ENTSO-E

Study on Power and Heat Sectors: Interactions and Synergies

February 2023

ENTSO-E Mission Statement

Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the **association for the cooperation of the European transmission system operators (TSOs)**. The 39 member TSOs, representing 35 countries, are responsible for the **secure and coordinated operation** of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E **brings together the unique expertise of TSOs for the benefit of European citizens** by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the **security of the interconnected power system in all time frames at pan-European level** and the **optimal functioning and development of the European interconnected electricity markets**, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

Our vision

ENTSO-E plays a central role in enabling Europe to become the first **climate-neutral continent by 2050** by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires **sector integration** and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources.

ENTSO-E acts to ensure that this energy system **keeps consumers at its centre** and is operated and developed with **climate objectives** and **social welfare** in mind.

ENTSO-E is committed to use its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

Our values

ENTSO-E acts in **solidarity** as a community of TSOs united by a shared **responsibility.**

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by **optimising social welfare** in its dimensions of safety, economy, environment, and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and **innovative responses to prepare for the future** and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with **transparency** and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

Our contributions

ENTSO-E supports the cooperation among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its **legally mandated tasks**, ENTSO-E's key responsibilities include the following:

- Development and implementation of standards, network codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy;
- Assessment of the adequacy of the system in different timeframes;
- Coordination of the planning and development of infrastructures at the European level (Ten-Year Network Development Plans, TYNDPs);
- Coordination of research, development and innovation activities of TSOs;
- Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the **implementation and monitoring** of the agreed common rules.

ENTSO-E is the common voice of European TSOs and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

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Executive Summary

In light of the ambitious goals set by the European Union's (EU) Green Deal, Fit for 55 and Repower EU packages, several energy sectors are expected to undergo **massive decarbonisation**, following the power sector where the generation mix is on track for full decarbonisation.

The recently published ENTSO-E Vision '**A Power System for a Carbon Neutral Europe**' and the **ENTSO-E Innovation Roadmap** clearly state the importance of including Heat and Transport sectors in the future integrated planning across sectors and voltage levels. Indeed, their decarbonisation passes through direct or indirect electrification, which implies higher electric loads (energy consumption and peak load) and changing load profiles but also new flexibility opportunities.

In the Mobility sector, decarbonisation patterns have been well identified, and the impact of smart charging/Vehicle-to-Grid has been addressed by ENTSO-E with a specific **Position Paper**. Therefore, attention here is given on the Heat sector, comprising space heating and cooling as well as heat and cool demand for industrial processes (in short, the H&C sector), which accounts for approximately half of EU final energy demand (with large differences between Northern and Southern countries) and 40 % of CO_2 emissions. The H&C sector is 80 % fossil-fuel dependent and the remaining 20 % is renewables (RES), based mostly on biomass and RES-fed heat pumps in addition to marginally geothermal, solar thermal waste-to-heat and waste heat. The recent 'REPowerEU' Plan requires an acceleration of the decarbonisation, adding the extra target for reducing EU dependency on imported fuels, which very heavily impacts the H&C sector. Among other proposals, REPowerEU proposes to double the rate of deployment of individual heat pumps, resulting in a cumulative 10 million units over the next 5 years and 40 million by 2030[1].

The decarbonisation of the H&C sector relies on increased energy efficiency gains, electrification and the higher use of RES. According to the proposed review of the Renewable Energy Directive, or 'RED III', reaching the target of a 40 % RES share in the EU's final energy consumption by 2030 will require an estimated ~40 % RES share in the H&C sector.

Direct electrification can benefit from mature and efficient technologies such as heat pumps but, compared to the fast electrification rate of the mobility sector (e.g. the recent support of the EU Parliament for the proposal of the European Commission (EC) to ban the sale of new fossil-fuelled cars from 2035), the H&C sector will take more time to electrify for several reasons. First, the life cycles of heating facilities, typically linked to buildings renovation, are longer than for vehicles, and the upfront investment is higher. Decision-makers in the H&C sector are, in many cases, not the same as heat users as, for example, the centralised heating or district heating (DH) system, and when the property owner is not also the property user (rented houses/offices/leased commercial).

Tariff and regulatory schemes for energy consumption and grid services, if not swiftly adapted, may discourage investments in this direction. More generally, compared to electricity and gas, there is no market set-up or trading environment for heat, which remains very locally-oriented with relevant regulation fragmented (even at district level) and lacking a harmonisation process at the European level.

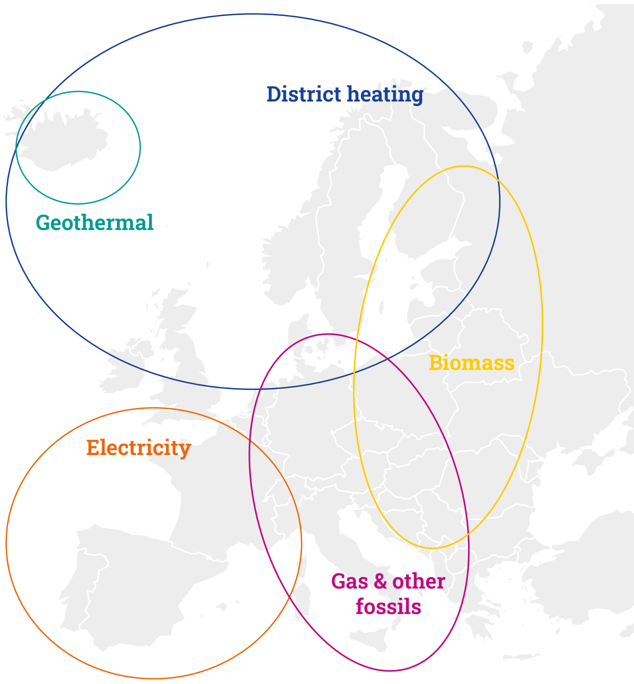

Figure 1. Geographical characteristics of heating systems in Europe (ballpark figure).

Heating systems show distinctive and peculiar characteristics in different countries, regarding technologies, sources utilised, approaches (individual/collective/DH) and national trends. Regarding synergies between H&C and electricity sector in terms of services needed by the power system (demand

1 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

response, short- and long-term flexibility) a harmonised market regulation will be necessary.

Under the future perspective of an **integrated energy system (also called the System of systems)**, the interactions between the Power and Heat sectors and synergies to be pursued fall under 3 categories:

- Electrification of heating systems implies electric load increase and load profile modification, but also opportunity in the form of flexibility provision through demand response and the exploitation of the intrinsic thermal performance of H&C systems;
- Thermal storage systems in specific applications (industrial and ad-hoc storage systems) ensure medium/long term duration flexibility at the energy system level; and
- The most efficient use of energy sources, conversion devices and consumption patterns, including Combined Heat and Power (CHP), DH and Waste-to-Heat could support the co-optimisation of both sectors

This Study analyses the current situation of the H&C sector in the EU and its objectives for 2030 and 2050; it provides a comparative description of the H&C technologies, including prospects for the integration of RES and thermal storage. **The main aim is to analyse the impact of these future evolutions on a) the energy system, b) the power system and c) TSO practices.** To achieve these objective studies, the EC's Joint Research Centre (JRC) and ENTSO-E's Ten-year Network Development Plan (TYNDP) were used. Particular attention was paid to **market analysis**, with a description of the relevant stakeholders and the role of Transmission System Operators (TSOs) within this framework, as well as to the future innovations needed.

Selected innovative use cases, particularly those with the participation of electricity TSOs, are provided in the Appendix.

To promote the multiple opportunities identified and described in this Study, ENTSO-E highlights the following aspects.

Key findings and messages

Relevance of H&C sector and state of play

1) H&C is the **largest energy consuming sector** (representing 80 % of domestic energy consumption) while simultaneously being the **least decarbonised one**. Its integration into the future 'System of systems' is less straightforward than transport and gas/hydrogen sectors as energy in the form of Heat is significantly **less transportable** than electricity and fuels (liquid, gaseous, solid).

2) The H&C sector is also the **largest CO_2 emitting** sector, and its decarbonisation is **paramount for reaching climate targets in addition to energy independence objectives**. The four levers in order of effectiveness towards this aim are:

- energy savings in final consumptions (efficiency);
- increasing the RES share in H&C supply;
- electrification of the H&C sector; and
- switching to decarbonised fuels on the demand side.

Moreover, H&C should be fully integrated in the system optimisation of matching the available energy supply sources to efficiently cover the different sectors' energy needs.

3) European countries' H&C sector characteristics display very different situations concerning structure and energy sources used metrics, data collection as well as **decarbonisation paces and paths**.

4) Some countries are ready **for a high H&C electrification rate** (1100–1600 GW_{th} additional electricity demand for heating devices), while others require power system and infrastructures enhancements to accommodate a 40–60 % electrification rate of the H&C sector to reach the EU target of 40 million Heat Pumps in 2030. In terms of additional energy demand and peak power increase, this could be manageable for the power system under the condition that the new devices are equipped and prepared to provide flexibility to the power system.

Heat through efficiency and CHP

5) The H&C sector **decarbonisation is strictly linked to its efficiency improvements**: heat pumps deployment to reduce final energy consumption by 3–5 times in comparison to a conventional gas boiler, better thermal insulation of buildings as well as the exploitation of their thermal capacity as system flexibility means, and the widespread utilisation of waste heat recovery for optimal energy mix utilisation. The combination of all these solutions could multiply the benefits.

6) In particular, waste heat recovery from low temperature processes (data centres and low enthalpy industrial processes) is an emerging trend, provided that suitable final uses are available in terms of low temperature short distance and compatible times of use. A good example is how DH/Cooling systems are unevenly deployed across EU countries. Systematic waste heat recovery is also aiming at **sustainability and at a circular economy**.

7) Combined Heat & Power (CHP) is the archetype technology for power and heat integration and its more sophisticated version as trigeneration (including Cold), stemming from energy efficiency objectives only. Through the logic of System of Systems, such integration should equally consider the benefits of coordinated operation with the power system needs and dynamics. To achieve this, integrating different storage systems and developing hybrid systems is necessary.

Heat through Renewables & Thermal Storage

8) Renewable-based Power to Heat technologies require **high upfront investment costs** for consumers with relatively long pay-back times. DH using non-fossil sources, especially if combined with CHP, is a consolidated best practice, but its adoption also requires a deep integration with the building sector and spatial/urban planning decisional processes. To move towards the adoptions of these solutions, appropriate economic/financial/tariffication/taxation schemes should be envisaged.

9) Thermal storage can provide **flexibility** to the energy system in two different forms: a) Thermal inertia of buildings, heating/cooling facilities and industrial processes, as both implicit & explicit demand response providing short-term flexibility and peak shaving at competitive costs; b) Thermal tanks/pits built-on-purpose for storing vRES surplus providing medium term (not up to seasonal) flexibility at the energy system level for a holistic energy mix optimisation.

Heat through electrification, switching demand to decarbonised fuels & flexibility

10) Electrification of the H&C sector, feasible for low temperature processes, directly impacts the power sector, as an extra load in terms of energy and peak demand, as well as changes in the load profile curve, particularly the increase of the Load Duration Curve. On the other hand, it is also a new source of flexibility, as **thermal demand management and thermal storage** capabilities can be exploited for a mutually beneficial sector integration.

11) High temperature processes will instead require no-emission fuels, such as hydrogen and its derivatives; however this has a high indirect impact on the power system, with more electrolysers connected to the grids.

12) P2Heat units operating today were installed and commissioned with the only aim to supply thermal energy. A retrofit and their digitalisation, supported by the standardisation of both assets and data exchange processes, will be **key enablers for exploiting the flexibility** resources from the heating and cooling sector, allowing them to provide frequency and other ancillary services, namely Frequency Containment Reserve (FCR), automatic Frequency Restoration Reserve (aFRR), manual Frequency Restoration Reserve (mFRR) and congestion management

13) Consumer-**smart appliances and devices** (heating resistors, electrode boilers, heat pumps, meters, sensors, ICT infrastructure) enabling flexibility provision is a key pre-requisite for successful widescale Power–Heat integration. They should be **widely available, cheap and user-friendly**.

Market enablers

14) Heat markets do not exist historically due to their **inherent local footprint**: heat&cool long transport and extensive/meshed heat grids are not feasible; therefore, a wide pool basis for a wholesale market cannot be established. However, the coupling with the electricity sector requires common/equivalent metrics and market mechanisms/tools to be utilised especially for flexibility provision, which must be compared by grid operators against other flexibility sources. A harmonised **regulatory framework** is necessary to pool the different potential resources from various technologies and use cases and exploit them efficiently. **Pilot projects** can start from paradigmatic use cases such as 'Heat as a Service', or DH networks/Industrial districts which become 'Open Access' for several competing heat producers and consumers.

15) Standardisation and digital connectivity are also fundamental to establishing the value chain of P2Heat, steering manufacturers and organisational processes towards protocols and data management that guarantee observability and controllability, and avoid entry barriers for newcomers.

Innovation & Cooperation

16) A **supportive framework for innovation** is crucial to demonstrate and speed-up the time-to-market of the required technical and digital solutions (for example thermal storage techniques and applications), as well as that of new energy services and business models centred on consumers[2]. TSOs should continue to monitor technology progresses and, especially for flexibility provision (short and long thermal storage), participate in demos/pilot projects to assess the capabilities, potential and shortcomings of the solutions proposed by the industry.

17) The cooperation of TSOs with various stakeholders of the wide and diverse ecosystem involved, especially Distribution System Operators, DH operators and energy managers of heat intensive industries, is a prerequisite of the successful integration of the two sectors in order to understand the reciprocal needs and constraints and build up new know-how and related skills' capacity building.

2 https://eepublicdownloads.entsoe.eu/clean-documents/mc-documents/210414_Financeability.pdf

Introduction

1.1 Why address the Heating & Cooling Sector?

The EU aims to reduce CO_2 emissions by 55 % by 2030 ("FiT for 55" package) and to become climate-neutral by 2050 in line with the Green Deal and the Paris Agreement. One of the main challenges to meeting this goal is the decarbonisation of the H&C sector. According to the EC National Energy Climate Plans (NECPs) assessment of the H&C sector, nearly 50 % of the Final Energy Consumption (FEC) is used for H&C purposes in Europe. The remaining energy is consumed by the transport and electricity sectors. Thus, H&C is **the EU's largest final energy use** (Fig. 2), and it is expected to remain so, as this is also mentioned in the RepowerEU.[3]

With approximately 79 % of the energy in the H&C sector originating from fossil sources, the decarbonisation of the H&C sector is of paramount importance. The **main decarbonisation pathway** of the H&C sector relies on the electricity sector as electricity is the **most mature widescale energy carrier** and can **lead to rapid decarbonisation trends**; this makes the **Heat and Power sectors integration** a promising strategy to reduce greenhouse gas emissions. As TSOs are main players in the cross European transmission of electricity, with this Paper ENTSO-E intends to contextualise the decarbonisation of the H&C sector into the TSO environment, highlighting their tasks and potential business opportunities from the transition to an integrated energy system.

