for ‘hydrogen readiness’ installations under the Combined Heat and Power Act.

***Infrastructure/supply***
The strategy includes several measures addressing the adaption of existing infrastructure and initiating the construction of new elements of the supply infrastructure:

- Assessment of the need for long-term action within the transformation process together with the relevant stakeholders, both for dedicated hydrogen infrastructure as well as parts of the natural gas infrastructure that can be adjusted and backfitted to make it $H_2$-ready. Preparation of regulatory basis for the construction and expansion of a hydrogen infrastructure.
- Continuing efforts to better link up the electricity, heat, and gas infrastructure, considering the potential of the existing hydrogen infrastructure whilst also ensuring its compatibility in the EU context.

***Research, education, innovation***
Creation of new funding initiatives for research and innovation along the entire hydrogen value chain, in particular within the 7th Energy Research Programme. Key measures are:

- Development of a roadmap for the German hydrogen industry together with the science and business communities and civil society

- Setting up demonstration projects on green hydrogen with the help of research being conducted into international supply chains, including the development of supply and technology relations, testing of robust and modular solutions globally, inclusion of production sites located in the partner countries under the German development cooperation.

- Cross-ministry research campaign entitled ‘hydrogen technologies 2030’ as strategic bundling together of research activities into hydrogen-related key-enabling technology, including the following elements: 1) ‘regulatory sandboxes for the energy transition’ that aim to bring up PtX technologies that are close to market to an industrial scale and accelerate the process of innovation transfer; 2) Large-scale research projects entitled ‘hydrogen in the steel and chemical industries’, paving the way for climate neutrality; 3) Feasibility studies and atlases of potential to help pinpoint economically suitable global locations for a future, green hydrogen industry, taking into account future developments of energy needs and of the natural resources available in the various countries; 4) International networks and R&E cooperation to prepare new markets for German technology exports; 5) Establishment of a new research network on hydrogen technologies to foster networking and an open dialogue between business and science that can inform public funding policy.

- Development of a pro-innovative framework paving the way for the market entry of hydrogen technologies, including assessments of measures such as research and experimentation clauses that could test the market entry of hydrogen technologies and facilitate their transfer into practice. In this context, a pioneering project for scientific policy advice is to be set up with the aim of laying the basis for practical work to further develop the national and European legal framework to allow for a large-scale roll-out of applications for the production, storage, transport, and use of hydrogen and for related business models that are economically viable. This includes the development of a quality-assurance infrastructure that meets all the security requirements, complete with an assessment of the systems’ and installations’ efficiency, and of a billing system that is in compliance with calibration law and is based on reliable metering procedures. Any obstacles existing under the national or European legal framework must be identified and proposals for its development made.

- Fostering education and vocational training nationally and internationally: Imparting knowledge and skills to the staff that are to produce, operate, and do maintenance work in fields where hydrogen has so far played no more than a minor role; Cooperation between training and research, for instance by setting up centres of excellence at non-university research institutions and institutes of higher education; Work with export markets to foster cooperation on vocational training and strengthen efforts for capacity building with special programmes, for instance for PhD students.

***Need for action at European level***
The strategy highlights the intention of making use of the German EU Council Presidency in the second half of 2020 to proactively progress key hydrogen-related dossiers, e.g. in the context of the preparations for the legislative package on sector coupling and gas market design, including the Hydrogen Action Plan and the strategy on Smart Energy System Integration.

- Set reliable sustainability standards and develop quality infrastructure for green hydrogen and its downstream products at European level, including support for the development of European regulations, codes and standards in the various fields of application. In parallel to this, Germany plans to intensify the dialogue on common standards with other countries to pave the way towards a universalisation in international organisations.

- Intensify investment in research, development and demonstration of green hydrogen at EU level, e.g. by creating a new Important Project of Common European Interest (IPCEI) for the field of hydrogen technologies and systems as a joint project with other Member States, focusing on the entire value and use chain for hydrogen (generation, transport, distribution, use).

- Support for the drafting of the EU Hydrogen Strategy

- Explore the possibility to establish a European hydrogen company to promote and develop joint international production capacities and infrastructure.

***International hydrogen market and external economic partnerships***
The strategy outlines measures to build up and intensify international cooperation on hydrogen at all levels, both for the development of hydrogen technologies and markets and for possibilities and opportunities to convert production and the export of fossil fuels to hydrogen. The following measures are specified:

- Integration of hydrogen into existing energy partnerships and the establishment of new partnerships with strategic exporting and importing countries
- Progress the cooperation with partner countries in the context of a hydrogen alliance along the entire value chain in coordination with EU initiatives.
- Strengthen the existing international activities, particularly in the context of the energy partnerships and of multilateral cooperation, such as that of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA). Compilation of atlases of potential for the generation of green hydrogen and its downstream products to help with the identification of future countries of destination and opportunities to export installations.
- Pilot projects in partner countries to explore whether and how green hydrogen and its downstream products can be produced and marketed on a sustainable and competitive basis.
- Intensify dialogue with current exporters of fossil fuels with a view to a gradual global energy transition including hydrogen.

## Hydrogen: a renewable energy perspective (International Renewable Energy Agency 2019)

***Summary and main findings***
This report provides an in-depth perspective on the nexus between hydrogen and renewable energy, on hydrogen supply economics in light of the rapidly falling cost of renewables and the role of hydrogen in the energy transition towards decarbonisation. The existing challenges that have hindered hydrogen development to date are reviewed and provide guidelines for strategic considerations and future hydrogen commodity trade.

***Current situation of hydrogen***

- Today, further acceleration of efforts is needed to ensure a significant share of hydrogen in the energy systems in the coming decades.
- In recent years, two key developments have boosted hydrogen use: (i) the cost of renewable hydrogen supply has decreased; and (ii) the urgency of greenhouse gas emission mitigation has increased.
- As a consequence, the automotive industry, energy-intensive industries, trucks, aviation, shipping and heating applications have shifted their interest for decarbonisation towards hydrogen.
- Ensuring a low-carbon, clean and affordable hydrogen supply is essential.
- ***Hydrogen sources:*** (i) fossil fuel-based hydrogen (grey hydrogen); (ii) fossil fuel-based hydrogen production with carbon capture, utilisation and storage (blue hydrogen); and (iii) renewable hydrogen (green hydrogen).
- Green hydrogen is expected to grow rapidly in the coming years. Today it is technically viable and is quickly approaching economic competitiveness, driven by the drop in costs of renewable power and by systems integration challenges due to rising shares of variable renewable power supply.
- Blue hydrogen has some attractive features, but it is not carbon-free and public acceptance can be an issue. If used for global hydrogen commodity trade, transparency on verification and certification to account for non-captured $CO_2$ emissions and retention of stored $CO_2$ will be crucial. Although blue hydrogen may serve as a transition solution, this poses challenges in terms of production upscaling and supply logistics.

- Currently, the efforts are on reducing electrolyser costs and supply chain logistics. Electrolysers are scaling up quickly, and their costs are expected to decrease by 50 % by 2040 - 2050, becoming soon the cheapest clean hydrogen supply option. However, no radical technological breakthroughs are expected.
- Synergies may exist between green and blue hydrogen deployment.

***Barriers***

- A hydrogen-based transition will need time and a dedicated new supply infrastructure.
- Hydrogen supply costs per energy unit are 1.5 to 5 times those of natural gas.
- Currently, significant energy losses occur in hydrogen production, transport and conversion.

***Policies and strategy***

- Hydrogen should not be considered as the only solution, but instead, a complementary solution with electrification for countries with ambitious climate objectives.
- Decarbonisation of a significant share of global emissions will require green and blue hydrogen.
- Policy makers should create legislative frameworks to facilitate hydrogen-based sector coupling, utilising the synergies between hydrogen and renewable energy. Hydrogen can increase renewable electricity market growth, broaden the reach of renewable energy to industry, and be used for seasonal energy storage.
- Existing hydrogen pipelines may be refurbished for hydrogen transport, thus reducing investment cost.
- It is unclear if the solution is a radical natural gas replacement or gradually introducing mixtures of hydrogen.
- The trade of energy-intensive commodities produced with hydrogen (e.g. ammonia) needs to overcome cost and efficiency barriers.