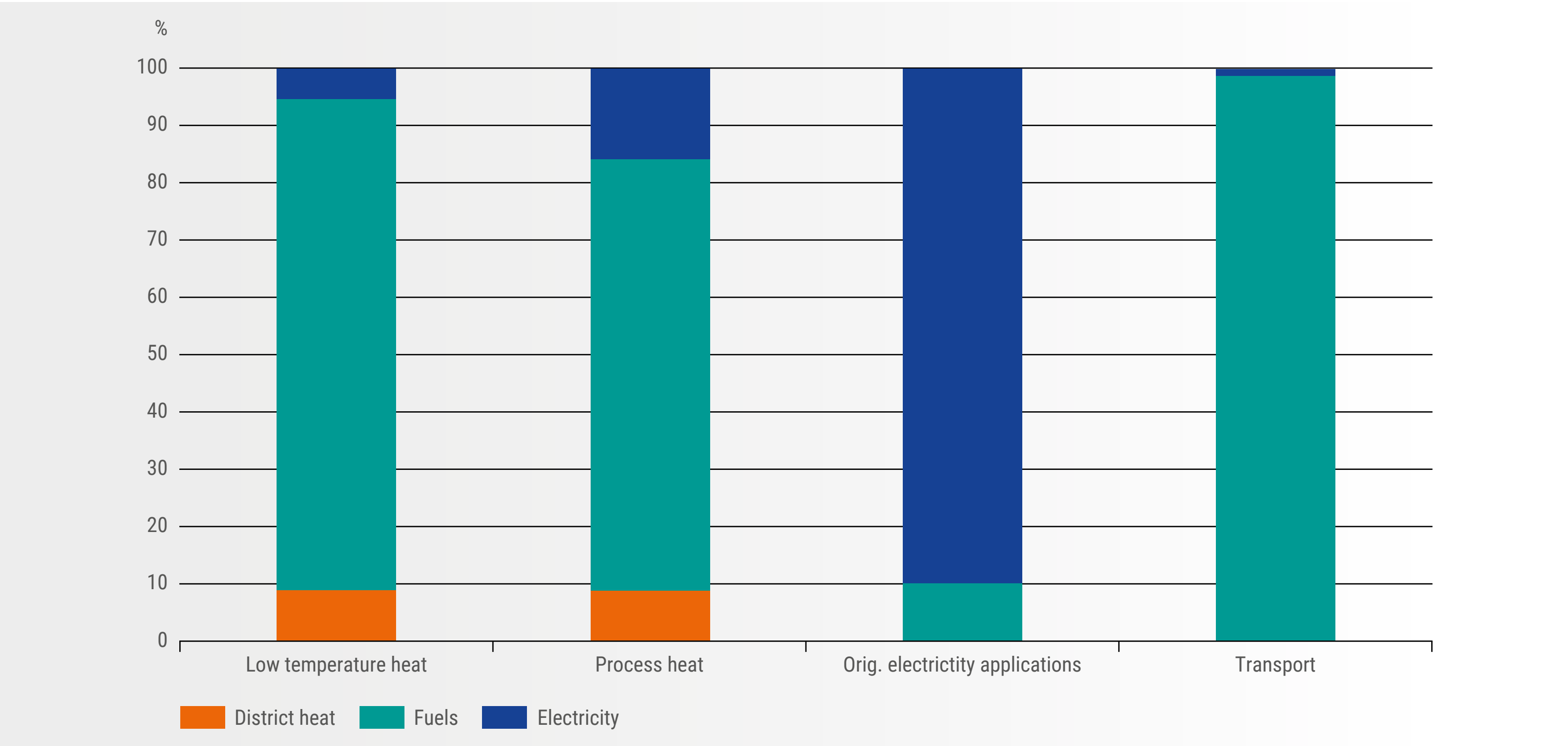

Figure 2. EU energy consumption and fossil contents of main energy sectors (Fraunhofer Institute).

3 https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

1.2 How to make the transition?

The H&C sector is a fairly fragmented sector (Fig. 3) characterised by an ageing and inefficient building and appliance stock and by a reliance on fossil fuels, with some countries lacking many connections with the electricity sector.

The thermal sector at the national level reflects legacy energy policies, industrial and urban development patterns, consumers preferences and local standards.

The EC's H&C strategy clearly makes the case that the **integration of different energy sectors** is one of the solutions to accommodate higher shares of variable RES, mostly wind and solar. In this clean transition process, the decarbonised firm capacity paired with vRES deployment play a key role. The electrification of heat production is meaningful to reduce the relative carbon output only when the electricity comes from renewable sources. Combined with a reduction of demand, the deployment of renewable and sustainable energy sources such as waste heat have a great potential to reduce fossil fuel imports and ensure the security of energy supply in an affordable manner for the end consumer. Finally, **digitalisation** is an opportunity to increase the share of H&C demand met by a wide range of RES.

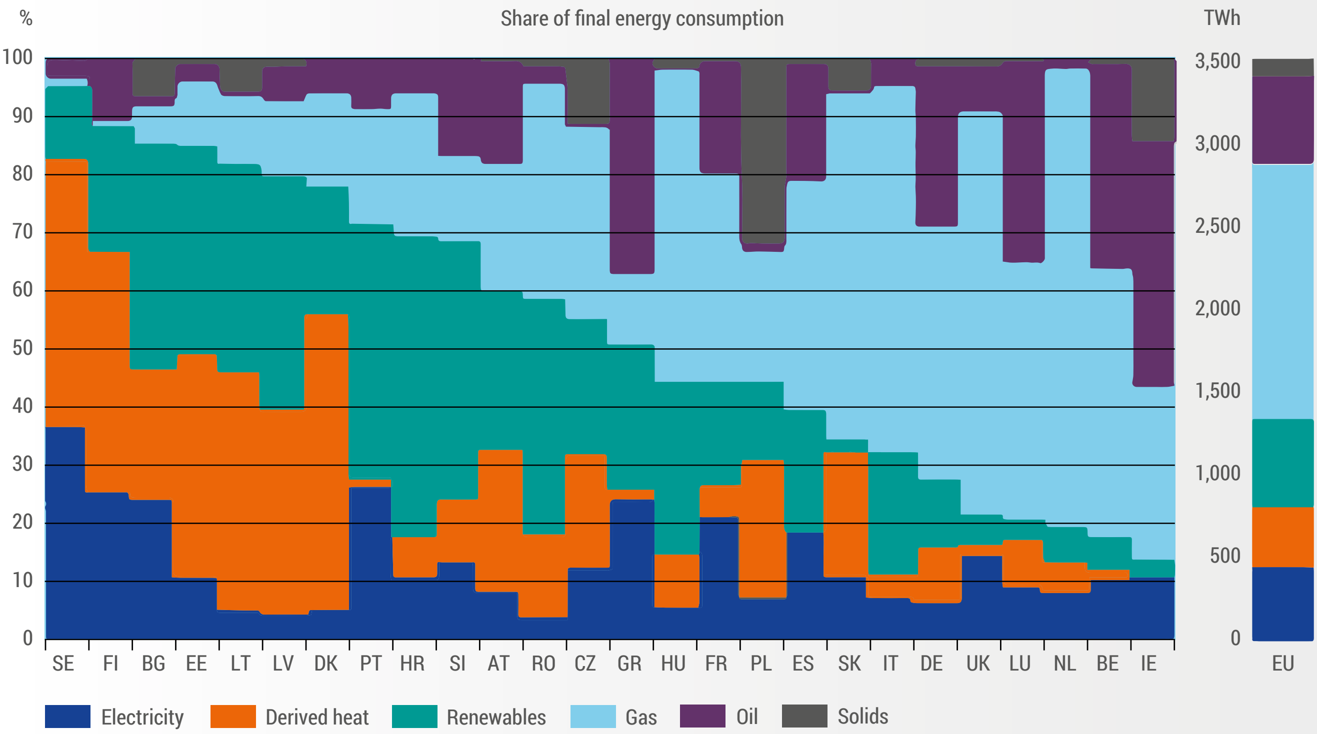

Figure 3. Graphic overview of EU fragmented H&C energy source mix. Source: JRC IDEES Database (JRC, 2018)

1.3 Energy System Integration

The European electricity system, increasingly dominated by volatile wind and solar energy production, will require flexibility resources which can serve as the primary enabler for the full decarbonisation of the energy mix. The generation capacity of clean electricity can easily be channelled into large heat pumps or electric boilers, and **the converted heat energy** can be **stored** in hot water/fluids for certain applications/time horizons **at a cost of approximately 10 times lower** than that of an electric battery. In fact, these two examples of storage cover different system needs, but the cost affordability calls for deeper innovation and uptake of thermal storage for suitable applications. It must be integrated with the possibility for demand to accommodate the heat production when not actually requested by the user. Thus, this "power-to-heat" process provides a precious route to the market for RES-based electricity, which might otherwise have been curtailed or "sold" at a negative price. This will be in addition to intrinsic flexibility deployable as demand response, both implicit (elasticity of demand to price) and explicit (offers on a specific flexibility market), which instead relies on the thermal inertia of devices and facilities of heating systems.

From an integrated system perspective, a brief taxonomy of Heat sector streams is reported in Fig. 4.

1.4 Heat accounting principles

Due to its intrinsic quality degradation with decreasing temperature (exergy), Heat is a peculiar form of energy: "quality degradation" with temperature and "usable energy / recovered heat" concepts do not apply to the electricity domain; therefore, energy efficiency concepts apply in different logic and metrics (the apparent paradox of COP > 100 % in Heat Pumps). Even energy accounting is challenging and sometimes controversial; proper energy and carbon accounting becomes essential for the decarbonisation assessment of sector integration.

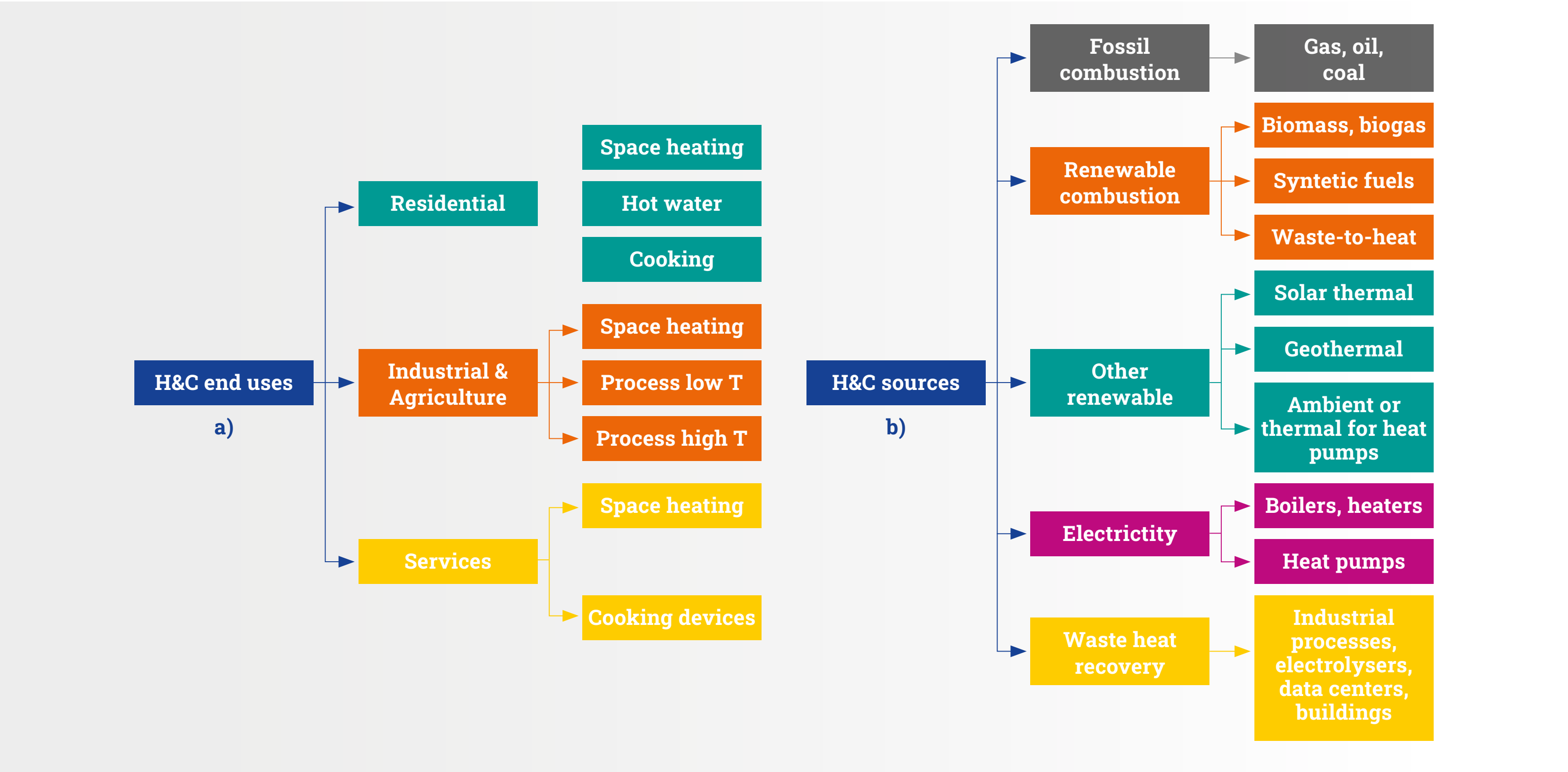

Figure 4. Taxonomy of the H&C Sector. The H&C end uses on subfigure (a) refer to non-electrifiable uses. For subfigure (b), it should be noted that cogeneration is not a source but rather an efficient generation method as well as a coupling device.

1.5 Scope and Context of the Paper

The Paper presents the key characteristics and prospects of the H&C sector, regarding the electrification process, RES integration and efficient allocation of energy resources to energy final uses, including conversion and storage (i.e. sector coupling). More specifically, it assesses the **impact of the H&C decarbonisation and efficiency improvements pathways** on power system planning, operation, markets and business models, also providing recommendations for a stronger sector integration. An elaboration of quantitative future scenarios or simulations for H&C electrification, which shall be needed for a grid planning exercise, is not in the scope of this Paper, which instead focuses on:

1) The concise presentation of the H&C sector today and the related technologies such as heat pumps, cogeneration (CHP), DH networks and thermal energy storage (TES) deployment, as well as prospects.

2) An analysis of the electrification of the heat demand and the **flexibility potential** for the electricity system operation.

3) An overview of technological, market and policy aspects that affect TSOs' business practices in relation to the goals set by the European Green Deal, the Fit for 55 Package, REPowerEU Plan, and related directives/regulations (RED III, Efficiency, Gas & Hydrogen networks, TEN-E, Buildings, etc.).

The crucial role of digitalisation is also addressed, with special attention to the consumers' perspective and to the means for motivating them to actively participate in markets to achieve better exploitation of the thermal flexibilities. Finally, some relevant innovative use cases of P2Heat integration are presented, through their major findings and encountered challenges.

2. Heating and Cooling Sector Overview

2.1 Heating & Cooling Demand & links to the power sector

2.1.1 H&C by sector

The H&C sector represents half of the energy consumption in the EU, being supplied almost 80 % by fossil fuels. **Buildings**, including residential and services sectors, currently account for **40 %** of the total final energy consumption in the EU: residential alone is responsible for **54 %** of H&C consumption, followed by services (21 %) and industry (24 %). (Fig. 5 & 6)

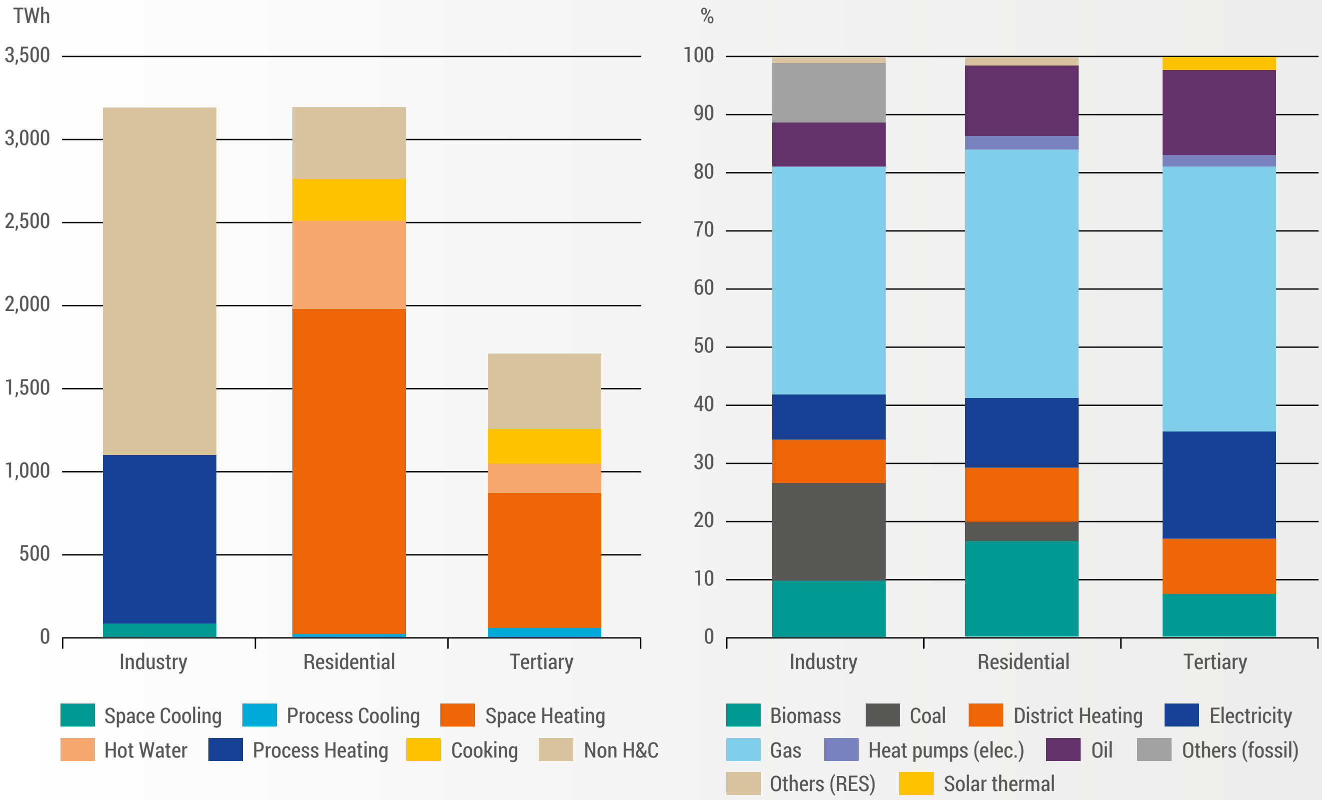

Figure 5. (a) H&C FEC and (b) various sectors primary sources decomposition for H&C, in EU-28. Data Source: JRC IDEES Database (JRC 2018).