## Spatially Resolved Optimization for Studying the Role of Hydrogen for Heat Decarbonisation Pathways (Jalil-Vega and Hawkes 2018)

***Summary and main findings***

- An optimisation approach to investigate the role of hydrogen networks in heat decarbonisation pathways through 2050
- Two case studies: (i) with independent hydrogen network, (ii) by retrofitting the gas network into hydrogen
- Best pathway for average hydrogen price: heat networks supplied by a combination of district-level heat pumps and gas boilers in the domestic and commercial sectors and hydrogen boilers in the domestic sector
- Best pathway for low hydrogen price: retrofitting the gas network into hydrogen, replacing gas by hydrogen boilers in the commercial sector and a mixture of hydrogen boilers and heat networks supplied by district-level heat pumps, gas, and hydrogen boilers for the domestic sector.

***Approach***

- Modification of HIT model (mixed integer linear program that minimises total system cost for investment and operation of heat and electricity supply technologies and infrastructure).
- Region spatially disaggregated in zones.

- Inputs: heat and electricity demands; gas, heat and electricity network infrastructure costs, heat supply technology parameters, fuel, electricity and carbon prices
- Outputs: size and location of heat supply technologies, operation in each time slice, electricity generation/consumption.

***Decarbonisation strategies***

- Independent hydrogen network: gas boilers replaced in time by heat exchangers and air-source heat pumps. No participation of hydrogen technology in the commercial sector.
- Retrofitted gas network: no contribution of gas boilers by 2050.
- Most district heat networks are supplied by a combination of natural gas district boilers and district-level air source heat pumps. No hydrogen boilers are observed, showing that the lower hydrogen carbon emissions do not offset its higher price compared to natural gas.
- Cost-effective decarbonisation pathway is achieved by a mixture of energy carriers and heat supply technologies.

**Potential for hydrogen and Power-to-Liquid in a low-carbon EU energy system using cost optimization (Blanco et al. 2018)**

***Summary and main findings***

- Objective: evaluate the Power-to-X options and integration between sectors and the optimal capacities needed to achieve a low-carbon system.
- The current EU policy framework does not hinder hydrogen development, but it does not provide strong support either.
- Competition between all sectors (residential, commercial, industry, power and transport) for hydrogen use, and between alternative sources of fuel (e.g. hydrogen, methane, XtL,[7] electrofuels and biofuels) is considered.
- The three largest drivers for hydrogen are limitations on $CO_2$ storage, low biomass potential and low technology cost.
- Hydrogen complements electricity as a main energy carrier and enables the downstream liquid production through PtL.
- Hydrogen use grows as more constraints are added to the system.
- PtL acts as a complement to biofuels rather than a competing alternative.

***Approach***

- Inputs: demand for services and materials, fuel prices, technology costs, efficiencies and lifetimes, technologies' evolution over time, maximum flows for all energy sources for each country, associated mining costs for fossil fuels for each country, interconnection between countries.
- Software: TIMES (The Integrated MARKAL-EFOM System)
- Includes: investment, fixed, annual, decommissioning and operational cost, and taxes, subsidies and salvage value in the objective function.
- Each process is represented by its efficiency (input-output), cost (CAPEX and OPEX) and lifetime.

- Several policies are included: $CO_2$ tax, technology subsidy, regulations, targets, energy efficiency, feed-in tariffs, emission trading systems and energy security
- 23 possible scenarios from combination of fuels (methane, biomass, coal, electricity), technologies (reforming, gasification, electrolysis and variations therewith and carbon capture), size (centralised, decentralised) and storage alternatives (underground, centralised and distributed tank)
- 4 delivery options: hydrogen compression, transmission, natural gas blend, or liquefaction

***Decarbonisation strategies***

- Policies should target hydrogen distribution, besides mere production.
- Action is needed to cover applications like steel and heavy-duty transport, and close the gap in deployment.
- Without applying further regulatory instruments, $CO_2$ storage would prolong the use of fossil fuels.
- Policy adoption on $CO_2$ storage and biomass availability will define the future of power-to-liquid options.
- A regulatory framework needs to set targets that promote hydrogen use in various sectors.
- A specific technology subsidy scheme is needed to improve the business case in early stages, as well as initiatives with stakeholders to overcome the infrastructure barrier.
- Research and demonstration of CCS is needed.

## A review of four case studies assessing the potential for hydrogen penetration of the future energy system (Chapman et al. 2019)

***Summary and main findings***
This study reviews four case studies assessing the potential for hydrogen penetration in the future energy system. The future potential of hydrogen as an energy carrier and future areas of research to help lower economic barriers for hydrogen adoption are assessed. Simulation models were used to investigate four case studies that provide a global view augmented with specific national examples.

***Current situation of hydrogen***
Hydrogen is an energy carrier that allows the decarbonisation of transport, industry, and space heating as well as storage of intermittent renewable energy generation.

***Case studies***
Four case studies were selected to exploit existing data while providing a global view augmented with specific national examples, and provide guidance for a future research roadmap to lower the development cost.

- *Case 1 - Global energy model:* assesses the potential penetration of hydrogen in a global energy system model if it is used only for fuel cell vehicles, as a city gas alternative, co-firing in natural gas-fired power plants, and methanol production.
- *Case 2 - Social welfare economics evaluation:* focus is on the social cost of the emitted carbon (SCC), and the impact on climate change if hydrogen could be efficiently produced from nuclear energy, renewable energy, or fossil fuel plus carbon capture and storage systems.
- *Case 3 - Hydrogen as an energy carrier for road vehicles in US:* analyses the use of hydrogen to cover existing energetic requirements for road vehicles and transportation sector, defining requirements if hydrogen was produced via electrolysis using renewable energy resources.
- *Case 4 - Decarbonising the gas grid using hydrogen*: accounts for the introduction of hydrogen for heating of the households in UK, where so far the main focus has been on the electrification of heat.

***Main findings***

- Hydrogen has the potential to account for approximately 3 % of the global energy consumption by 2050.
- The increasing use of hydrogen can provide significant energetic benefits while decarbonising the global energy system.
- In the US, using hydrogen for road transportation would result in a reduction of waste energy of nearly 10 % and a 30 % reduction in $CO_2$ emissions.
- Hydrogen might provide the least cost alternative to decarbonise space heating in the UK.
- With the current levels of technological maturity, the implementation costs remain still a significant barrier for the transition to a hydrogen economy.
- Implementation costs come largely from two sources: (i) the cost of producing, storing, and transmitting hydrogen is high, and there is still potential for significant cost reduction in these processes; (ii) the transition to hydrogen will require a dedicated effort to construct new hydrogen infrastructure, being a significant challenge in infrastructure projects globally.
- The widespread abandonment of nuclear power, considering it a prominent carbon-free energy source from the global mix and a source for large-scale production of hydrogen, can impose a significant challenge for investment in alternatives.
- If fuel cell vehicles penetrate the market as identified, and city gas can be replaced with hydrogen there is a potential to account for approximately 3 % of energy consumption from hydrogen by 2050 in the OECD nations.

## Trends in design of distributed energy systems using hydrogen as energy vector: A systematic literature review (Fonseca et al. 2019)

***Summary and main findings***

This study presents a systematic literature review of distributed energy systems involving hydrogen as energy carrier. The study comprises a mapping of energy sources, a detailed revision of hydrogen-related technologies, the identification of hydrogen end-uses, and the objectives evaluated during the design, plan and operation of systems using hydrogen, with the aim of identifying how hydrogen is used and which criteria (i.e. economic, technical, social and environmental) are evaluated in the literature. The results constitute baseline information that can be used for the preliminary stages of research and project planning of distributed energy systems involving hydrogen.