A total of **22 %** is attributed to the **space heating needs** in the **residential and tertiary sectors** (Fig. 6).

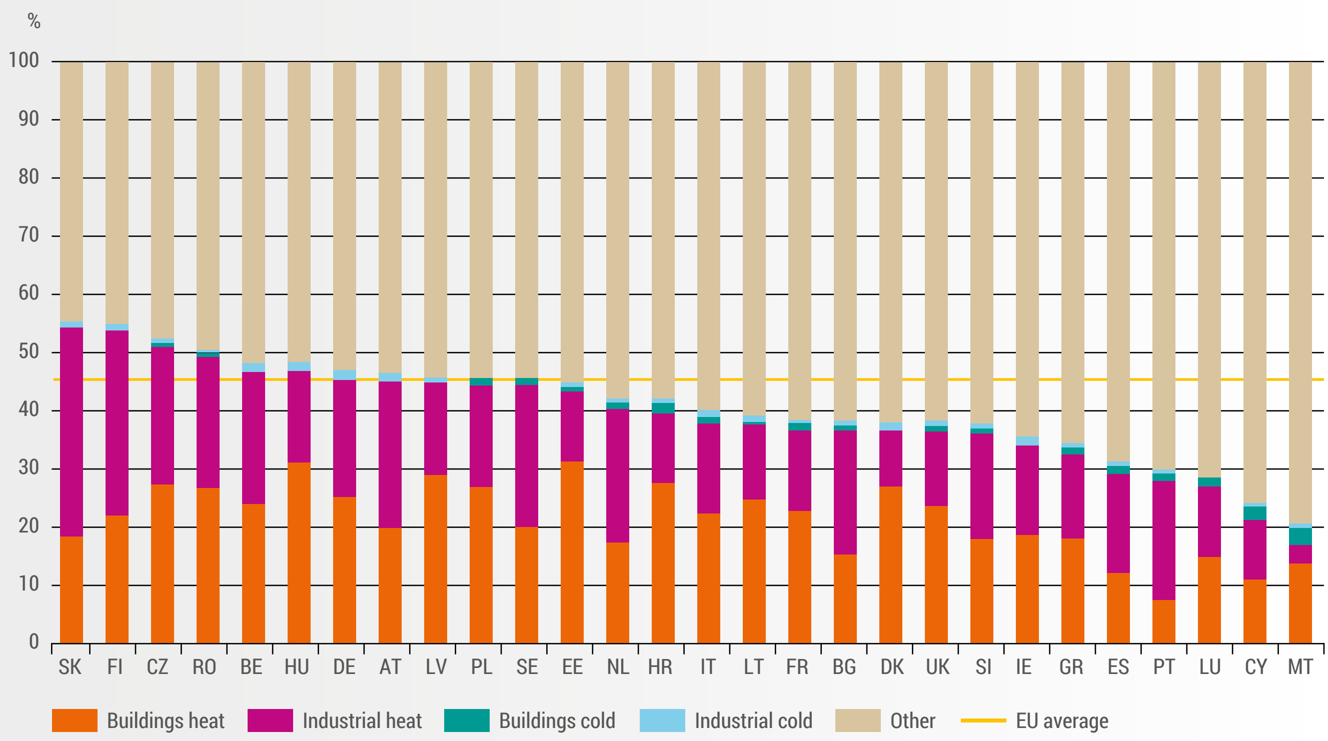

Figure 6. FEC per Member State for H&C services in EU-28, 2015. An average of 42 % of the final energy demand goes to H&C services. Data Source: JRC IDEES Database (JRC 2018).

2.1.2 Relevance of electric H&C in the power system

According to the baseline scenario of **Heat Roadmap Europe**, heat pump penetration increases strongly until 2050 and could represent 7 % of the total electricity demand (Fig. 7) , while hotter summer periods shall cause an increased uptake of air conditioning systems; however, in the general trends of demand and peak power evolution, these effects at European level should remain manageable.

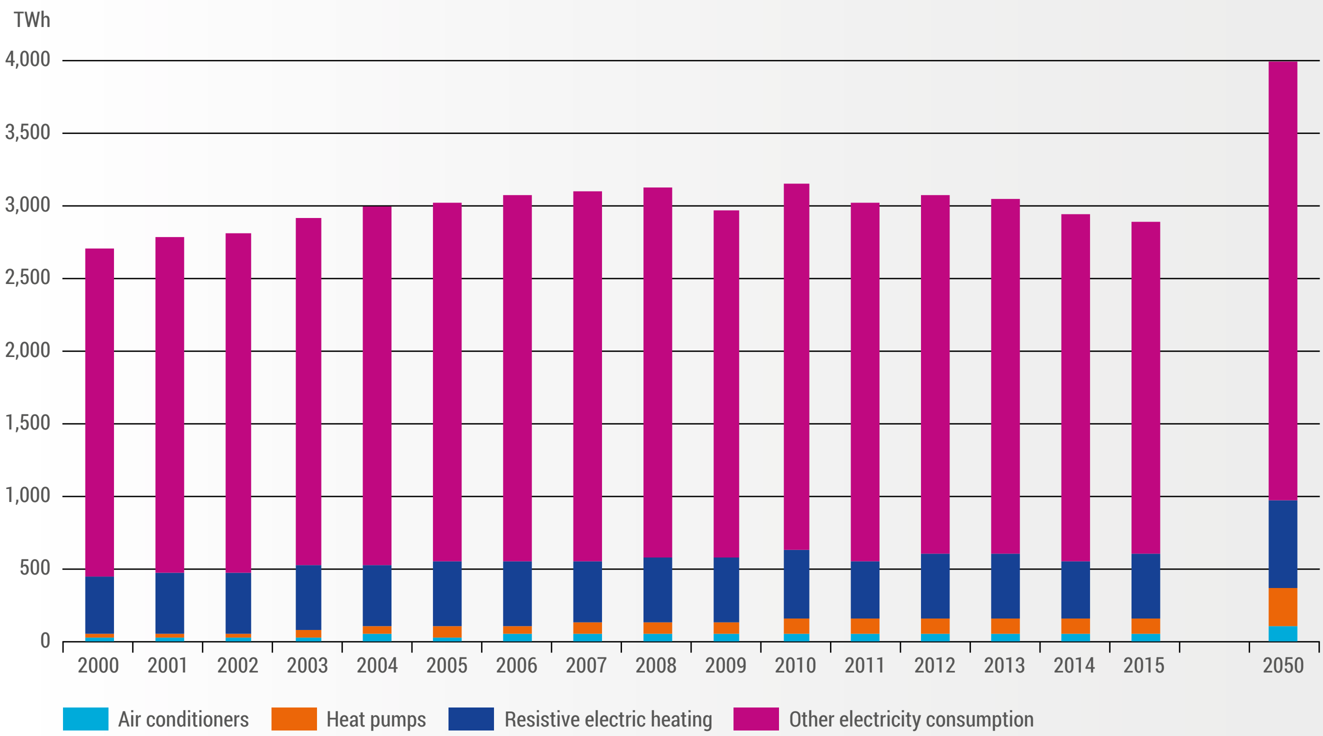

Figure 7. Share of electricity consumption for H&C purposes in EU-28.

The yearly load profile of overall H&C demand is as per Fig.8.

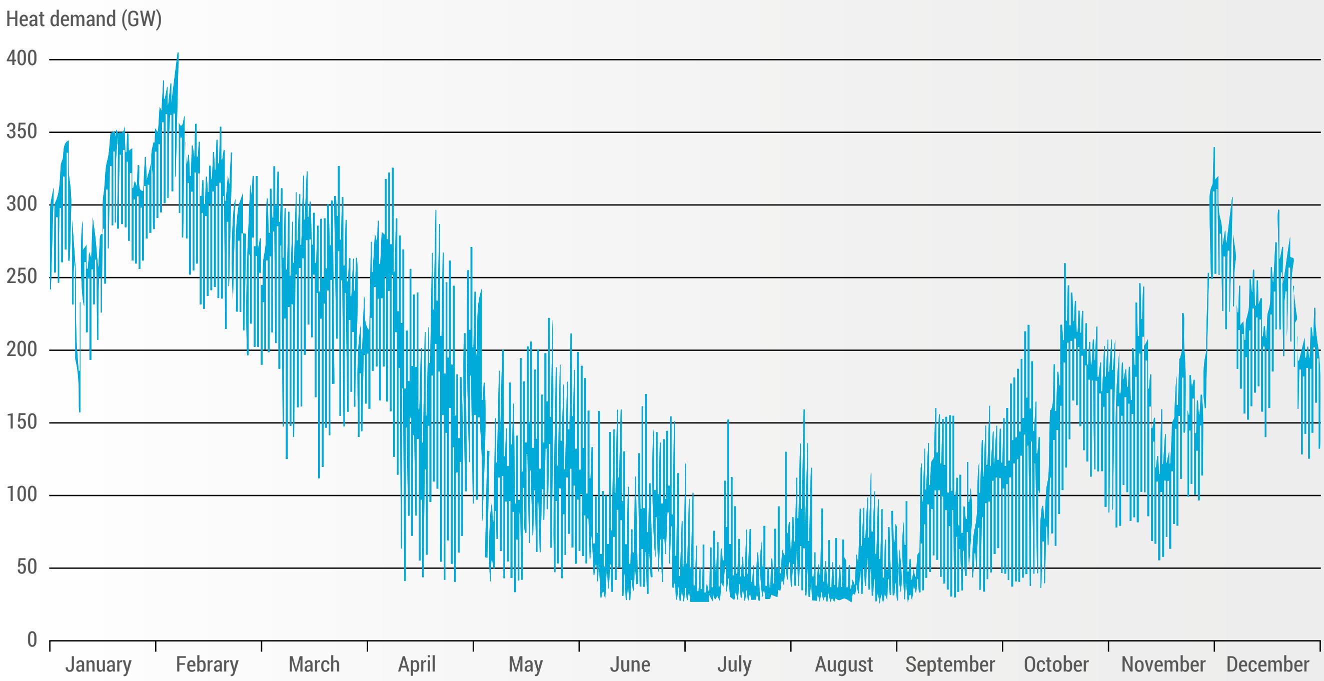

Figure 8. Typical yearly load profile in Europe for the year 2016 (JRC Database).

2.1.3 Allocation of sectorial H&C consumption

The current TFEC[4] for H&C in buildings (residential and tertiary sectors) and the industry amounts to 5,431 TWh and makes up 46 % of the TFEC in the EU-27. Heating and cooling accounts for more than 50 % of the TFEC in 9 Member States. The highest TFEC was recorded in Germany (1,270 TWh), followed by France (712 TWh) and Italy (645 TWh). The residential sector alone is responsible for 54 % of total H&C consumption, followed by industry (24 %) and services (21 %). Currently, each of these sectors has the potential to reduce demand, increase efficiency and shift to RES. Regarding the breakdown of the TFEC across all EU Member States, a total of 22 % is attributed to the space heating needs in the residential and tertiary sectors, which makes the "sector integration" with the power system a promising strategy to reduce greenhouse gas emissions. On the other hand, cooling is already mainly powered by electricity

H&C makes up more than 50 % of the TFEC in nine Member States. The highest TFEC was in Germany (109.2 Mtoe), followed by France (61.2 Mtoe) and Italy (55.5 Mtoe).

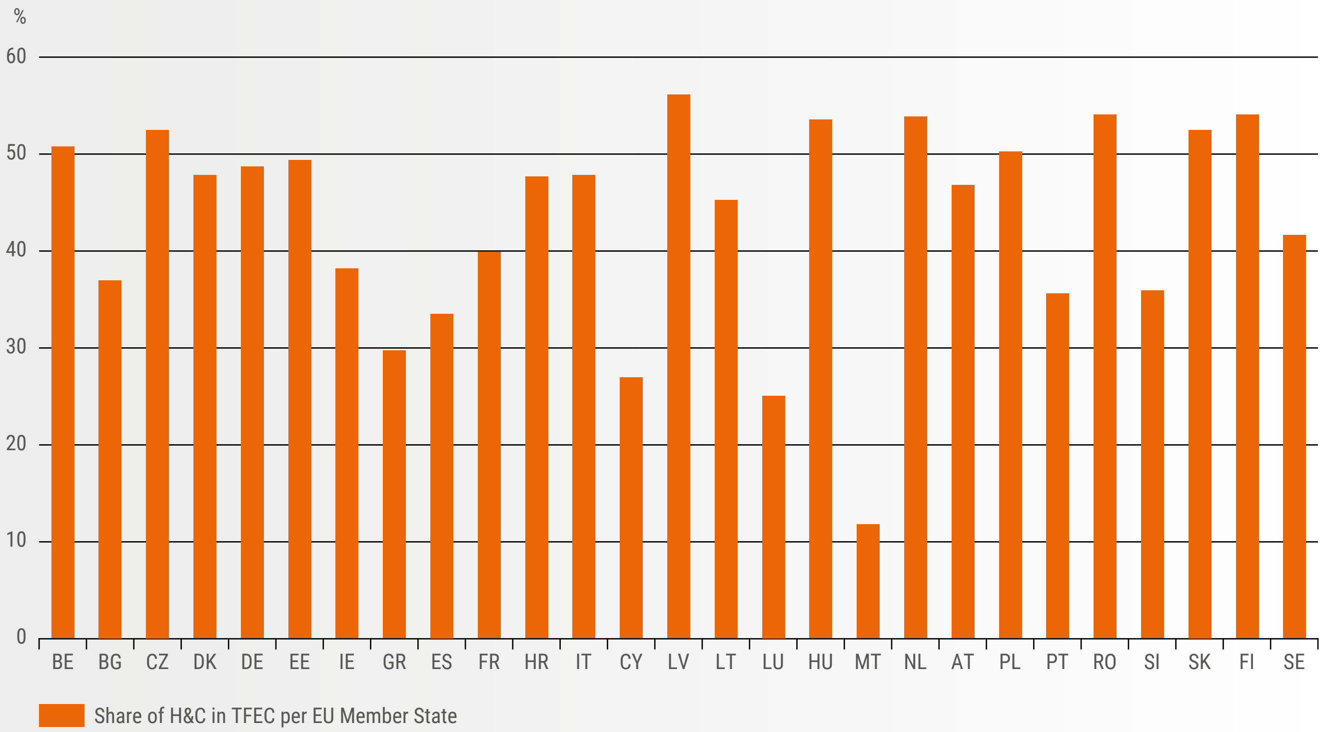

Figure 9. Share of H&C in TFEC per EU Member State. Data sources: European Commission (2021)

4 Final energy consumption is the total energy which reaches the final consumers' (such as households, services, industry) door and excludes that which is used by the energy sector itself. It is noted that there is an efficiency between the final energy (gas, oil, electricity, etc.) and the thermal energy that is provided (heating) or removed (cooling).

2.1.4 Renewable Energy in H&C

The share of renewable energy in the H&C sector is approximately 21 % in the EU-27 and is expected to reach 33 % in 2030, according to the final NECPs. The share of renewable energy was above 50 % in 2020 for 5 EU countries whereas in Sweden, this share was even above 60 %. The main RES technologies currently used for H&C in the EU-27 are biomass, heat pumps, geothermal, solar thermal, renewable municipal solid waste, and waste heat.

The share of renewable energy in the H&C sector is expected to reach 33 % in 2030 but the levels of ambition vary considerably between Member States, as per new directive RED III, by an indicative **1.1 %** annual increase with specific indicative national top-ups.

Member States must provide any information regarding the constraints that may have caused them not to meet the requirements, such as structural barriers arising from the high share of natural gas or cooling, or from a dispersed extra-urban population's settlements structure with a low population density.

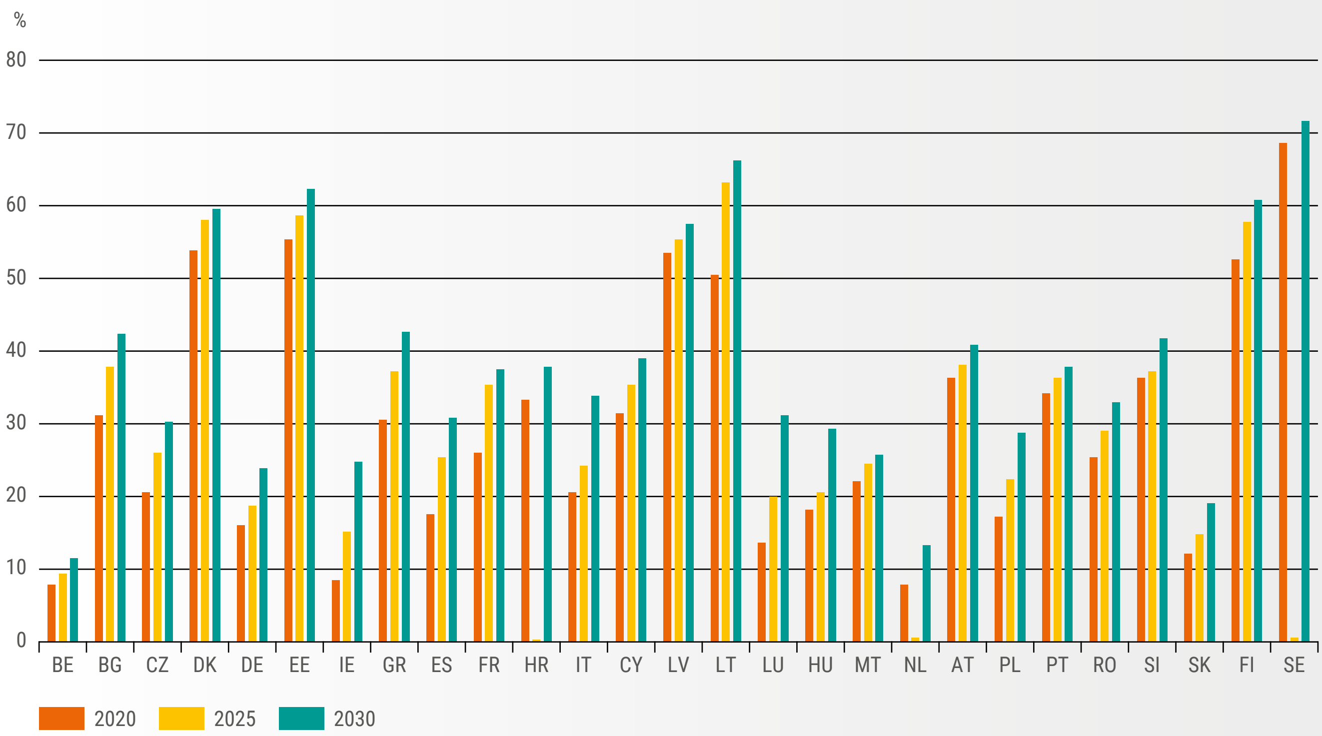

Figure 10. RES share in the H&C sector for 2020, 2025 and 2030. Data sources: European Commission (2021)

2.1.5 Combined Heat & Power generation

CHP process is a well-established technology with high efficiency, by using the waste heat (unavoidable for thermodynamic reasons) of thermal electricity generation in a boiler for heating purposes, on the spot for industrial sites or channelled through DH for space heating. The rationale is to use the otherwise wasted heat and thus deploy a strong energy saving measure: energy efficiency raises from 45–55 % to 65–85 % (depending on CHP installations and on site-specific parameters).

This is the most traditional and simple method to integrate Power & Heat sectors; usually heat demand determines the plant operational schedule (electricity-follows-heat operation mode). Developments of CHP in the direction of High Efficiency (HECHP) are incentivised and contribute to Energy Efficiency targets of EU directives (EED).

CHP plants shall decline in some Member States if the source is not renewable or sustainable, determining the termination of public incentives if they cannot reach HECHP status; this is expected more for centralised plants than for decentralised CHP in industry and agriculture. The situation is very different in the Member States due to legacy industrial structures and the type of available energy sources (Fig. 11).

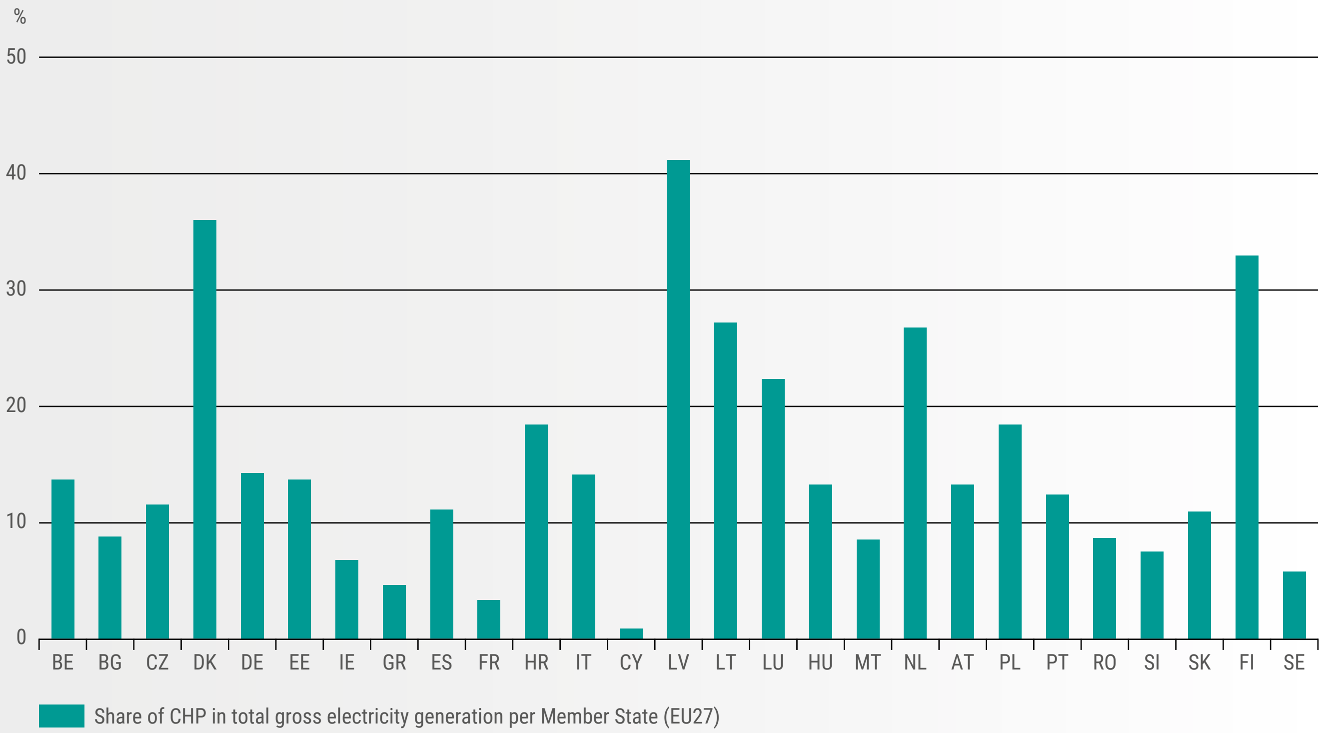

Figure 11. Share of CHP in total gross electricity generation per Member State (EU27).

2.1.6 District Heating across Europe

Overall, there are more than 6,000 DH systems across Europe, and many cities and regions envisage a growing role for them in their energy plans; some are also looking at district cooling, which is much less widespread as it requires more specialised conditions and more complex design.

The role of DH in the heat supply mix depends on each country and differs considerably across the EU. Figure 12 shows the overall heat demand for DH (in nominal values, blue bar) and the share of heat demand that is covered by district. In nominal values, Germany, Poland and Sweden feature the highest heat demand covered by DH. However, in relative terms, Nordic and Eastern European countries feature significantly higher shares.

DH is particularly dominant in northern European Member States, while renewables – due to large biomass shares – are leading in the east. Consequently, the Baltic countries, which combine both, exhibit a share of around 80 % of low carbon heating fuels. The heat supply in central and western countries, however, is largely based on natural gas.

Electricity as a fuel is most popular in southern European countries, where direct-electric heating is still widely spread, as well as in some northern European countries, where heat pumps are more established in the heating market. The heat-pump-deployment trend is most promising in Sweden and Finland, aiming at shares beyond 40 % for 2030.

Regarding the fuel mix of DH, the situation is similarly heterogenous between the different countries. At a European scale, the main sources of supply are natural gas (48 %), biomass (27 %) and lignite 9 % (Fig 5).

In accordance with RED III, an indicative **2.1** percentage point annual increase in the use of renewables and waste heat and cold in **DH and cooling** for Member States is set, starting from the share in 2020. In absolute terms, some countries show decreasing energy consumption, due to efficiency improvements in the building stock and DH networks.

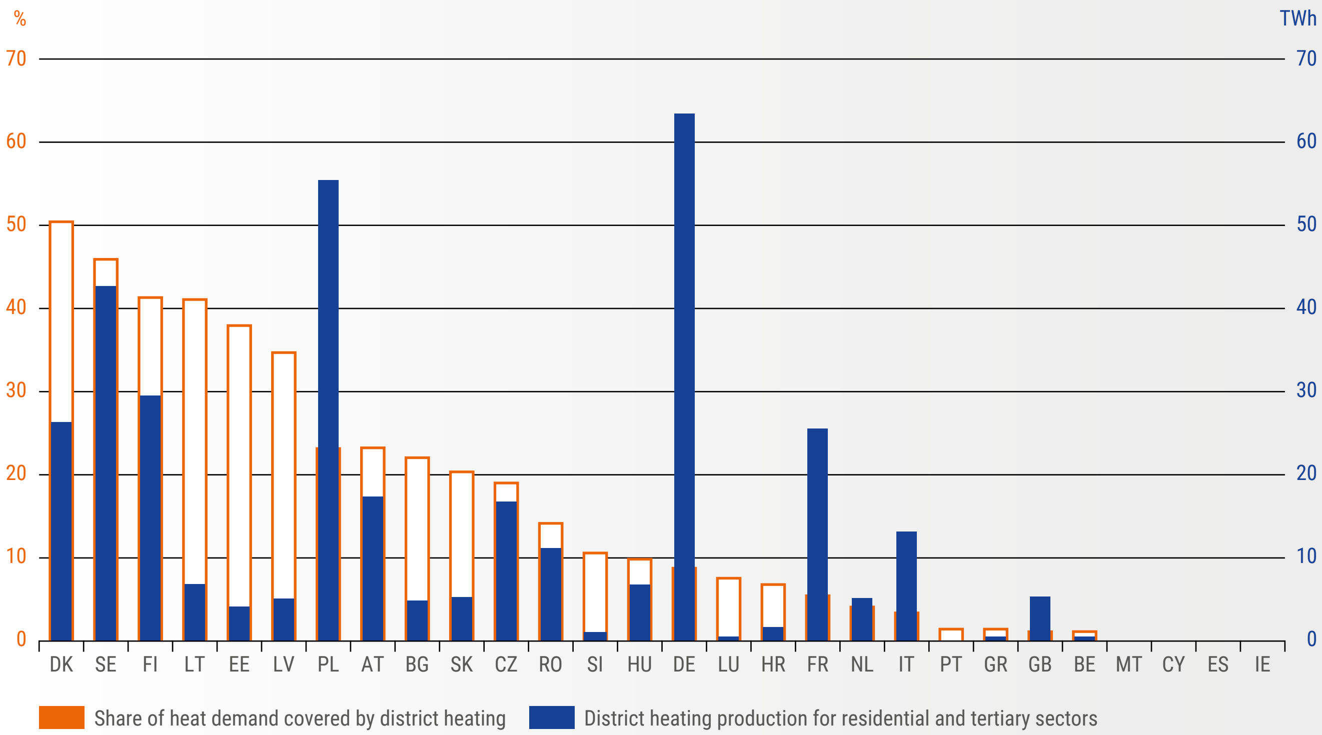

Figure 12. District heat for the residential and tertiary sectors in 2015 across all EU member states (EC report, METIS Study S9: Cost-efficient district heating development).

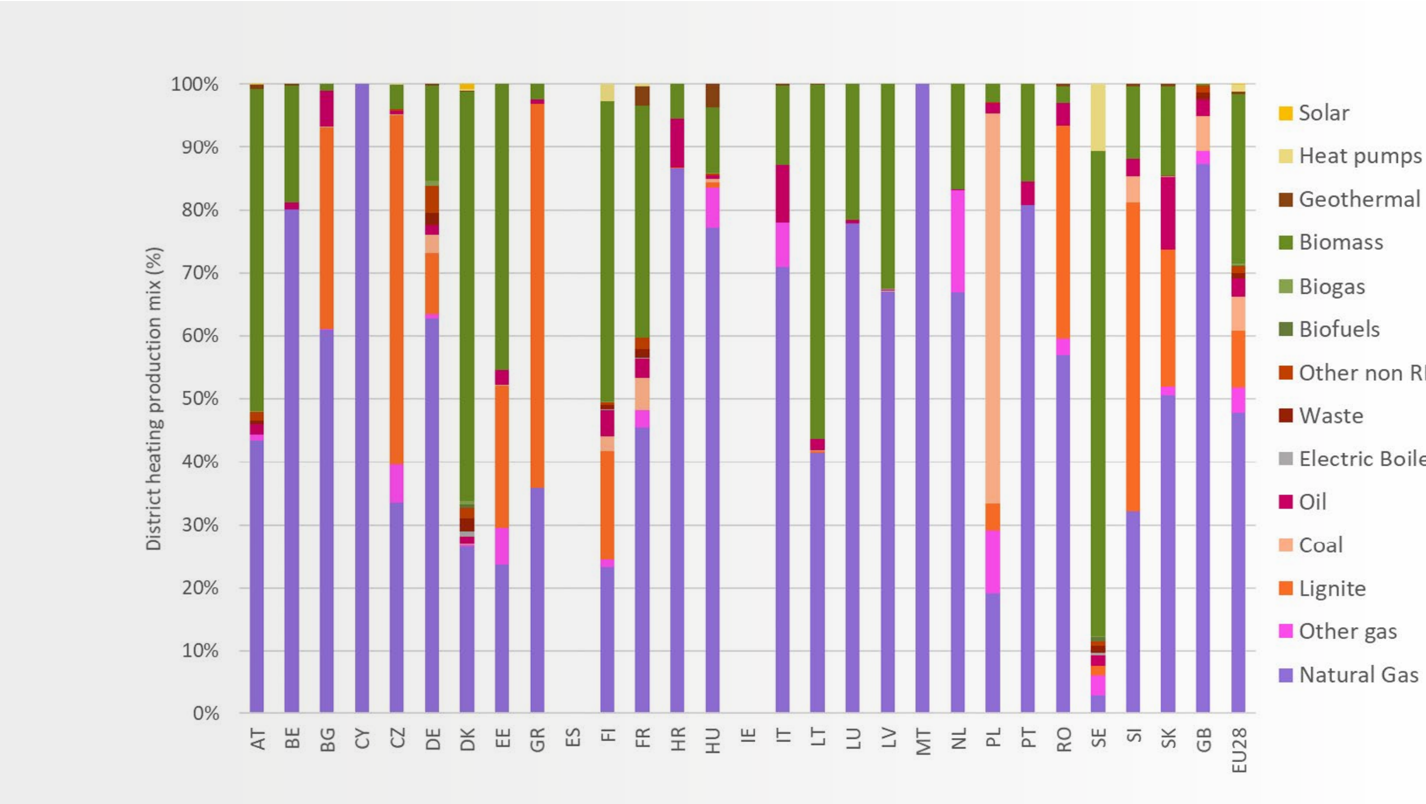

Figure 13. District heating production mix for residential, commercial and industrial sectors (EC report, METIS Study S9: Cost-efficient district heating development).

Sustainable H&C in Sweden: Revolutionising District Heating?