***Main findings***

- A significant interest on the transformation of energy systems has emerged as the result of the need to develop an energy framework independent of fossil fuel reliance, the concerns about climate change and air quality, and the need to extend the supply of electricity.
- The deployment of power plants located close to end users and using multiple energy sources and carriers, and the increasing share of renewable energies, suggest the need for the design of distributed energy systems.
- Designing distributed energy systems is challenging due to the simultaneous goals and constraints to be considered, the incorporation of different energy carriers, and the establishment of the relationships and inter-dependence level among them.
- In the design, plan or operation of hydrogen-based distributed energy, different scales of the application cases are considered (e.g. household, neighbourhood, buildings, universities, current power plants).
- When it comes to technologies, electrolysers are prevalent over fuel cells, although reforming, gasification and methanation processes have also been studied.

- The installed capacity of electrolysers is larger than for fuel cells.
- For small systems (<20 kW), the size of electrolysers is more influenced by the intermittence of renewables and therefore a higher capacity with respect to the peak demand may be required.

***Strategies for the future***

- A more integrated approach, including all the hydrogen supply chain stages and project stakeholders, is needed to address issues like the energy system's safety, which may generate consumer rejection.
- Most of the publications have considered the application of hydrogen as a storage medium for mitigating renewable production fluctuations. However, the hydrogen use as fuel in cars, scooters, boilers or combined heat and power units (alone or in blend with natural gas), and as raw material for the industry have also been addressed.
- The design and analysis of distributed energy systems including hydrogen has been predominantly focused on techno-economic issues.
- There is a lack of approaches including data uncertainties for weather conditions, prices and demands. As a consequence, future work to include social aspects, and considering specific context conditions (e.g. sources availability, weather) and the uncertainty of model inputs should be explored in order to improve the decision-making process for planning this type of energy system.

## Handbook of Climate Change Mitigation and Adaptation, Second Edition. Ch. Power-to-gas (Chen et al. 2017)

***Summary and main findings***

This chapter presents an overview of the storage technology 'power-to-gas' for the decarbonisation of all energy sectors. Power-to-gas and power-to-x enable decarbonisation by neutralising the $CO_2$ footprint of all energy services. Renewable electricity converted into chemical energy carriers can use the existing vast fossil infrastructure with sufficient storage and transport capacities. A technical pathway of decarbonisation including costs is described for Germany and necessary policy frameworks are derived.

***Storage technologies***

- All flexible energy systems need storage for energy security and to match the consumption loads, especially when renewable resources need to be integrated.
- Each energy transition requires a storage transition.
- Charging, storing and discharging can happen in one system, or be distributed to different sectors.
- Among energy storage options (electrical, electrochemical, chemical, mechanical and thermal) thermal energy storage is still the cheapest option, but it is not suitable for electricity storage.
- Pumped hydro, batteries, and compressed air can be used as infrastructure to store wind and solar power.

***Power-to-gas***

- Power-to-gas (producing hydrogen or synthetic natural gas from water electrolysis by using electricity) is a type of chemical storage, which is more cost-efficient than batteries.
- In the methanation process, $CO_2$ is consumed as a reactant, which ideally can come from residual biomass or residues as biogenic sources (biological methanation). The exhaust heat from the process can be used to increase efficiency and improve the carbon footprint. Methane is easier to store, compress and transport, but this process requires additional energy.

- Admixture of up to 1.5 % hydrogen in natural gas is possible, without needing further research needs and equipment adjustment requirements.
- In deficit times due to fluctuating renewable energy, hydrogen can be converted to electricity via especially adapted gas turbines.
- The efficiency of pure Power-to-gas hydrogen storage systems is 5–12 % higher than with methanation.
- Coupling of the power and gas grid makes storage of great volumes of energy possible and allows for the spatial separation of storing and usage of renewable methane.

***Decarbonisation strategies***

- Infrastructure for the generated gas includes aboveground storage (short-term buffer), underground storage, and salt caverns (long term). These are technologically ready for all sectors (i.e. completely developed for methanation, and some existing for hydrogen that may need further development).
- Supporting policies should remove subsidies for fossil energy and market barriers for new technologies, interlink the electricity, gas, heat, and transport sectors, merge energy markets via energy storage and energy transmission, and build up strategic renewable reserves and limited tax exemptions. Storage or electromobility should be cross-financed with $CO_2$ funds, fossil fuel savings, and cheap renewables.
- Power-to-Gas and Power-to-X are essential technologies that save costs by using existing fuel storage and transmission infrastructure, and are essential to decarbonise electricity, heat and the chemical industry.
- Policy makers need to make society aware of the need of an energy transition including storage.

## 11.3. Sector integration

**Sector Coupling in Europe: Powering Decarbonisation (Bloomberg Finance L.P. 2020)**

***Summary***

The report examines the impact of sector coupling on the power system. First, a possible path for sector coupling in "northern European archetypes" until 2050 is described. Then, based on this path, the implications of sector coupling for the electric system are analysed. Finally, the report identifies how policymakers and regulators might address some of the biggest challenges related to sector coupling and its impact on the power system.

***Main findings***

The described pathway for sector coupling in "northern European archetypes" until 2050 shows the following results:

- The described scenario shows that the electrification of transport, buildings and industry would make a significant contribution to climate goals. Electricity could supply a significant share of the energy consumed in Europe by 2050, displacing fossil fuels. Emissions from transport, buildings and industry could be reduced by 60 % over the period 2020-2050 through sector coupling.
- Sector coupling is a huge undertaking that will not succeed without policy action. For successful sector coupling, incentives are needed to reduce emissions, early efforts must be supported, and a market for green hydrogen must be created.

The main findings related to the impact of sector coupling on the power system are as follows:

- Increasing electricity demand due to sector coupling requires a much larger power system.

- Due to the coupling of the transport and building sectors, the intraday and seasonal load profiles will become higher and steeper. These changes require a more flexible power system. However, sector coupling will also create new sources of flexibility.
- How the power grid-related issues are handled is critical to the success of sector coupling.
- As more hydrogen produced by electrolysis is fed into the gas grid, the electricity and gas systems become more integrated.
- Energy consumers and civil society will play a key role in enabling smooth sector coupling for the power system. Their commitment and participation cannot be taken for granted.

The key findings related to the decisions of policymakers and regulators are as follows:

- Flexible electricity tariffs lead to minimisation of net peak demand. Policymakers must ensure the availability and acceptance of flexible electricity tariffs that provide strong incentives for all consumers.
- Government support and regulatory changes are needed to ensure that the electric grid can handle the impacts of sector coupling.
- Regulators and policymakers play a crucial part in facilitating the integration of electricity and gas systems.
- Policymakers will likely need to modify capacity mechanisms or create additional revenue streams to maintain the pace of power system decarbonisation.

**Sector coupling: how can it be enhanced in the EU to foster grid stability and decarbonise? (Trinomics 2018a)**

***Overview***
The study focuses more broadly on sector coupling (SC) including opportunities for SC, ways in which SC can be achieved and barriers and bottlenecks to SC. In this study, SC is considered from both the end-use perspective (e.g. coupling of sectors such as heating and transport) and the supply-side coupling (e.g. integration of electricity and gas sectors through e.g. power-to-gas technologies). Two sections of the report are relevant for heating: Section 2.4. discusses coupling of RES deployment to the energy demand for H&C in buildings. Section 3.1.2. briefly addresses high-temperature (HT) heat demand in industry.

***Solutions for space heating***
The paper identifies two main solutions to decarbonise energy consumption for heating:
a) end-use sector coupling through heat pumps and (to a lesser extent) electric boilers and
b) cross-vector integration through the production of hydrogen and synthetic methane, which can be used for heat production in CHP for large buildings or district heating, or hybrid heat pumps or gas boilers in individual buildings.

The two solutions can be complementary (e.g. heat pumps and RE district heating with a CHP installation; the former can operate during times of low electricity prices and the latter during high electricity prices). Combining power-to-heat options (heat pumps and electric boilers with heat storage) allows for producing heat when electricity is available in excess.
The most cost-effective decarbonisation technology depends on local conditions, such as the climate.