Heat networks will play an important role in the future heating of buildings. To meet climate targets, decentralised energy solutions are gaining policy as well as industry focus. Described as the DH equivalent of a self-driving car, a solution that combines tried-and-tested hardware and cutting-edge software – in the form of a self-learning algorithm – has the potential to help to significantly reduce carbon emissions in the energy-intensive domestic heating sector. (**Source**)

Nordic Countries: Best Practices

Trigeneration of electricity, district H&C and utilisation of waste heat

In Helsinki, **Finland**, the local energy, and electricity company Helen produces efficiently both H&C based on CHP-production and combined district H&C.

Large-scale solar panels in district heating

Denmark is among the world's leading countries in integrating large-scale solar heating into the DH systems. The number of solar heating plants larger than 1000 m^2 has increased significantly during the recent years.

Geothermal district heating

Due to its geological location, **Iceland** has vast energy resources in geothermal energy. Geothermal energy is used both in electricity generation and heat generation. Replacing fossil oil with geothermal heating has resulted in significant reductions simultaneously in emissions and economic benefits.

Utilisation of waste heat from industry

Industrial waste heat accounted for 7 % (4 TWh) of the total DH production in Sweden, mainly from the pulp and paper, steel and chemical industries.

Waste management and waste-to-heat is an interesting sustainable option regarding DH. Everything that cannot be reused or recycled is delivered to an incineration plant that ensures proper final treatment through stringent requirements for flue gas cleaning. Unwanted environmental gases are taken out of circulation, and the energy is recovered and delivered to DH. Incineration with energy recovery results in a significant reduction in greenhouse gas emissions compared to the alternative of landfills. DH plants utilise the surplus heat from waste incineration to provide warm water and heating to buildings.

District Heat from Waste Heat of Data Centres: A Circular Energy System

Waste heat recovery from data centres is an emerging trend (already under implementation in Nordic countries). Data centres are excellent sources of heat as they **produce heat evenly throughout the year**. The reuse of data centre heat presents an opportunity for energy conservation that can fit specific circumstances. Data centre operators will thus explore possibilities to interconnect with DH systems and other users of heat to determine if opportunities to feed captured heat from new data centres into nearby systems are practical, environmentally sound and cost effective.

The revised European Standard CEN-EN 16325 on guarantees of origin (GOs) now includes a standard for GOs for H&C, implementing the RED. This could support waste heat recovery from data centres, differentiating from fossil-based generated thermal energy and as such increasing the acceptance of data centre waste heat.

2.2 Zoom on H&C in residential sector

For its size and widespread presence, the residential H&C sector represents the highest potential for sector coupling in terms of flexibility: demand response and load profile shaping; therefore, a zoom on households' consumptions patterns is reported here.

2.2.1 By type of fuel

In 2019, natural gas accounted for 32 % of the EU final energy consumption in households, electricity for 25 %, renewables for 20 % and petroleum products for 12 %. Three Member States use mostly other energy products: Denmark relies mainly on derived heat, Poland on solid fuels and Ireland on petroleum products. Derived heat covers the total heat production in CHP plants; it includes the heat used by the auxiliaries of the installation which use hot fluid (space heating, liquid fuel heating, etc.) and losses in the installation/network heat exchanges. For auto-producing entities (= entities generating electricity and/or heat wholly or partially for their own use as an activity which supports their primary activity), the heat used by the undertaking for its own processes is not included[5].

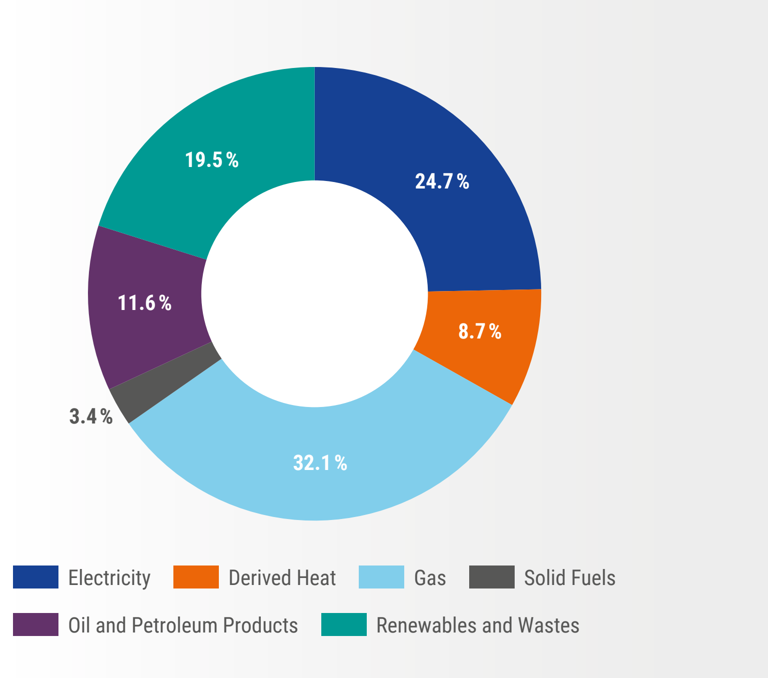

Figure 14. FEC in the residential sector by fuel, EU, 2019 (Eurostat).

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2.2.2 By type of end-use

In the EU, almost two thirds of energy consumed by households is for space heating while the proportion used for water heating is approximately 15 %; cooking devices and especially space cooling represents minor consumption. Heating of air and water, with 78 % of households' final energy consumed, presents a high potential for sector coupling, in terms of flexibility: demand response and load profile shaping.

The lowest proportions of energy used for space heating are observed in Malta (18 %), Portugal (27 %) and Cyprus (37 %); the highest in Luxembourg (82 %), Belgium (73 %), Slovakia (73 %), Estonia (71 %), Hungary (71 %) and Lithuania (70 %).

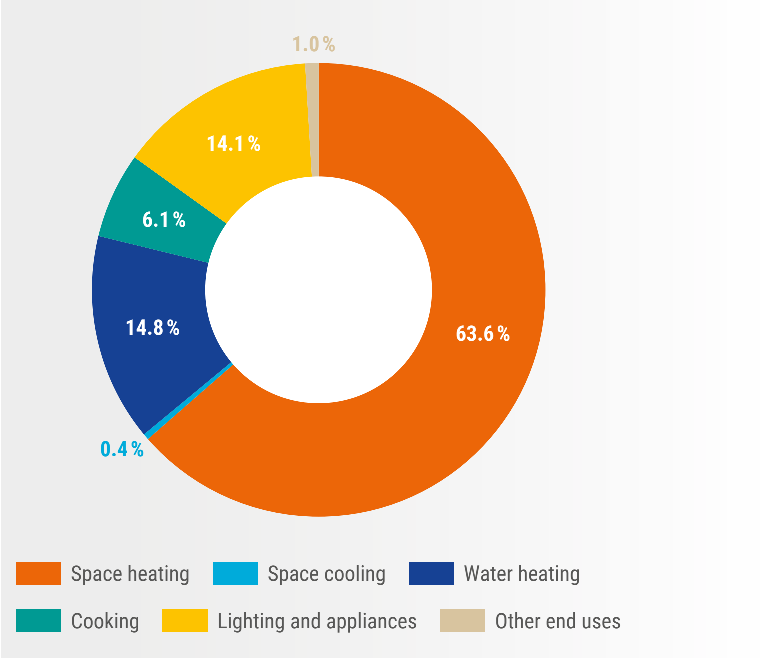

Figure 15. Final energy consumption in the residential sector by type of end-use, EU, 2019 (Eurostat).

2.2.3 Use of energy products in households by purpose

Most of the **energy products** are almost exclusively used for **space and water heating** (from 93 % of oil products to 100 % of derived heat); only electricity has a wider use (58 % for lighting & appliances, 26 % for heating space and water, 12 % for cooking and 2 % for cooling (Fig. 16).

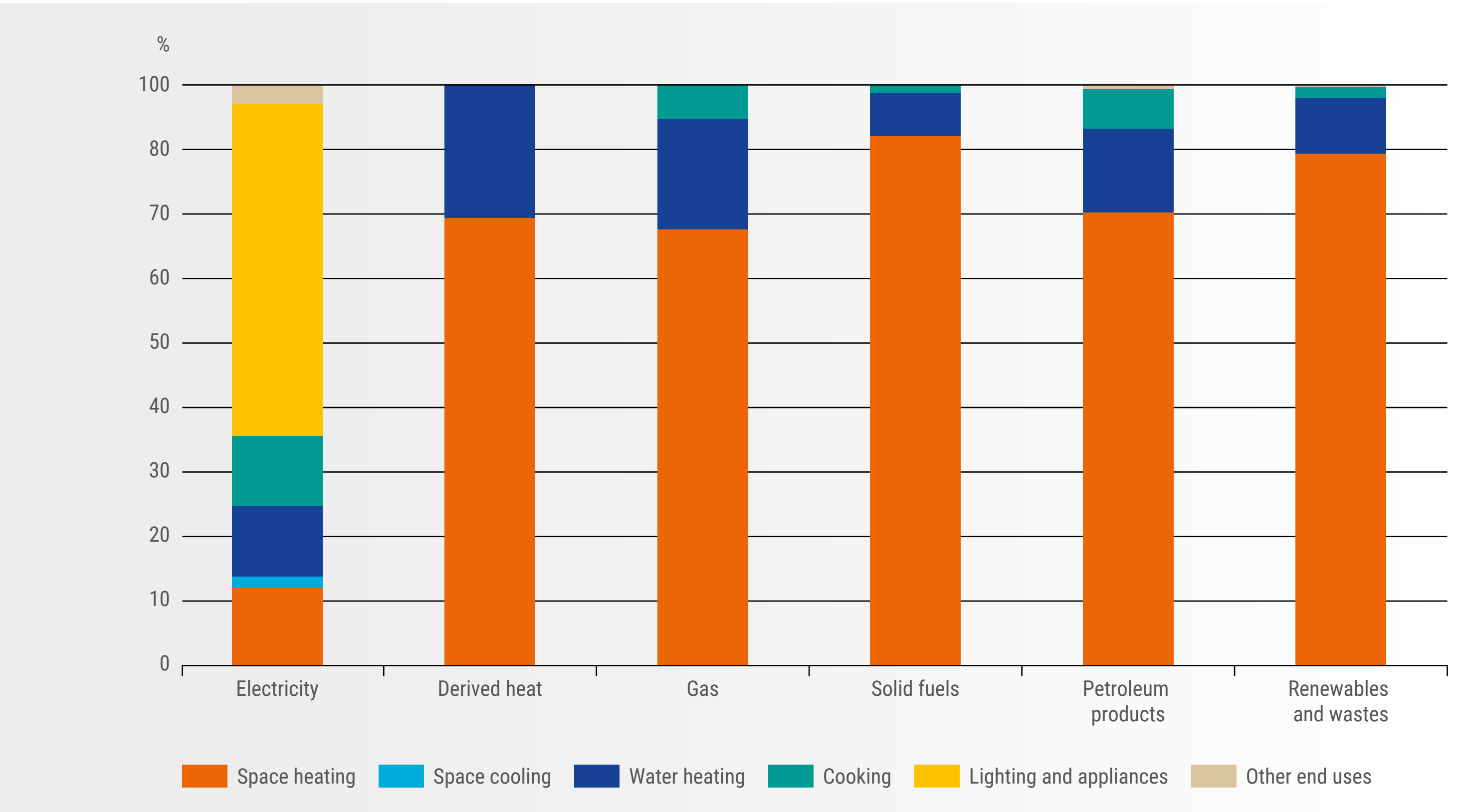

Figure 16. Final energy consumption in the residential sector by type of end-uses by energy products (Eurostat).

The symmetric analysis (Fig. 17) shows that electricity covers 100 % of the energy needs for lighting and space cooling, 82 % for the other end-uses and 50 % for cooling. **Gas** plays an essential role in **space heating, water heating** and cooking, respectively 38 % and 41 % and 31 %. Renewables cover 28 % of the energy needs for space heating, 13 % for water heating and 6 % for cooking. Derived heat plays an important role only in water heating (13 %) and in space heating (10 %), whereas oil products still cover 14 % of space heating energy use, 13 % of cooking and 11 % of water heating (Fig. 17).

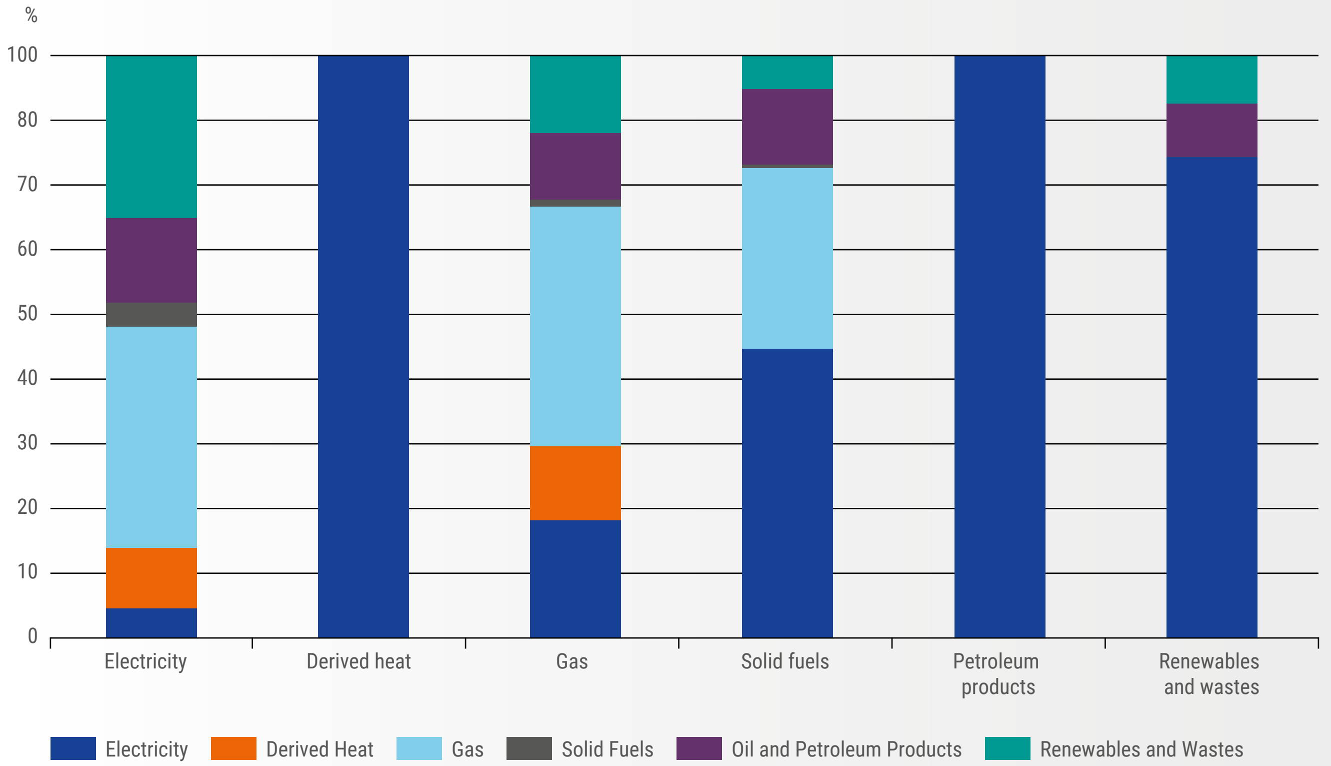

Figure 17. Part of the main energy products in the final energy consumption in the residential sector for each type of end-use (Eurostat), 2019.

2.3 Overview of the H&C Technologies

Key concepts and outcomes are reported here. A basic taxonomy of heating systems can be sketched as per the figure below; focus of innovation is today on electric-based and on sustainable renewables technologies.

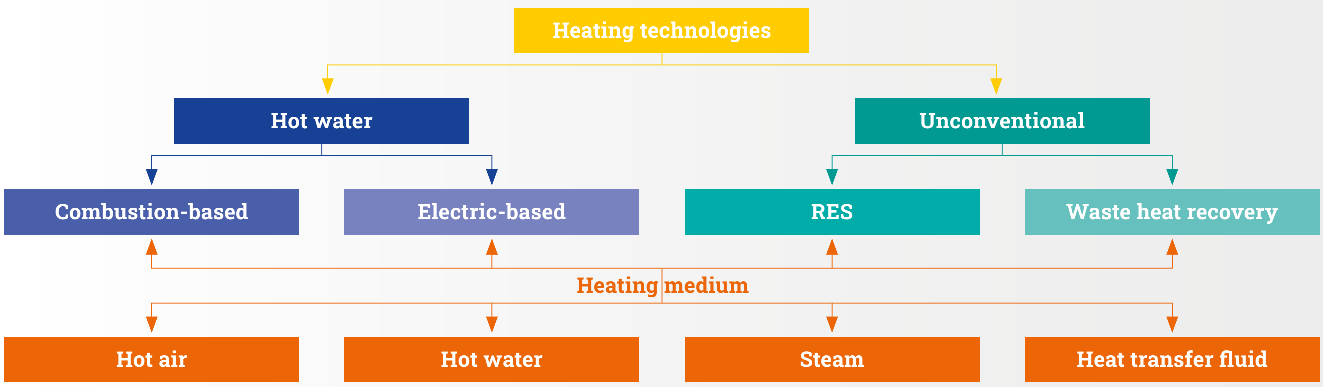

Figure 18. Classification of heating technologies by energy source, location of the equipment and heat transfer medium.

Mature available H&C technologies for the residential and tertiary sectors that are considered as best choices for their technical merits, provided comfort, economic viability and CO_2 reduction potential are presented in Table 1.

Technology	Characteristics					
	Space needs	**Availability of sources**	**Efficiency**	**Combined technologies***	**Easy use**	**Installation cost**
Condensing gas boilers	Medium	Gas grid	Higher efficiency than traditional boilers	Solar thermal, Heat pumps	Yes	Low
Biomass boilers	Space for biomass storage	Biomass	Presents improving margin	Solar thermal	Requires ordering and delivery of fuel, clean-ing of the ashtray	Higher than gas boilers
CHP, fuel cells (co-production of heat and power)	Limited	Electricity, as (or other fuel), hydrogen	High fuel efficiency, efficiency losses with decreasing capacity,	Gas boiler (covering peak load), storage	Yes	Depends on technology and size
Solar thermal	Depends on roof construction	Depends on solar irradiation	Is improved with high consumption per m^2 collector	Boilers, Storage	Yes	Depends on type
Thermally driven heat pumps	Significant**	Free heat source: air, water, ground	Typically, lower than electric heat pumps, but less affected by tempera-ture difference	Heat storage (serves flexible demand), PV, Hybrid heat pumps***	Yes, also easy to remote control	Lower than electric heat pumps (smaller units)
Electric heat pumps	Significant**		Produce heat with a relative high energy efficiency, Affected by temperature difference			High
Electric heating (resistors)	Very low	Electricity	Less efficient than heat pumps	Heat storage	Yes, also easy to remote control	Low

* Commercially available **Space is required for the heat pump itself as well as the infrastructure for collecting the heat from the heat source
*** Combination of an electric heat pump with a condensing boiler

Table 1. Commercially available technologies for H&C sector in residential and tertiary sectors

The main technologies for the H&C Sector in industry sector, along with a brief description of their main characteristics, are given in Table 2.

Technology	Characteristics
Natural gas boilers for industry	High utilisation of energy input; emissions can be low using the right technologies
Oil boilers for industry	High utilisation of energy input; emissions can be low using the right technologies
Biomass boilers for industry	Uses a CO_2 neutral energy source
Economisers for boilers for industry	Increases the energy efficiency
Heat pumps for industry	Produce heat with a high energy efficiency
Thermally driven cooling	Utilises waste heat for producing cooling
Mechanically driven compression cooling	Produces cooling with a high energy efficiency
Free cooling, seawater	Produces cooling from a renewable and CO_2 free resource at nearly no energy cost; only slightly exposed to yearly temperature changes
Free cooling, groundwater	Produces cooling from a renewable and CO_2 free resource at nearly no energy cost
Cooling tower	Produces cooling from a renewable and CO_2 free resource at nearly no energy cost; very exposed to changes in weather

Table 2. Available technologies for H&C Sector in industry sector

According to the location and perimeter of the heating device, the heating systems can be classified as per the table below.

Category	Type
Individual flat heating systems	› Fireplaces and stoves (wooden pellet) › Natural gas (potentially hydrogen in future) › Biomass boilers › Electric boilers and resistors › Electric-driven heat pumps › Fan coil units › Solar collectors
Central heating systems (in building level)	› Natural gas or oil burning boilers › Biomass (wood or pellet) boilers › Gas-driven heat pumps › Electric-driven heat pumps › Solar collectors
District Heating	› CHP › Electric- and gas-driven boilers › Electric- and gas-driven heat pumps › Solar heating units › Waste to heat

Table 3. Classification approach of the common heating systems based on the location of the device that provides the heat, i.e. in local and central systems

2.3.1 Heat Pumps

Running on clean electricity, heat pumps would not only reduce emissions associated with the heating sector but also increase the efficiency of the energy system. Furthermore, when using fossil electricity, the CO_2 emissions for a kWh of heat can be lower than burning the fossil fuel. This results from the high performance that this technology can provide, using either ground or air source reservoirs, delivering a thermal output several times greater than the required electric input.

Efficiency

Electric heat pumps could be used in wide applications and very different heat sources. That is why a general approach is introduced to estimate the Coefficient Of Performance (COP) based on the temperature levels (source, sink).

The COP of electrical heat pumps is a function of the temperature of the heat source (in this case the ambient temperature) and the temperature of the heat sink (in this case the supply temperature in the central heating system). Therefore, the energetic performance of electrical heat pumps should be evaluated according to local conditions and thus be evaluated as a Seasonal Coefficient Of Performance (SCOP) when compared with other alternatives.

COP (Coefficient Of Performance):

Describes the efficiency of the heat pump and is defined as the ratio between the useful heat transfer for heating or cooling and the required drive energy, considering temperature variances and loads of the heat pumps. The useful energy can either be heating or cooling energy depending on if the heat pump is used to provide heating or cooling. The COP is normally related to a specific operating condition. For cooling and air conditioning applications EER, Energy Efficiency Ratio, is sometimes used instead of COP.

SCOP (Seasonal Coefficient of Performance)

Describes the average COP during a heating season. Depending on the definition, the SCOP value could also include other parts of the heating system than only the heat pump. For cooling and air conditioning applications SEER, Seasonal Energy Efficiency Ratio, is normally used.

Figure 19 and the following tables present the basic principle of compressor-driven heat pumps and the main characteristics of their typologies.

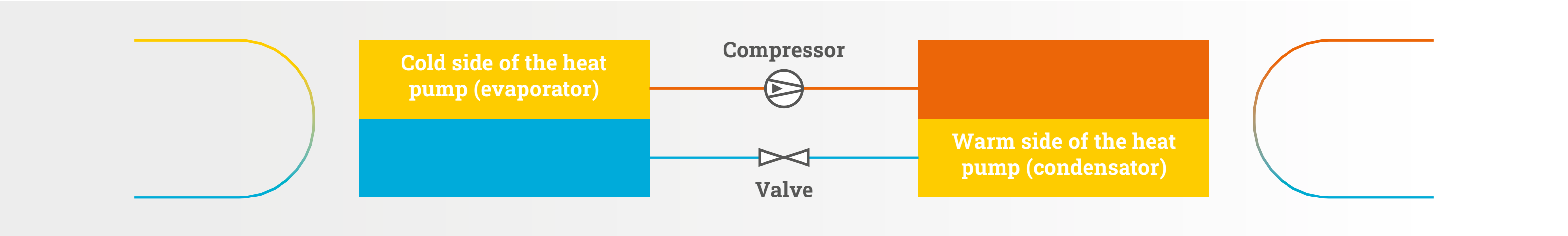

Figure 19. Compression-heat pump. An engine driven heat pump is similar as the compressor can be engine- or electrical-driven. The main difference to sorption-driven heat pumps is the way the refrigerant is regenerated[6,7].

Size/Application	
Small Scale › Residential Sector (up to 20 kW thermal for single-family housing, more for multiple) › Tertiary Sector (several hundred kilowatts thermal)	Large scale › Industry › District H&C (in the order of magnitude of one or more MW thermal)
Heat Pump Unit Type (design or operational principle) Sources (usable for all types): Air-to-Air (A-A), Air-to-Water (A-W), Ground Source (Geothermal): Horizontal/Vertical, Ground Water, Exhaust Air	
Compressor-driven (Mechanically driven)	
› Electrically driven	› Gas engines driven › Gas engine driven heat pump air/brine to water › Gas engine groundwater
Sorption (Thermally-driven)	
› Gas driven › Direct fired absorption heat pump air/brine to water	› Heat (Hot water, steam) › Absorption
› Adsorption heat pump brine to water	› Water/Lithium Bromide › Ammonia/Water › Adsorption

Table 4. Categorisation of heat pumps by type of size/application and heat pump unit itself.

	Electrically Driven	Gas driven heat pumps	Absorption driven (single effect)
Thermal power output (MW_{th})	1–10	0.025–0.85	0.15–12
Cooling generation capacity (MW_{th})	0.7–7	0.025–0.7	0.1–10
COP Heating/Cooling (%)	350/205	120/100	170/70
Electricity consumption (%/MW_{th})	10	1.2	1.5

Table 5. Efficiency characteristics of large-scale heat pumps[8]

6 https://publications.jrc.ec.europa.eu/repository/handle/JRC109034

7 https://heatpumpingtechnologies.org/market-technology/heat-pump-work/

8 https://publications.jrc.ec.europa.eu/repository/handle/JRC109006

2.3.2 Combined Heat and Power

CHP enables the integration of the energy system by efficiently linking electricity, heat and gas (including future decarbonised gases) at the local level and providing energy when and where needed.

Overall, CHP is found to be an efficient enabler for reaching carbon neutrality by 2050, and it is also versatile for many applications:

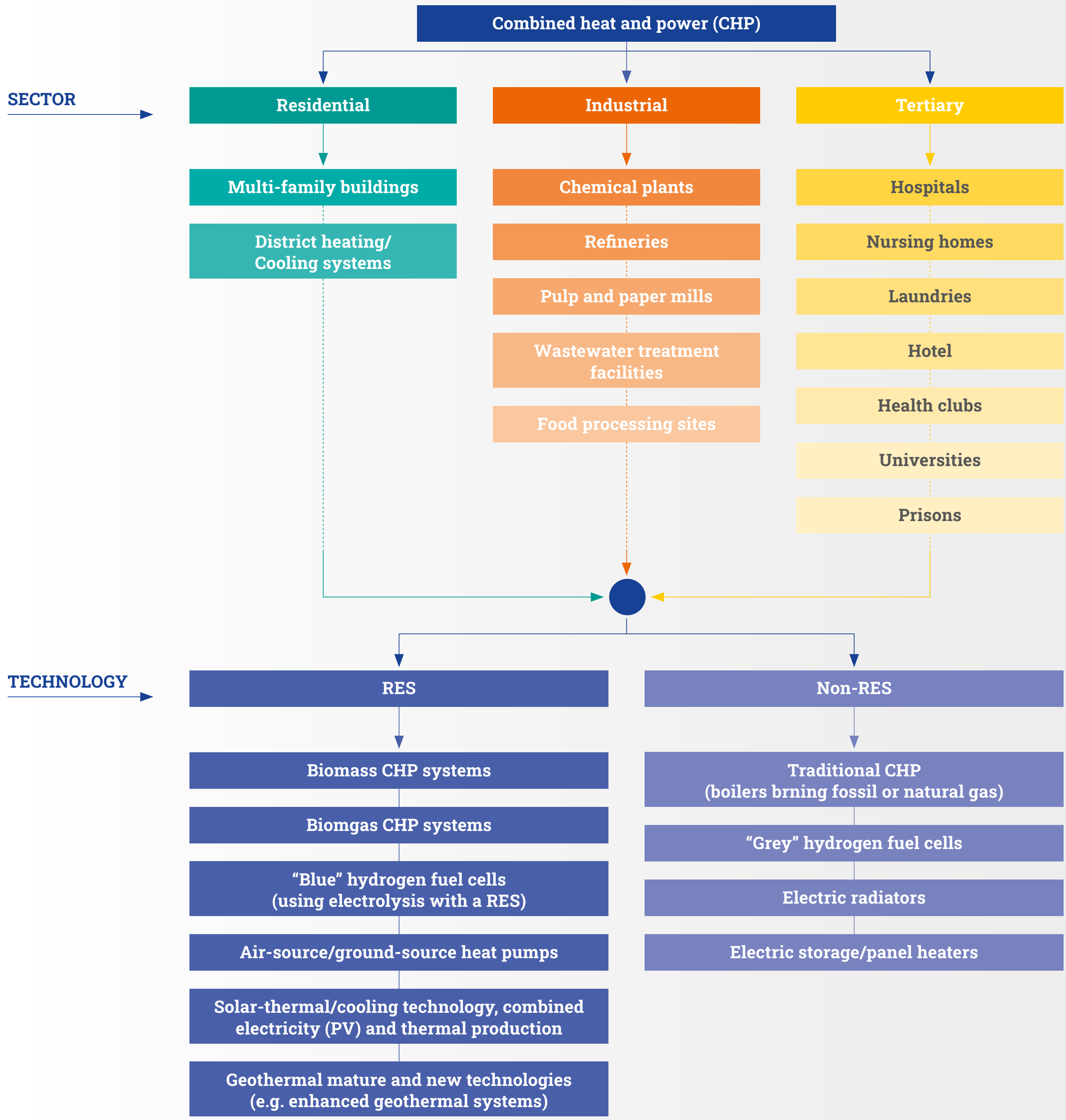

Figure 20. CHP technologies in the different sectors (to replace RES: "green" hydrogen, Non-RES: "Blue", "Grey" Hydrogen)

Main innovation points, drivers and barriers

- Electrical efficiency is expected to increase, especially for gas engine/turbines and fuel cell.
- Lifetime is expected to increase by 5 to 10 years for most technologies.
- Expectations of fuel cell CHP learning potential is very high as both CAPEX and lifetime.
- CHP can be considered "hydrogen ready" to the extent that it can operate on a blend of hydrogen and natural gas.
- CHP can flexibly and cost-effectively operate in thermal networks introducing an intrinsic flexibility element between power and thermal systems' respective needs: the deployment of CHP plants together with thermal networks may unlock the potential of centralised thermal storage.
- CHP does not compete but complements variable renewable generation to meet seasonal peak demand due to high shares of electrified heat, alongside batteries, hydro storage and demand-side management to meet electricity system needs.
- The lack of available thermal networks to distribute the cogenerated heat is the major bottleneck concerning the utilisation of new CHP plants.
- The market structure and the national/European regulatory context do not necessarily allow CHP to capture all the value they bring to the heat and power systems, including the avoidance of electricity network reinforcement costs.
- Revenue streams, taxes and tariffs may not always provide appropriate price signals to projects that are cost-effective from a system perspective.
- CHP can be optimised to maximise system energy/resource efficiency and flexibility, complementing high variable RES electricity generation technologies; CHP are used as a mid-merit technology: they stop producing when renewables and nuclear generation are sufficient to cover the demand. Therefore, CHP does not displace variable renewables or nuclear power.

2.3.3 District Heating

4th generation district networks work at low temperature (50°) networks, resulting in reduced heat loss and making it feasible to connect to areas with low energy density buildings; they will allow more heat sources to be incorporated, even those with poorer quality from an exergy perspective (low temperature resources). The use of these sources can alleviate the power system load, maximising the utilisation of RES. The 4th generation systems are located closer to load centres and generators than traditional central-station generating plants, and the distributive nature and scale of these systems allows for a more nodal and web-like framework, enhancing accessibility to the grid through multiple points. 4th generation systems can use diverse sources of heat, including low-grade waste heat, and can also allow consumers to supply heat.

The piping is the most expensive portion (50 % to 75 %) of DH and usually consists of a combination of reinsulated and field-insulated pipes in both concrete tunnel and direct burial applications, so it is important to optimise its layout and use, possibly in a coordinate manner with power grid expansions. The progressive adoption of low temperature and pressure networks, together with the more widespread use of insulated pipes and leak detection technologies, have allowed for reduced heat losses and the corresponding substantial increase of efficiency in heat distribution.

Heat storage technologies are key for district heating systems under the sector integration perspective. They contribute to reducing the gaps between heat demand and generation caused by both time difference due to the intermittence of heat generation sources (e. g. solar) or cost fluctuations of the thermal energy throughout the day. Heat storage technologies can be deployed daily up to seasonally, allowing the decoupling of heat demand and production and enabling heat to be supplied in the most cost-effective manner.