***Solutions for high-temperature heat demand in industry***
Technology solutions mentioned to decarbonise high-temperature (>200°C) heat include electric boilers for the combustion of biomass, renewable methane or hydrogen in industrial boilers. Heat pumps for HT energy use are being developed but are not commercially available at the moment.

***Seasonal energy storage***
Hydrogen and synthetic methane can be a solution for seasonal energy storage allowing for usage of abundant solar energy in summer and reducing the peak electricity demand in winter.

## Decarbonising the EU heating sector: Integration of the power and heating sector (Kavvadias et al. 2019)

***Overview***
The report focuses on the integration of the heat and power sectors and how such an integration can contribute to the energy efficiency and climate change mitigation targets. It presents a detailed analysis of the energy breakdown by types of use and fuel shares in the heating sector, costs, efficiencies, emissions, and their links to the power system. The study focuses on two main energy transition pathways: 1) electrification of heat and 2) centralised co-generation and district heating networks. The option of using renewable and low carbon gas is acknowledged but not further examined in this report.

***Findings and conclusions***
An analysis of the electrification of heat pathway finds that:

- Replacing all fossil-based heat generation technologies by heat pumps overnight would result in a 16 % reduction of emissions in the EU from the heat and power sectors combined. Percentages per Member State range from 65 % (FR) to 4 % (PL, EE) depending on the current and projected mix in the power and heat sector.
- Without additional “clean” capacity, the additional electricity demand for heating will likely come from dispatchable sources, which usually have higher emission rates compared to the average electricity generation mix. In a future, decarbonised power system the emission reduction gains could amount to 25 % even without considering additional clean capacity.
- Replacing all fossil-based heat generation technologies by heat pumps overnight would represent an additional 26 % of the total electricity demand, representing 526 TWh. The increase in winter peak demand could range between 20 % and 70 % with an average of 41 %.
- Firm power capacity of the current power system starts to become inadequate for electrification rates above 32 %, representing about a 60 % replacement of fossil-fuel heat. Beyond this threshold, flexibility measures will play a more relevant role.

An analysis of the centralised co-generation and district heating pathway finds that:

- The present power plant fleet could satisfy 58 % of the European space heating demand. The utilisation of this CHP could result in the reduction of costs of the total energy system by 17 % and 20 % for current and future scenarios respectively.
- The overall efficiency of the energy system would increase significantly if all current and future steam-based power plants were to operate in CHP mode connected with district heating networks. Efficiency gains could be as high as between 63 % and 76 % in the current scenario and between 73 % and 80 % in the future scenario.
- Operating thermal power plants in CHP mode increases the curtailment of renewable energy by ~ 1 to 9 % for the current scenario and 6 to 10 % for the future one. This could be alleviated by enhanced interconnections or storage capacity.

## Influence of heat pumps on renewable electricity integration: Germany in a European Context (Bernath et al. 2019)

***Summary and main findings***
This study assesses how heat pumps in district heating grids contribute to renewable electricity integration. The study considers interdependencies with other sectors such as the heating and transport, techno-economic optimisation model that minimises the costs of generation, transmission and storage of electricity for Europe. The energy system in Germany is examined in three scenarios in a European context for the year 2050. A sensitivity analysis of $CO_2$ and gas prices complements the analysis.

***Methodology***

- Enertile (Fraunhofer Institute for Systems and Innovation) provides an integrated modelling approach to the electricity and heating sectors, considering decentralised heat pump systems and district heating grids with multivalent heating.
- The Enertile model optimises capacities and dispatch of electricity and heat generation simultaneously, considering the interdependencies between heating and electricity generation. It has an hourly resolution which makes it possible to consider fluctuating renewable electricity generation.
- The modelled regions include all Member States of the European Union, plus Norway and Switzerland, and countries in North Africa and the Middle East.
- The objective function contains all costs incurred by the major infrastructures: conventional power plants, renewable energy technologies, combined heat and power, cross-border transmission capacities, storage technologies, and centralised heating technologies in heating grids.

***Constraints/Hypotheses and scenarios***
The study assumes that demand of electricity, heating, and hydrogen in every region is met at all times, decentralised heat pump systems are modelled as buildings with defined demand, a heat pump, and storage, unlimited electricity exchange is possible.

***Scenarios***

- GERMANY scenario: Germany in isolation without considering its neighbouring countries.
- EUROPE scenario: Germany in a European context integrating industrial heating grids.
- EUROPE LIMITED: scenario restricts network expansion for cross-border transmission capacities

***Strategies***

- Reducing $CO_2$ emissions requires the substitution of fossil fuels with renewable energies.
- Replacing fossil fuels in electricity production reduces the $CO_2$ intensity of electricity generation, and in turn, sector coupling provides additional flexibility by fostering the integration of renewable energies for other processes.
- Heat pumps play a major role in the investigated range of fuel and $CO_2$ price developments.
- It is concluded that the higher the achieved levels of decarbonisation and renewable electricity, the more competitive heat pumps become in heating grids.
- Considering other flexibility options such as industrial heating grids, electric mobility and hydrogen production could reduce the contribution of heat pumps to the integration of renewable energies.
- Heat sources like industrial waste heat or underground sources can enhance the application of heat pumps.
- Renewable heating technologies (e.g. geothermal, solar thermal energy) are main competing technologies.
- When limiting the modelled region or the grid expansion, the share of heat pumps decreases as it becomes more difficult to exploit the potential of low-cost renewables.
- The higher the achieved levels of decarbonisation and renewable electricity, the more competitive heat pumps become in heating grids.

## 11.4. Gas infrastructure

## The role of trans-European gas infrastructure in the light of the 2050 decarbonisation targets (Trinomics 2018b)

***Overview***
This study analyses and summarises existing **European and non-EU decarbonisation storylines** which depict possible futures for the trans-European gas infrastructure up to 2050. On this basis the authors **developed 3 own storylines**: (1) "Strong electrification" (2) "Strong development of methane (CO2-neutral)" and (3) "Strong development of hydrogen".

All three storylines predict a **decreasing gas demand for heating** (-50 % and more) due to significantly enhanced building insulation**.** In (1), most of today's gas-based heating systems are substituted by more efficient **all-electric heat pumps** or by **district heating systems.** Large parts of today's heating related gas infrastructure are **decommissioned** in this storyline. In storylines (2) and (3) a strong electrification in heating is foreseen in households not connected to gas distribution grids today. Even though the overall amount of gas needed for heating and flowing in the grid is reduced, the number of users stays almost constant and gas grids are further used. In (3) the substitution with **hydrogen** is more complex and **requires the adaption of the distribution grids as well as the conversion of end user equipment.**

***Assessment of existing storylines***
Focusing on heating related gas infrastructure, most storylines predict a **decreasing gas demand for heating** due to significantly **enhanced building insulation** and the substitution of most of today's gas-based heating systems by more efficient **all-electric heat pumps** using ambient, low-temperature heat and electricity or by **district heating systems** based on renewable heat. However, both, the assumptions and the results on the share of gas-fueled technology versus electricity-based technologies in the heating sector vary widely across storylines.

Overall, for the whole energy system, the analysed storylines do ascribe a **future key role to gas infrastructure** due to its ability to store and transport energy **efficiently, at large scale, over long periods of time, and flexible** to varying demand.

The study does emphasise that many storylines point to the fact that **structural differences** develop between energy systems designed with a -80 % GHG reduction ambition (often still a lot of natural gas in use) and with a -95 % ambition (less importance of gas). **Many solutions for -80 % may not be viable for a simple extrapolation to -95 %**.
Moreover, the authors state that a **one-size-fits-all solution for all Member States seems unlikely**. While some EU countries pursue approaches and policy priorities that aim at **decarbonising the gas grid** by 2050, others still focus mostly on **security of supply for natural gas** and a **substitution of coal by fossil natural gas** to reduce CO2 emissions.