The in-building equipment (or customer installation, i.e. radiators, pipes and substation) need to be considered as well, and can be equipped with additional equipment such as individual heat storage or accumulation tanks, or a heat pump for temperature boosting in the case of low temperature networks. Control and billing systems are often installed with the substation. Digitalisation for customer empowerment is a fundamental enabler. District cooling has a huge potential to reduce the increasing electricity demand and the rejection of waste heat into the urban environment linked to massive use of air conditioning and chillers. This can be a significant factor in reducing the Urban Heat Island effect.

The low temperatures of modern DH systems allow the integration of local, distributed heat and cold generation as well as waste heat and cold reutilisation. This can lead to significant energy savings and a drastic reduction of primary energy use and CO_2 emissions. Such a strategy, however, requires that the building stock is prepared for receiving the low temperature heating, respectively the high temperature cooling. Integrated urban planning and the development of proper heat zoning plans shall first guarantee a coherent energy strategy at the level of districts, the city and its hinterland. However, this also implies that proper building retrofit strategies are implemented.

2.3.4 Biomass

Biomass is the largest RES contributing to the H&C trajectories for renewable energy up to 2030.

Biogas is a versatile renewable fuel used for electricity generation (57 %) but is also a very effective solution for heat generation. Furthermore, when upgraded to biomethane, it can be injected into the existing gas grid or used as a renewable fuel to support the decarbonisation of the transport and heating sectors which depend heavily on fossil fuels.

Wood biomass is of great importance to the production of heat and electricity in district systems using the latest technologies, whereas biomethane is seen as a key fuel to decarbonise the H&C sector, especially for district heating and CHP.

To avoid concerns of sustainability of biomass, RED III and EU 2050 decarbonisation scenarios assume that nearly all biomass for bioenergy will be produced within the EU, with an increasing use on waste and residual materials in the future, as well as forestry certificates showing product quality and sustainability in the whole chain from production to supply.

Challenges identified

- The investment costs required to install biomass heating systems are relatively high (this includes administrative costs linked to permitting, for example chimneys.
- The biomass stock requires significant empty space, contrary to traditional energy solutions, such as the condensing gas boilers.
- Lack of harmonisation of emission testing methods and of standards for the eco-design of biomass heating systems.
- Public acceptance can be also considered a challenge as households are increasingly concerned about deforestation and are unsure whether the production of wood-based biomass is environmentally sustainable.
- Air pollution due to fine dust, NOx and other substances from wood fired heating systems.

2.3.5 Solar-thermal Systems

Challenges identified

- Solar-thermal systems face high upfront investment costs;
- There are still subsidies for fossil fuels and non-renewable technologies, and there are regulated prices for conventional fuels (which is also relevant for other non-fossil technologies);
- A lack of awareness on solar-thermal (as the technology is sometimes confused with solar PV) and a lack of skilled installers as well as informed urban planners and qualified architects has been observed.

Specific measures that will assist in removing these barriers are:

- The incentivisation mechanisms to consumers to adopt solar thermal technologies;
- The training of practitioners in installing solar-thermal systems in residential areas and industries;
- The increase of the R&D efforts and funding.

2.3.6 Thermal Energy Storage

There are several available technologies for this, which can be classified according to the physical phenomenon used for heat storage (sensible, latent, or chemical heat storage), to the location within the network (centralised or distributed), or to the time span of the storage (daily or seasonal storage). Although latent and chemical heat storage technologies are currently less developed, sensible heat storage (where advantage is taken from temperature changes in the storage material) is the most mature and widely used for both short-term (daily, e.g. water tanks) or seasonal (e.g. boreholes, tanks/pits, aquifer) storage. Figure 21. Classification of Thermal Energy Storage Units by a) the type of technology, b) the materials of the TES units (PCM: Phase Changing Materials), c) sector and d) application.

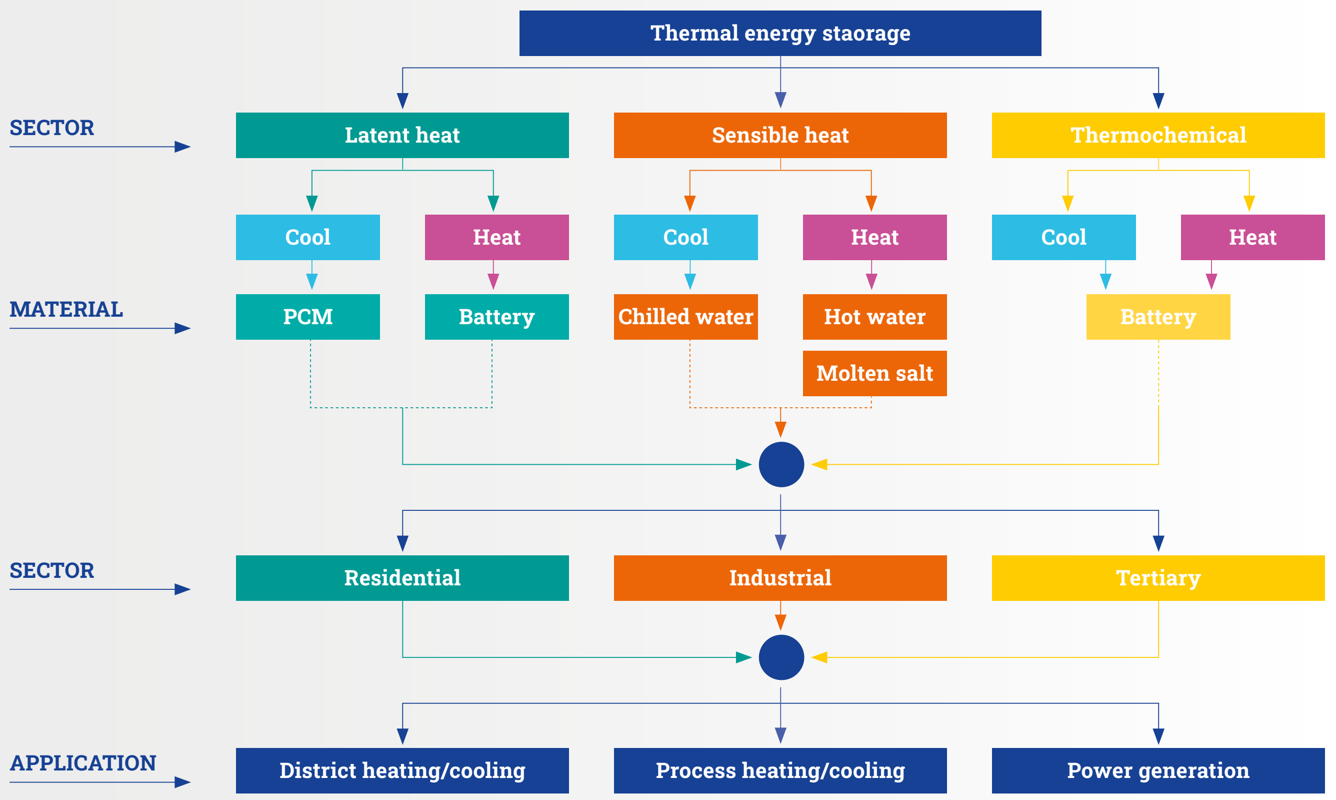

Figure 21. Classification of Thermal Energy Storage Units by a) the type of technology, b) the materials of the TES units (PCM: Phase Changing Materials), c) sector and d) application.

Thermal Energy Storage (TES) is discussed in the current research and the development of thermal energy storage is mainly focused on reducing the costs of high-density storage, including thermochemical process and phase-change material (PCM) development, due to its ability to achieve energy storage densities of 5–20 times greater than sensible storage.

In Figure 22, some key technologies are displayed with respect to their associated initial capital investment requirements and technology risk versus their current phase of development.

The integration of TES is easier during construction. Penetration could be higher in emerging countries with high rates of new buildings. TES potential for CHP and DH is also associated with the building stock.

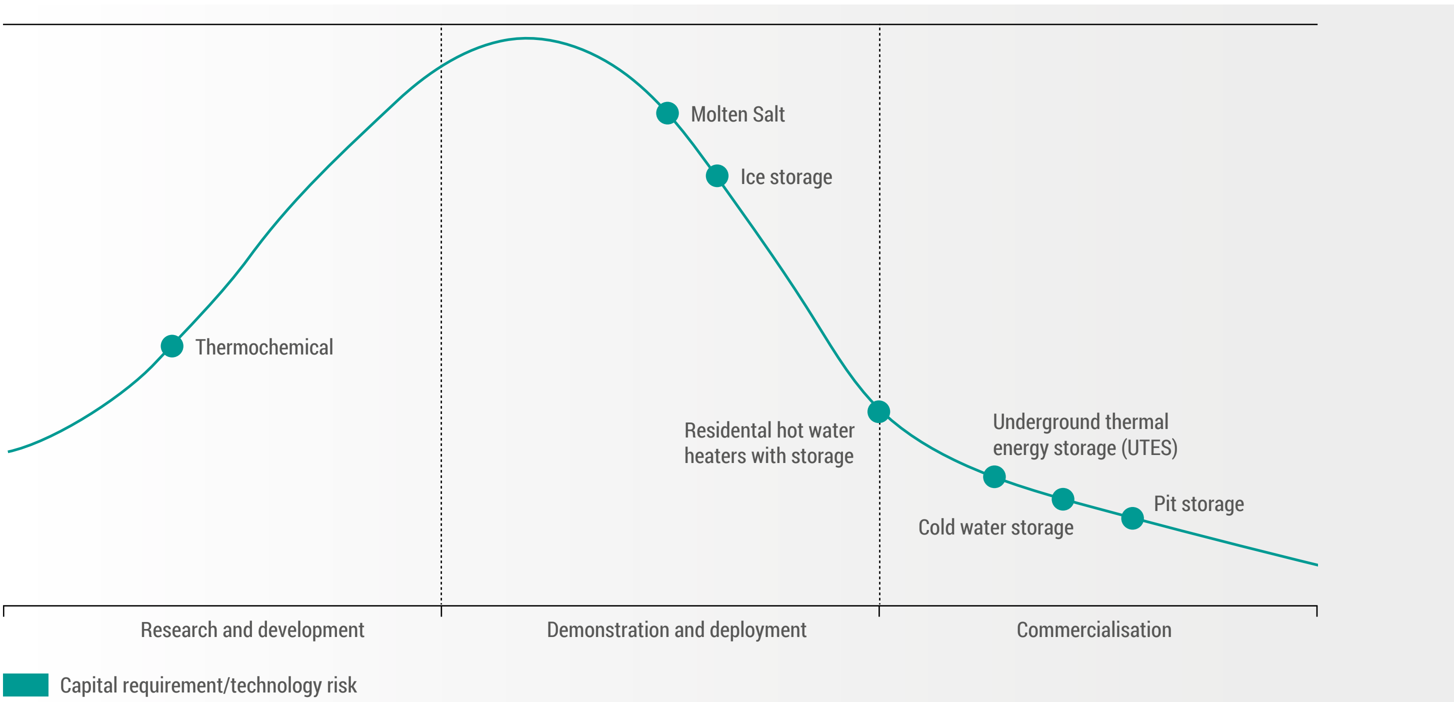

Figure 22. Maturity of thermal energy storage technologies (Source: Seasonal Solar Thermal Energy Storage, Thermal Energy Battery with Nano-enhanced PCM, 2018).

2.4 Renewable Energy Integration prospects

Increasing the share of RES used in H&C sectors will have a positive impact on the decarbonisation efforts for 2050, the EU economy, its citizens and the environment. The Member States have developed their NECPs to reach the 2030 targets and effectively move towards a 100 % renewable H&C. With these data available, **the average target for the RES share in H&C sector for 2030 is 40 %** whereas the current share is 21 %. Thus, H&C is still a carbon intensive sector and there is significant room for improvement towards decarbonisation.

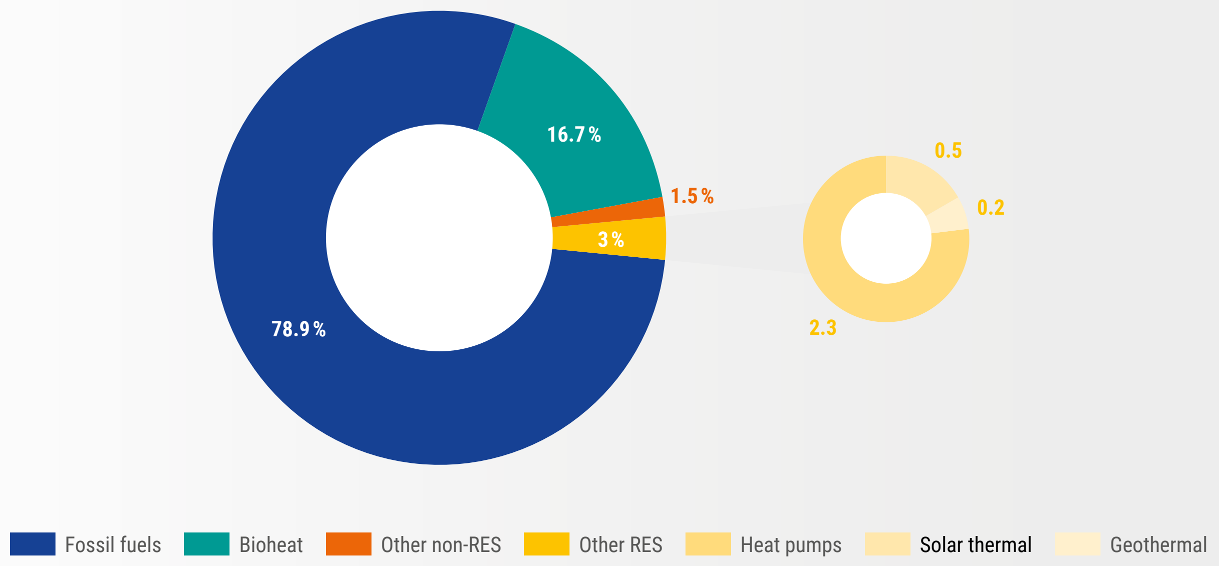

Figure 23. Contribution of the different energy sources in H&C in EU28 in 2018* (in %) (Source: JRC Technical Report, EC, 2019).

2.4.1 Biomass

Biomass is considered a RES (i.e. trees and crops are replanted and waste is continuously produced) and is "controllable" as opposed to wind and solar, meaning that it can be adjusted to meet the energy demand. In addition, the biomass plants can replace fossil fuel plants during their phase-out period, significantly reducing the dependence on carbon-based fuels for energy. Generating energy from organic waste materials can significantly improve waste management and help Member States achieve the EU goals for sustainability and a circular economy.

Sustainable Bioenergy

Sustainable bioenergy reinforced criteria in line with the EU Biodiversity Strategy will:

- Prohibit sourcing biomass for energy production from primary forests, peatlands and wetlands;
- No support for forest biomass in electricity-only installations as of 2026;
- Prohibit national financial incentives for using saw or veneer logs, stumps, and roots for energy generation;
- Require all biomass-based heat and power installations to comply with minimum greenhouse gas saving thresholds;
- Apply the EU sustainability criteria to smaller heat and power installations (equal or above 5 MW).

(Source: EC Factsheet, decarbonising our energy system to meet our climate goals, July 2021)

Uncertainty in the use of biomass for heat: In July 2020, the Social and Economic Council of the Netherlands (SER) published the advisory report "Biomass in Balance", in which it is recommended to reduce the use of bio-based raw materials for low-value applications such as the heating of buildings over the course of the coming years (SER, 2020). Instead of making heat production using biomass more sustainable, the focus will be on developing geothermal and aqua thermal technologies, which are more expensive, more innovative and smaller scale than biomass.

2.4.2 Solar-thermal Systems

Solar-thermal systems can be combined with other H&C technologies, and the variability of the solar source is mitigated using thermal storage. On average, these systems can provide 30–40 % of the annual energy required for space heating and 80–90 % of the energy needed for water heating[9], depending on the relative temperature of the heat source and heat sink. In theory, it could also reach 100 %, depending on the size of the solar field and the heat storage. Solar-thermal systems: a) are characterised by low operational expenditures (OPEX) and stable prices because they do not require fuel usage and the costs are driven mostly by capital expenditures (CAPEX) and performance, b) are scalable, c) do not produce CO_2 emissions, and d) exhibit high temperatures and high energy. It should be underlined that the systems sold in the EU are mostly produced in the EU itself, and the European technology is at the forefront of the innovation worldwide. Nevertheless, the difference between the demand for special heating and the supply of solar energy are maximal oppositional between summer and winter.