***Development of three own storylines***

***Storyline 1 – Strong electrification***
There is only a small role for gas. The amount of gas in the European pipeline system is **halved by 2050** compared to today. The utilizstion of the gas system drops. Significant shares of the distribution and transport grid are **decommissioned**. However, **some gas infrastructure is still crucial**, especially gas storage, transport, and re-electrification units. Gas provides a large share of the **flexible peak power production capacity** as well as **long-term and strategic energy storage**. An increased share of the gas might be **transported twice** through the system, 1) after production from renewable sources to a seasonal storage and 2) after withdrawal from the seasonal storage. The study highlights the importance of ensuring that all relevant infrastructures remain available to the energy system **throughout the transformation process**.

***H&C:***
Gas demand for heating is significantly reduced due to strong **insulation** (-50 % in average), **increased efficiency** of heat production (e.g. condensing boilers) and due to **a fuel switch from gas to electricity** for the majority of today's gas users for heating (75 % - versus 10 % today - of heating provided from electricity). Consequently, **large parts of the gas distribution grid are not in use anymore** and are **decommissioned**. Remaining gas customers will be concentrated in single **(island) grids** which were able to be kept operational as they are **located close to CO2-neutral gas sources** e.g. in rural areas with a high availability of required feedstock (e.g. biomass for methane) or close to renewable surplus electricity for hydrogen production.

Even if the gas demand of individual gas consumers decreases due to refurbishment measures, the absolute cost contribution **(grid fees)** for the low-pressure distribution grid remains constant or rises due to more or less constant total costs for the grid section. For those remaining distribution grids, **the cost spiral could be**

**stopped**, which is that high (grid) costs lead to high energy costs causing additional customers to switch fuels. The small grids will likely require **their own gas storage for short- and long-term storage** or need to be connected to a gas transport pipeline including **reverse flow technology**.

***Storyline 2 – Strong development of methane (CO2-neutral)***
In sectors such as heating and industry, gas (increasing share of (bio)methane) will be used **until and beyond 2050 widely using existing gas infrastructure**. For security of supply, **large gas storages** will be in operation, required less for the reason of seasonality (lower gas-for-heating demand and drastically increased gas demand by transport sector) but more for **provision of flexibility in electricity generation**.

***H&C:***
In the heating sector the scenario foresees a **strong electrification of buildings** (50 % of heating demand versus 10 % today). However, electricity-based heating technologies are mainly used for buildings in areas without gas grid. The relevance of **gas in the heating sector will remain strong**, at a 50 % level throughout the period until 2050.

While the overall demand of gas is halved due to increased insulation of buildings and increased efficiency of heat production, the total **number of gas users stays relatively constant**. Some new consumers (e.g. former oil heaters) are connected to the existing gas distribution grid (fuel switch), while other consumers switch to electricity. Investments into the distribution grid are limited to small adaptions and replacements. New low pressure distribution grids are not built due to missing economic feasibility due to increased insulation and low per capita gas demand. The **costs for this part of the gas grid will remain constant** as the number of users remains constant.

***Storyline 3 - Strong development of hydrogen***
This storyline depicts a rather slow growth and slow market penetration of electricity-based technologies. At the same time, hydrogen technologies are being developed with increasing speed.

***H&C:***
According to this storyline, the heating sector will undergo similar developments as in the previous storyline. Increased insulation of buildings, strong electrification of buildings without gas grid connection (50 % of heating demand), significantly reduced gas demand in the low-pressure distribution grids. The main difference is that **hydrogen will be used to substitute natural gas in the grid**. This substitution with hydrogen is more complex than with methane as it **requires the adaption of end user equipment** due to the different burning properties of the gases. It will be necessary at some point to **convert the distribution grids and the user heating appliances to hydrogen use**.

***Implications of the storylines for transmission system operators***
The study depicts, that for TSOs the **CAPEX are expected to remain at a high level in all three storylines**, due to high investments in the past which must still be depreciated to a large extent. The investment levels will slightly decline in the next decade, despite **some specific investments needed** after 2030 to **refurbish grids to accommodate H2 in storylines 1 and 3**, and for **reverse flows of renewable gas mainly in storyline 2**.

The **OPEX** is expected to **remain at a high level in all three storylines** too. These costs are mainly fixed. Falling transported gas volumes would not lead to a proportionate cost decrease.

For most gas infrastructure assets **Third-Party Access (TPAs) tariffs** apply. In storylines 1 and 3 **falling gas volumes might have an increasing impact on grid tariffs**, which might in the long term **decrease the affordability and competitiveness of gas**. Storyline 2 would probably lead to the lowest grid tariffs.

***Policy recommendations***
The study bases the following recommendations on the analysis of three national regulatory regimes (Denmark, France and Poland).

- An **EU wide carbon tax or levy on all energy uses** is suggested, as it improves the economic feasibility of renewable gas and reduces the need for specific support.
- Facilitate injections of renewable gas into the grid by more **harmonised technical specifications** and by including **priority dispatch** in national legislation.
- **Support joint initiatives to upscale** and reduce the cost of the treating of renewable gas to meet grid quality requirements.

- Implement **an EU wide system of guarantees of origin (GOs) for all types of renewable gases** to facilitate the production and trade, and to allow proper counting of the share of renewable gas in the energy mix.
- The procedure of granting GOs should **avoid double counting**, as renewable energy will be increasingly converted in subsequent processes (e.g. power to gas to power).
- **Implement longer validity periods** (today: 6 months validity after issuing) for gas related GOs for renewable gas to allow for longer storage times.
- Implement **cost-reflective and non-discriminatory grid tariffs and connection charges** e.g. only charging direct connection costs to production facilities while socialising indirect upstream investment costs.
- Policies should focus on investments in **future-proof assets avoiding devalued or stranded assets** while enabling the gradual replacement of natural gas with carbon-neutral gas.
- **Revise depreciation rules for gas infrastructure assets** to reflect specific risks due to changing gas demand and supply patterns.
- **National regulations and tariffs** for connection to gas infrastructure should be **assessed and adapted** where necessary, to facilitate the decarbonisation of the gas supply.
- **Consider cross-subsidisation or subsidies for gas infrastructure** to keep gas grid tariffs affordable. This might have **distortive impacts**. Principles of economic efficiency, transparency and non-discrimination should be accounted for.
- **Provide financial support for renewable gas only temporarily** and phase out gradually to avoid that subsidy schemes harm the competitiveness of industrial end-users exposed to international competition.

## Impact of the use of the biomethane and hydrogen potential on trans-European infrastructure (European Commission 2019)

***Summary and main findings***

This study analyses the impact of the use of biomethane and hydrogen potential on the gas infrastructure. First, the technical potentials for biomethane and renewable hydrogen within the EU are assessed. Second, three scenarios are developed, each focuses on strong end-use of one of the three energy carriers: electricity, methane, or hydrogen. The three scenarios serve to analyse the impact of increasing use of biomethane and hydrogen on the gas infrastructure. Finally, recommendations for facilitating the deployment of renewable gas are presented.

***Main findings***

***Potential availability of biomethane and hydrogen in the EU and neighbouring countries***

The technical potential for both biomethane and renewable hydrogen vary significantly by Member States. Overall, the considered scenarios in this study show that the potential for renewable hydrogen in the EU by far exceeds the gas consumption in 2050. Whereas the technical potential of biomethane is not sufficient to meet the EU's gas demand.

***Technical and economic impact of increasing injection of biomethane and hydrogen into gas infrastructure***

The implication of increasing use of biomethane and hydrogen for the existing networks vary between the three scenarios. The blending of biomethane causes hardly any technical or regulatory barriers. In contrast, hydrogen can only be fed into the existing gas infrastructure up to a certain limit. For higher feeds, new infrastructure and technical modifications are necessary. In addition, there is no consistent regulatory framework for increasing hydrogen admixture to the gas network.

From an economic perspective, the hydrogen-focused scenario achieves the lowest system costs.

***Impact of considered scenarios on TSOs and DSO***

The reconfiguration of gas flows in case of a large change in the cost of service or transported volumes would cause the most significant long-term risks to TSOs. In particular, cross-border transmission investments would lead to increasing transmission tariffs, especially if dedicated hydrogen networks need to be developed.

Gas transmission investments prior to 2030 could result in stranded assets and re-evaluations of the regulatory asset base, given the uncertainty regarding OPEX levels and regulatory framework until 2050. DSOs will face similar risks, but the magnitude of the impact will be different and vary much more across regions.

***Readiness of the regulatory regimes to support decarbonised gases***
A variety of incentives exist to promote renewable gases, but these vary widely from Member State to Member State with few addressing grid connection and access. In contrast, the planning and regulatory frameworks for gas networks in the Member States have many similarities.

TEN-E and CEF regulations have contributed to the development of well-integrated and secure gas markets.

The following changes could now be considered to better support the use of hydrogen and biomethane in gas networks:

- Update of the TEN-E priority corridors, areas and eligibility criteria for PCI and CEF
- broadening the scope to include distribution projects and those that facilitate sector coupling
- inclusion of innovation and robustness to uncertainty in the selection criteria

In addition, there is a lack of coherence between national hydrogen blending frameworks, which could hinder the development of a unified European approach and thus the cross-border transport of hydrogen.

***Recommendations of the study***
The study provides the following recommendations for facilitating the deployment of renewable gas:

- Technical standards and specifications for hydrogen introduction should be developed;
- A stepwise development of "islands" of 100 % hydrogen networks should be investigated;
- Planning for new energy infrastructure should be more integrated and clear guidance from policymakers is expected
- The TEN-E and CEF regulations should support projects that facilitate the integration of gas from renewable energy sources and contribute efficiently to the energy transition
- A regulatory framework for power-to-gas that removes barriers to investment and further considers the role of TSOs should be developed
- A regulatory framework for dedicated hydrogen networks should be established in a timely manner;
- Incentives for renewable gases are required;
- Measures to mitigate the potential negative impact of declining gas demand and changing gas flows on network operators and network users should be considered.

**The future of gas in Europe: Review of recent studies on the future of gas (CEPS 2019)**

***Overview***
The report summarises 23 recent studies on the future of gas in Europe with their different outcomes and projections for 2030 and 2050. The role of gas and gas networks for heating and cooling is not the central focus but part of the report.

***Outcomes and projections (heating and cooling)***
***Building sector***

**Energy efficiency and building insulation measures** will reduce the overall energy demand and thereby the gas demand in buildings. Today, 38 % of total gas consumption in the EU is for heating buildings. Gas demand is expected to decline by 1.2 % per year on average.

According to the report, **heat pumps** are likely to be the preferred solution for heating and cooling **new buildings**, as they are more efficient than boilers, delivering up to three times more useful heat than electricity consumed.

The study considers **hydrogen and biomethane** as potential cost-efficient options for the heating systems of existing buildings, as, in some cases, the installation of heat pumps comes along retrofitting interventions with higher initial costs. However, sufficient quantities of renewable methane and hydrogen would have to be produced in order to maintain the current gas grid, which is projected to be unlikely.

Technically, hydrogen injections in the gas grid could be used in the short- and medium-term strategy to reduce natural gas consumption, while biogas and biomethane could provide an alternative to some of the methane used for heating.

According to the report, **hybrid heat pumps using both electricity and gas** could also provide competitive solutions for buildings connected to the gas grid and ensure heating during periods of peak demand on colder winter days. All these installations would need to use renewable electricity and renewable methane for their operation.
Most of today's **district heating systems** in Europe use natural gas or coal as fuel**. Hydrogen and renewable methane** for renewable gas-fired CHP plants are considered likely to compete with large-scale heat pumps, geothermal energy, biomass, and with sector-coupling solutions such as residual industrial heat.

***Industrial sector***
Electrification can be a solution for low temperature heat provision to industry. For essential high temperature heat processes, **hydrogen and biomethane** will be needed.

***Gas networks***
The **demand** for **renewable methane and hydrogen** and their **production potential** will have important implications for gas networks. Today's European gas network consists of around 260,000 km of high-pressure pipelines operated by **transmission system operators** and 1.4 million km of medium- and low-pressure pipelines operated by **distribution system operators**. As demand for gas is expected to decrease and the costs associated with the production of biomethane and hydrogen are high, **the gas network is likely to be downsized**. This smaller future grid must be capable of accepting biomethane or hydrogen, or a mixture of both. This may require adjustments or complete replacements. A likely transition that does not require major technical upgrade of the existing infrastructure would be the switch to **biomethane**. However, projections show that **insufficient quantities** of renewable methane will be produced to maintain current grid capacity. As a medium-term strategy, **hydrogen** could be **injected into the current gas grid**. However, there are limits to the extent hydrogen can be mixed with methane in the pipeline. Current research shows that blending hydrogen in small concentrations of up to **10 – 20 %** can be done safely without larger infrastructural upgrades. Regulatory standards would need to be reviewed, as for today, EU countries allow concentrations of hydrogen injections into the grid varying from 0.1 % to 12 %.

A complete switch to hydrogen would require dedicated pipelines. This would cause high additional costs. It might prove to be more cost-efficient for hydrogen applications on a local or regional basis. Furthermore, the future **potential for green hydrogen production** will be a determining factor for the extent to which long-distance networks transporting hydrogen will be developed.

As the choices which product will be transported through pipelines is likely to **be local rather than national**, and will vary across regions, the choices made by distribution companies might be the most consequential for the EU. However, as distribution networks and long-distance transmission networks are intertwined, the refurbishment of transmission grids would most probably require the refurbishment of all the distribution networks they supply.

Potential future modifications of the current gas networks are also depending on the demands for low and zero-carbon gaseous fuels in other sectors than buildings/H&C, i.e. power, industrial and transport sectors. Costs, convenience, availability, acceptability, and the infrastructure choices of the EU and its member states will likely influence the development. The report assumes **an increasingly decentralised management of distribution**.

## Gas for Climate. The optimal role for gas in a net zero emissions energy system (Navigant 2019a)

***Overview***

**When it comes to H&C**, this study for "Gas for Climate" focuses on **space heating** and excludes the potential use of renewable gas for hot water and cooling. The promoted "optimised gas" scenario for 2050 mainly suggests keeping the gas distribution network in use for all buildings connected to the grid today but changing from natural gas-powered boilers to hybrid heat pumps. These shall be running with biomethane and some hydrogen on peak demand winter days. Other buildings use all-electric heat pumps or renewable district heating. The gas grid shall be adapted for biomethane and hydrogen distribution instead of being decommissioned, with an overall saving of € 217 billion annually across the energy system by 2050 in comparison with their "minimal gas" scenario.

***Purpose and Approach***

The study's purpose was to investigate the potential role and value for renewable gas used in the existing gas infrastructure in a net-zero emissions EU energy system, compared to a scenario in which a minimal quantity of gas is being used.

Therefore, a "minimal gas" scenario and an "optimised gas" scenario were compared. Both scenarios arrive at a net-zero emissions EU energy system by 2050.

***Comparison of the "minimal gas" and "optimised gas" scenarios with focus on H&C***

***Buildings***

In both scenarios most buildings will be heated by all-electric heat pumps by 2050, and both scenarios assume increased levels of district heating.

In the **"minimal gas" scenario**, all-electric heat pumps (80 %) are complemented by district heating (20 %). As a result, electricity demand in the "minimal gas" scenario is 390 TWh, while renewable and low-carbon gas demand is zero for the space heating of buildings.

In the **"optimised gas" scenario**, all-electric and hybrid heat pumps (80 %) are the most important technologies for supplying heat in buildings, complemented by 20 % district heating. The share of hybrid heat pumps (37 %), using biomethane and some hydrogen during periods of peak demand, is restricted by the existing connections to the gas grid. The study assumes that all buildings that currently have a gas connection will still use it by 2050. New buildings (constructed between 2016 – 2050) will mostly use all-electric heat pumps and some district heating. All buildings without gas connections will switch to all-electric heat pumps or to a lesser extent district heating. The deployment of these technologies leads to a renewable gas demand of 231 TWh, from which 185 TWh is biomethane, 46 TWh is hydrogen. The demand for renewable electricity for heating in the "optimised gas" scenario lies at 399 TWh. It remains higher compared to the "minimal gas" scenario due to a lower refurbishment rate of buildings and therefore higher overall space heating demand.

***Hybrid heat pumps***

For buildings with an already existing gas connection the "optimised gas" scenario promotes the use of **hybrid heat pumps** due to the following arguments:

- They make use of the existing gas infrastructure, reducing the required expansion of electricity grids. This makes their introduction fast and cheap.
- They deliver peak demand at limited additional cost as the equipment is relatively low cost, because the expensive part of the heat pump capacity is replaced with low-cost gas boiler capacity.
- They require less consequent insulation of buildings compared to all-electric heat pumps, which leads to high cost savings per unit of energy.

The application of hybrid heat pumps does not necessarily require deep insulation of buildings, which leads to decreased insulation costs (€ 21 billion until 2050). However, this leads to higher total energy demand in 2050 (1,026 TWh) compared to the "minimal gas" scenario" (787 TWh).

***Biomethane***

In the "optimised gas" scenario, the heating of buildings with an existing gas connection will mainly be done with biomethane. The scenario foresees 228 large-scale thermal gasification plants generating about 1/3 and 31,000 small biogas digesters producing about 2/3. Parts of the biomethane production (~ 1/5) take place more than 15 km from the nearest gas grid. The study suggests transporting it as bio-LNG, which can afterwards be used for shipping.

***Hydrogen***
Using **hydrogen** in buildings requires **adjustments to the gas distribution infrastructure**. The necessary requirements to upgrade or replace parts of the distribution network to use 100 % hydrogen are still being assessed in several projects. In certain areas where supply of biomethane is limited, the use of hydrogen could be a viable option for the space heating of buildings. 20 % of the gas used for heating of buildings in the “optimised gas” scenario is hydrogen, either used in pure form or mixed with biomethane.

The study assumes, that **blue hydrogen** could still be in use in 2050 besides green hydrogen, as the costs could be similar by 2050. In order to replace blue hydrogen as quickly as possible with green hydrogen in the H&C sector as well, additional renewable electricity generation capacity must be constructed as fast as possible. Another option would be for policymakers to limit the use of blue hydrogen by 2050.

However, it should be kept in mind that any large scale-up of green hydrogen production prior to the moment when all direct electricity demand is covered by renewable energy will lead to an indirect increase in fossil electricity generation.

***Industrial sector***
In both scenarios, industrial **low temperature heat** will be based on direct electricity. **High temperature industrial heat** is mainly provided by hydrogen, plus some biomethane and hydrogen as industrial feedstock. In the “minimal gas” scenario 69 TWh of **biomethane** are used for high temperature industrial heat and feedstock.

In “minimal gas” green hydrogen is produced at industrial sites, not requiring gas infrastructure. In “optimal gas” green hydrogen is produced close to large-scale (offshore) electricity generation and transported to demand hubs using gas infrastructure.

***Imports***
It is considered feasible to generate all required energy in both study scenarios domestically within the EU by 2050. **Biomethane** is produced throughout the EU, so far mainly in states with a lot of woody and agricultural biomass (e.g., Germany, France, Poland, Italy, Sweden, Finland, Romania). The study expects that each Member State can produce sufficient biomethane to meet demand in buildings themselves by 2050. However, importing renewable energy is portrayed as an attractive alternative. This could include imports of solid biomass in the “minimal gas” scenario or imports of green hydrogen in the “optimised gas” scenario.

***Gas networks / Gas grid***
Gas infrastructure is currently used to distribute 20 % of EU’s primary energy consumption (5,000 TWh).

In the **“minimal gas”** scenario only small amounts of biomethane or natural gas would need to be transported to industrial sites in **transmission pipelines** for high industrial heat generation or blue hydrogen production. Most EU countries have legislation requiring the natural gas grid to be decommissioned when no longer in use. Consequently, **most of the existing gas transmission infrastructure and the entire gas distribution infrastructure would need to be decommissioned**.

In this minimal gas scenario, seasonal peaks in demand would be covered by biomass power plants.

In the **“optimised gas”** scenario, the existing **transmission** grid would be used for intra-regional and cross-border transport of hydrogen and mainly intra-regional transport of biomethane. The existing **distribution** grid would be used to distribute modest quantities of renewable gas to buildings, with high net system cost savings per cubic meter of gas. According to the study, the gas grid is very helpful in coping with **seasonal and daily fluctuations of energy demand** as there is no technical minimum threshold below which the gas network cannot be operated. For the heating of buildings some inter-seasonal storage for biomethane is needed too.
The scenario suggests **blending** methane and hydrogen in coming years while gradually creating **dedicated biomethane and hydrogen grids** via using the largest part of today’s infrastructure for biomethane and retrofitting part of the existing gas infrastructure for hydrogen with a limited need for additional hydrogen pipelines.

Due to expected high development and maintenance costs, the study does not suggest two complete parallel grids, but rather a **dense methane grid and a less dense hydrogen grid** connecting industrial areas and hydrogen fuel stations to a backbone along major routes.

***Oil pipeline system could be used to transport gas***
The 33,000 km of oil pipelines through many EU Member States could be repurposed for hydrogen transport, if no longer used for liquid oil products in 2050.

***Costs to maintain or decommission the current gas grids***
For the necessary **decommissioning** of the gas infrastructure, the study calculates costs of around **30 % of the costs initially required to build the infrastructure**. While the costs for the maintenance of the existing infrastructure, their adaptation and expansion regarding the "optimised gas" scenario would cost around 60 % more than the decommissioning by 2050, the study claims that the additional capacities needed in terms of electricity transmission and distribution infrastructure in the minimal gas scenario are higher. In addition to these lower additional energy system costs, the study stresses further non-cost related benefits of the "optimised gas" scenario namely the promotion of rural employment from additional biomethane production as well as potentially higher societal acceptance due to less necessary overhead powerlines.

## Gas for Climate. Gas Decarbonisation Pathways 2020–2050 (Gas for Climate and Guidehouse 2020)

***Overview***
This study of "Gas for Climate" builds on Navigant's 2019 study and analyses **decarbonisation pathways** from 2020 to 2050 based on the "optimised gas" scenario.

The study suggests the heating of today's buildings connected to the gas distribution network via hybrid heat pumps mainly using biomethane, while other buildings will be using all-electric heat pumps or renewable district heating. Today's natural gas grid shall gradually be developed into two separate grids for biomethane and hydrogen distribution.

***Purpose and Approach***
Gas for Climate's 2019 study pictured different options of 2050 net-zero emissions energy systems without explaining the exact path to get there. This study aims at providing such **pathways** for the transition towards a climate neutral "optimised gas" 2050 energy system including implications for the **gas infrastructure** and **policy recommendations**.

The central pathway of the study is called **"Accelerated Decarbonisation Pathway".** It is based on the EU Green Deal target of 55 % GHG reductions by 2030 compared to 1990 levels. It depicts a path, on which renewable and low carbon gases as well as todays gas grid contribute to the decarbonisation of the energy system, including the buildings sector and H&C. For this main pathway, the study assumes, that governments and companies withing the EU drive the decarbonisation, and necessary gas production can be scaled up in the EU, not depending on other parts of the world.

***Buildings***
The study refers to the "optimised gas" scenario, summarised above. It again stresses the importance of **combining the use of gas and electricity in the heating** of buildings until 2050 and beyond, as it **reduces societal cost and increases optionality**. The study suggests the use of modest electric heat pumps added to the existing gas boilers in all buildings connected to the gas grid today. With a smart control, they can be operated as **hybrid heat pumps**. As buildings get better insulated, the heat pumps take up a **higher share** of the heating. In 2050 still 37 % of the EU building stock would be heated in this manner. This would reduce insulation costs (fewer deep renovations), heating technology costs (smaller heat pumps and no low temperature floor heating needed) and would also reduce stress on the electricity infrastructure on cold winter days. The authors call their pathway "**robust"**, as the installations of the heat pumps, the insulations of the buildings, and the decarbonisation of the electricity and gas systems can take place independently.

Today's application of hybrid heat pumps is very limited. **Energy renovations are needed for almost all buildings**, even for hybrid heating solutions in order not to produce higher stress on the energy infrastructure. The refurbishments need to happen at a **higher annual renovation rate than today's 1 %**. Increasing the renovation speed and depth after 2030 to compensate for the lack of renovations before 2030 will be very challenging.

However, if things develop along the lines of the "optimised gas" scenario and the "Accelerated Decarbonisation Pathway" the amount of gas used for heating and hot water in the EU will decline from **today's 1,600 TWh** (almost all natural gas), towards **1,300 TWh in 2030** to the end state of **400 TWh in 2050**, all biomethane and hydrogen in hybrid heat pumps by then.

***Cooling***
As **demand for cooling usually correlates well with the availability of renewable electricity for solar PV**, the pathway does **not expect any gas to be used but rather electric cooling appliances. Short-term electricity storage** will help to bridge diurnal peaks of cooling demand in moments with less availability of electricity form solar PV, e.g. in the evening.

***Biomethane (infrastructure)***
In order to satisfy future gas demand (including heating) the pathway depicts a rapid increase in generation of biomethane from biomass waste and residues. The study suggests an increase in the supply of biomass **from sequential cropping and carbon farming,** mainly from the southern half of the EU. Furthermore, **large biomethane gasification units** shall be built at industrial locations and **biogas digesters** become a common sight in the European countryside.

For large biomethane plants feeding into small distribution pipes in regions with little gas demand it will be necessary to ensure that biomethane can flow upwards towards grids with higher pressure. Therefore, **reverse flow technologies** will have to be deployed.

***Gas networks / Gas grid***
The “Accelerated Decarbonisation Pathway” assumes a rapid scale up of biomethane and renewable hydrogen production capacities. It does not suggest the decommissioning of gas infrastructure, but rather describes its **further usage and upgrading** which is portrayed as **adding energy security** within an **integrated energy system**.

The study expects the need of two separate gas grids for methane and hydrogen to be balanced out by a decreasing total gas demand which leads to **no need of extensive additional gas infrastructure**.

Mentioned **exceptions are** additional gas distribution networks needed mainly in central and eastern Europe, where the coal phase out is expected to result in an increased demand of gas fired power plants. However, these expansions of gas infrastructure are not directly linked to H&C but rather to electricity generation.

**H&C related additional gas infrastructure,** projected by the study, are certain dedicated hydrogen pipelines needed for a **comprehensive pan-European hydrogen backbone infrastructure.** Furthermore, **hydrogen storages** might be needed as the share of intermittent electricity increases. The study suggests making **existing salt caverns** available and assessing the need for additional ones as soon as possible, as their creation takes much time.

***Policy recommendations***
First, the study points out, that current EU policies (EU-ETS, EU Clean Energy package, RED II) and NECPs are insufficient to decarbonise gas by 2030 and 2050, in heating and overall. According to the authors, they lack structural drivers for the scale-up of renewable gas supply during the 2020s, as well as for higher renovation rates of buildings, which slows down the deployment of all-electric heat pumps and leads to a long period in which large amounts of natural gas are still being used for heating, with only some increased grid injection of biomethane and almost no hydrogen.
In order to steer towards the “optimised gas” scenario the study suggests the following policies:

***General but relevant for H&C:***

- Provide more **long-term certainty and incentives** via the EU Green Deal by providing a **stable framework** (e.g. via Innovation Fund, increasing EU ETS prices e.g. € 100/tCO2 by 2030 and € 150/tCO2 by 2040 in combination with targeted and time-bound **Contracts for Difference**).
- Building up **European hydrogen and biomethane value chains** supported by EU and national stimulus packages
- Follow a **stepwise** approach, seizing **investment opportunities** for a cost-effective decarbonisation
- **No fiscal, financial, or legal measures that harm the security of the supply of current gas networks** in order not to risk removing a building block of an integrated energy system
- Foster an integrated energy system by **coupling the sectors electricity, gas, and heat** by **linking their markets** and infrastructures in a more coordinated way and by applying **integrated network planning** for electricity and gas networks

- Stimulate the supply of hydrogen and biomethane by a **binding mandate for 10 % gas from renewable sources** by 2030
- Foster **cross-border trade** of hydrogen and biomethane, e.g. by a **“Guarantee of Origin”** system
- **Clarify market rules** for green and blue hydrogen including hydrogen transport
- **Classify** certain investments as sustainable under the EU taxonomy rules: Investments in reverse flow technology, repurposing of gas infrastructure, new hydrogen infrastructure
- National policies should **remove potential hurdles for the reuse of infrastructure** for hydrogen
- “Connecting Europe Facility” (CEF) and “Trans-European Network in the field of Energy” (TEN-E) regulations shall support the integration of renewable gas
- A **long-term policy framework should offer incentives for biomethane** gasification (EU Innovation Fund providing funding for industrial scale biomass-to-biomethane gasification plants, European Standard setting body CEN working on standards for grid injection, Member States financing additional large biomethane plants and incentivising the building of methanation units added to existing biogas plants, a large program of Biogasdoneright piloting)

***for H&C:***
According to the study, current central EU policies driving decarbonisation in the building stock (Energy Performance for Buildings Directive (EPBD), Energy Efficiency Directive (EED), and Long-Term Renovation Strategies (LTRS)) fall short in delivering the **renovation speed** we need. Furthermore, **incentives for hybrid heat pumps are rare**. The authors point out, that in policy studies, **hybrid heating solutions are often not mentioned**, but it is usually assumed, that by 2050 buildings will be heated with electric heat pumps or by district heating. This study therefore suggests implementing the following H&C focused policies and measures (as part of the EU Green Deal):

- set ambitious binding targets for energy renovations of buildings regarding depth and speed
- increase the required minimal energy performance level of existing buildings
- provide long-term policy certainty and more ambitious political and regulatory frameworks to foster private investments and energy renovations
- organise energy renovations as step-by-step process of smaller renovations in individual renovation roadmaps to avoid lock-ins and lost opportunities
- unburden building owners (provide standardised solutions, support financing options, guarantees, renovation roadmaps)
- foster standardisation and innovation in the buildings industry to reduce costs
- include the option of hybrid heating solutions in policy studies and scenarios and plans (e.g. renovation wave plans)
- raise consumer awareness for hybrid heating solutions via EU and national programmes
- increase knowledge of installers of how to transform a gas-fired heating system into a hybrid heat pump
- support and create a sustainable market for hybrid heat pumps

## Decarbonisation of heat in Europe - Implications for natural gas demand (Honoré 2018)

***Summary of main findings***
In view of the important role of the decarbonisation of the heating sector for meeting the energy and climate targets, the study discusses the implications for natural gas demand. The study finds that most of the considered scenarios assume a modest decline in gas consumption for heating until 2030, which will be mainly concentrated on space heating in buildings. These projections can mainly be attributed to efficiency gains from thermal refurbishments and minimum energy performance requirements for buildings and the

associated lower demand for space heating. The study further concludes that pathways until 2050 differ largely and that it is uncertain what technological innovations will be developed by then, opening up more options for decarbonisation. The authors conclude that the gas industry needs to develop a strategy not only for the electricity sector but also for the heating sector in order to remain in its current form in the long term. Cooperation with electricity and the use of hydrogen and biogas may also be further options.

**Demystifying natural gas distribution grid decommissioning: An open-source approach to local deep decarbonisation of urban neighbourhoods (Zwickl-Bernhard and Auer 2022)**

***Overview***

The study investigates the decommissioning of a local distribution grid of natural gas in the heat supply of an urban district in Vienna, Austria. Currently, almost the entire heat demand of the district is supplied with national gas. The decommissioning includes the disconnection of the devices at the end-user's level. Based on an open-source modelling approach, the study considers two different local deep decarbonisation pathways, namely, electrification of all energy services and an expansion of the district heating network. Several indicators are assessed to compare the different decarbonisation options.  The study concludes that alternative scenarios of lower/zero-emission energy service provision possible and its economic advantage increases in the longer term with increasing CO2 prices.

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