2.5 Thermal Energy Storage

Thermal energy storage can be used to optimise different H&C technologies, i.e. managing the excessive clean energy from variable RES and providing flexibility for the thermal consumers and the electric system. Current research and development of TES is mainly focused on reducing the costs of high-density storage, including thermochemical process and phase-change material development. The feasibility of TES is based on a specific design and technology.

Major barriers to the wider spread of TES in DH networks are:

- Technical restrictions, such as: TES thermal losses, storage density of water tanks, phase-change material tank limitations regarding the material fatigue and restricted discharging power;
- Economical/market barriers, such as the high investment cost and the country-specific boundary conditions (high diversity of the TES market development, promotion and penetration).

Finally, the TES potential is associated with the building stock; given that the integration of TES is easier during construction, the penetration could be limited in countries with low rates of new building construction.

9 "Competitiveness of the heating and cooling industry and services", Part 1 of the Study on the competitiveness of the renewable energy sector, EUROPEAN COMMISSION, ENER/C2/2016-501 28 June 2019

3 Power to Heat and Electricity System Integration

3.1 Future scenarios

Heat Roadmap Europe (HRE) studies – which promote DH for future energy systems – have analysed heat supply in Europe, focusing on the increasing share of DH to cover approximately 50 % of heat demand in 2050. From this DH production, large heat pumps would produce 25–30 % of the total DH production.

To investigate the optimal electrification levels that provide benefits to the energy system, alternative scenarios regarding the built environment on an EU level have been created which vary according to the level of electrification as well as the technologies selected to be replaced by heat pumps. The baseline scenario (BLS), used as reference, is defined developed according to the European heat scenarios in 2015. The EL20–EL100 scenarios describe a stepwise replacement of decentralised-fossil and resistive-electric heaters with heat pumps. The number in the scenario name refers to the replacement rate of fossil-fuel-driven technologies, i.e. 100 implies that all decentralised fossil fuel technologies are replaced with heat pumps. These technologies were chosen as they are the main sources of CO_2 emissions in the European building's heat sector. The EL100BIO scenario assumes a displacement of biomass in the heat sector. The EL100ALL scenario describes a fully electrified heat sector in Europe, to quantify the maximum impact of electrification (although it is not realistic, it serves as an upper limit). In comparison to the EL100BIO, it is additionally assumed that all the households connected to heating networks have switched to heat pumps.

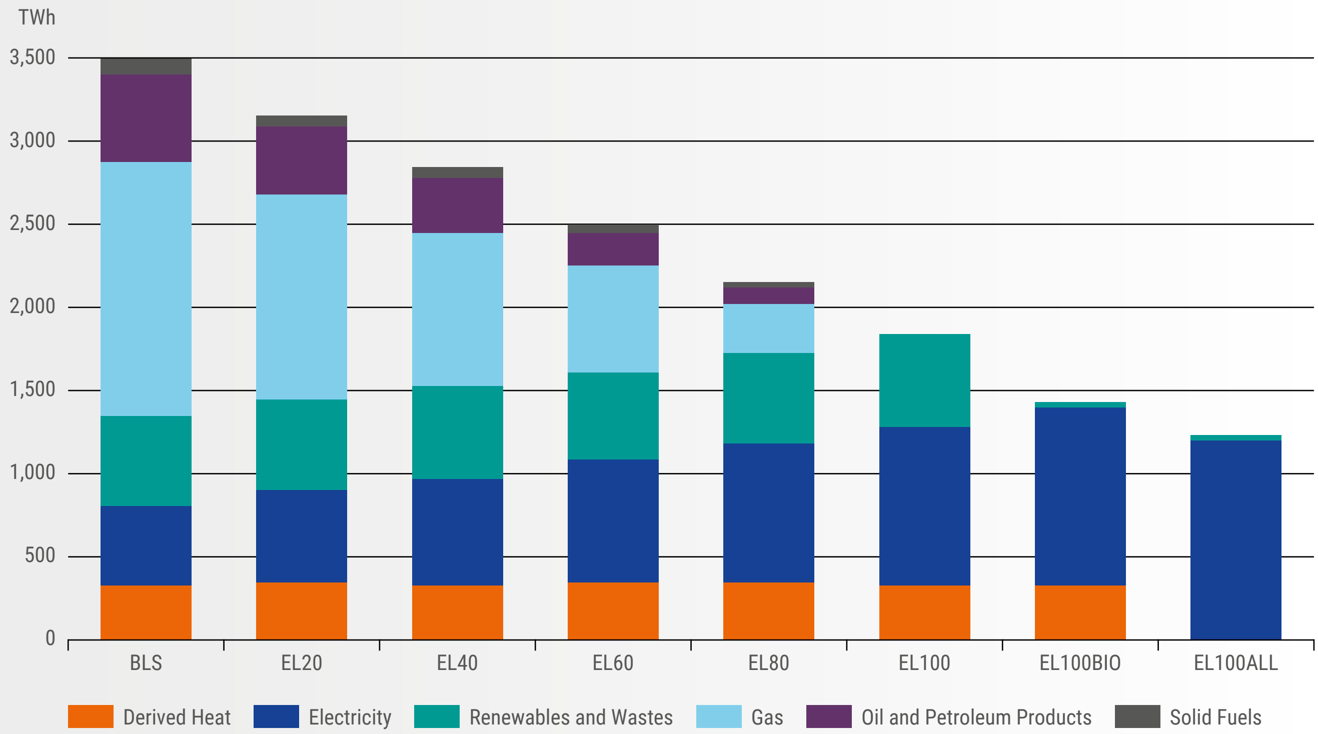

Figure 24. Scenarios for the electrification of the heating services — space heating and domestic hot water — of the built environment on an EU level. Derived heat describes heat delivered by heating networks (Source: JRC Technical Report, EC, 2019).

According to an initial parametric analysis regarding the decarbonisation of the EU heating sector through electrification[10], most EU national power systems could cope with higher heat-electrification rates due to the relative sizes of heat and power demands. Specifically, an additional heat pump capacity in the order of 1.1–1.6 TWth 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 (BG, CZ, DK, EE, EL, ES, HR, IE, LT, PT, RO, SE) could be prepared for even full electrification scenarios, whereas 3 Member States (AT, BE, FI) would require enhancements in their power systems to accommodate 40–60 % fossil-fuelled heating technologies being substituted by electricity. Flexible electric demand is identified as a key enabler of larger heat electrification shares. A more thorough study should be performed by ENTSO-E in the future, using the more accurate probabilistic methodology developed in the ENTSOE Seasonal Outlooks or in ERAA.

3.2 Electrification of the H&C sector

3.2.1 Flexibility Provision Capabilities

The electrification of the H&C sector is an efficient option for the consumers, providing excellent geographical coverage, high efficiency, environmental sustainability on a RES-based electricity generation mix and level of comfort. H&C assets have an implicit flexibility (i.e. thermal buffer of closed environments) that guarantee a low marginal cost of participation into balancing and other schemes.

Wholesale market price signal activation:

- Flexible CHP can provide heat for DH networks as well as balancing services for the electrical grid. CHP can provide downward services (less generation) but jeopardise heat demand (with respect to which CHP is usually designed) or upward services if heat demand allows (assuming it is not coupled with thermal/electrical storage) Cogeneration plants which traditionally use natural gas are expected to transit to carbon-neutral synthetic fuels.
- The electrification of the H&C sector will be driven by significant investments into heat production using electric boilers or heat pumps, which are suitable for both up and down power regulation (i.e. to increase or decrease electricity consumption respectively). This concerns new installations but in the short/medium term, the prevalence will be on retrofits. These solutions will enable consumers and heat operators to tap into the balancing markets and take advantage of the increased number of hours with low electricity prices while still meeting heat demand. High-RES generation can drive down energy prices but makes Active System Management situation more volatile, creating hedging opportunities between energy spot prices and services.
- Market regulation should facilitate the participation of these flexible heating resources into the energy mix with enabling means. Regulation shall create an ecosystem which involves the participation of distributed resources in the market by defining the most efficient requirements (technical and economical), evaluating the combinations of spot market participation and futures market. For example, one way of participating in both Reserve Capacity and Spot Markets is to utilise an optimisation and bidding strategy that simultaneously targets both markets.

Digitalisation shall have a role as an enabling tool to reduce or eliminate the barriers (costs) that distributed flex assets have when building the necessary infrastructure to participate in the balancing market. The digital tool facilitates the data exchange, offering a solution to reduce reliance on hardware when opting for certification chains based on Software. In this context, digitalisation will be the key enabler for the transition phase, enhancing the communications and data exchanges among system operators and flexibility providers:

- Regarding system balancing, the condition for qualifications implies a) the connection of units or portfolio of units to the TSO's Control Centre, b) a real time data exchange and specific response time and c) definition of prequalification conditions.
- Participation of P2Heat assets or portfolio of assets in Reserve Capacity Markets, i.e. aFRR and mFRR need a multi-stage/multi-player process for generating the day-ahead heat plans. Although participation in mFRR is less complicated, it requires an activation signal provided by the TSO's Control Centre.

10 Source: "The decarbonisation of the EU heating sector through electrification: A parametric analysis", Energy Policy, 148, 2021

- Participation in FCR involves hard technical requirements, such as dedicated local controllers including fast measurements of grid frequency, a runtime dispatcher for asset portfolios and fast communication between P2Heat units and local controller. Moreover, the portfolio of assets must be able to respond fast when frequency deviations are occurring in the power system.

H&C systems can provide flexibility (when the driver is electricity consumption) for congestion management (redispatch) and congestion alleviation:

- Additional water-based heat storage can be used to shift power production. Heat storage offers flexibility in a simple, relatively efficient, and low-cost manner. The long-term flexibility of the storage facilities is related to cost-efficiency (large investments required).

- The responsibility for implementing this algorithm (congestion management and balancing) may fall under the existing energy traders or Balancing Responsible Parties (BRPs) for physical assets or Balancing Services Parties (BSPs) for aggregated assets. However, this may expand the business cases for each of these players, i.e. an energy trader to be qualified as BRP or a BSP taking the responsibility of energy trade. Alternatively, a new player that has the capability to perform both roles, i.e. an energy trader and BRP with a wide range of assets in portfolio, may be considered.

- Most of the existing P2Heat units today were installed and commissioned according to requirements imposed by the thermal supply, whereas the fast electrical control, performance and data exchange with the TSO was not considered. Thus, enabling the existing P2Heat units to enter the ancillary service markets will require additional costs for retrofitting, i.e. modifications in local control to meet both the thermal demand but also the fast response in electrical power output. However, the new installations may account for all these aspects from the planning and design phase.

CHP: More flexibility can be provided by the thermal generation

The use of CHP generated in centralised power plants and delivered via district heating is a highly efficient option to serve both heat and electricity needs. CHP can operate as a baseload unit while also providing flexibility if necessary. For the heat and power sector coupling, some features that make this integration favourable are:

- The highly efficient CHP production and district H&C;

- The cost-effectiveness of the thermal energy storage compared to the electric energy storage units;

- The flexible P2Heat technologies.

The Effect of Thermal Energy Storage

Heat storage allows the combined benefit of high RES and CHP deployment by increasing the flexibility of the system and thereby facilitating the integration of both energy sources. The benefit derived from the incorporation of thermal storage becomes relevant when high-RES electricity production has to be incorporated in the systems, instead of being curtailed.

TES Concepts: Key components are electric power from wind and heat pumps exchanging with seawater

The seawater storage can be loaded using solar energy and seawater heat pumps. Because of the long time (approximately 6 months) to load the storage, the specific time periods and loading capacities can be selected freely and adjusted to the time periods when wind power is available; therefore, the electricity has the lowest costs.

The energy content of the heat storage depends on the volume (m^3) and the temperature difference (°C) between the empty and full storage. **Standard pit heat storage** is a well-known solution. The volume of the biggest existing pit heat storage is 200,000 m^3.

An alternative is a **fully floating storage**. This solution is more experimental and will need to deal with shallow seabeds and the forces generated by tides and frozen sea during the winter. Such a solution could draw on recent developments in offshore wind farm technology and would be easily replicable worldwide. (Source: “Helsinki ‘s Hot Heart“ Storage, Helen Energy and Electricity Company)

Solar thermal energy and seasonal underground thermal energy storage for a DH scheme

The surplus heat (or cold) produced with renewable energy n summer (or in winter) can be stored in thermal reservoirs (mainly aquifers), which then can be used to meet the winter (or the summer) heating demand, thereby reducing the need for non-renewable heat sources during peak times. The use of phase-change materials, which are efficient against energy loss and are substances that release or absorb enough heat to maintain a regulated temperature, can be a good solution.

3.2.2 Impact on the Energy System

Heat pumps' integration in District H&C Systems

- Heat pumps represent a competitive option to biomass. While biomass boilers focus on heat generation, heat pumps are increasingly focusing on electricity (high connected loads, etc.). Services such as participation in the energy balancing market could generate additional income, but from the perspective of the small biomass operators this is too expensive, or else the knowledge about this "new business" too low and thus the risk too great.

- The addition of a new domain (electricity in addition to heat) brings additional hurdles especially for rural heating network operators with regards to new requirements, regulations and know-how.

- The shift towards more large-scale heat pumps clearly implies a reduction in energy input to district heating networks. However, whether this goes along with a reduction in heat production costs and CO_2 emissions strongly depends on the individual electricity price and the carbon content in each country, as well as on the heat mix of the displaced heat networks and of the replacing heat pump-based heat network.

The mass adoption of the electrified H&C sector solutions by consumers will require the design of new business models that facilitate flexibility provision through controllable H&C systems. Thus, in the future, the selection of electrified H&C solutions would become the preferable choice, providing the existence of tangible benefits, and not just an obligation.

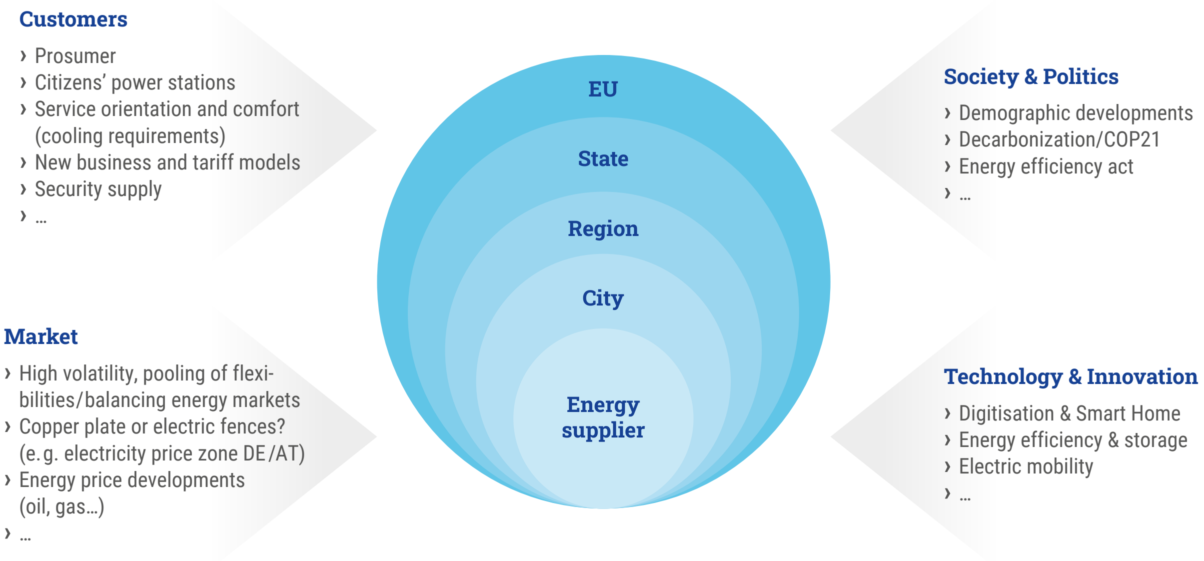

Figure 25. Aspects and challenges for district heating network operators/energy suppliers (Source: Heat Pumps in District Heating and Cooling Systems, Task 4: Implementation barriers, possibilities, and solutions. IEA Report, 2019).

Heat pumps to become mainstream

Heat pump technology is identified by the EU Strategy for Energy System Integration as a key technology to decarbonise space heating and domestic hot water production, as well as cooling for buildings and industry. The heat pump sector is already the biggest contributor to the increase in renewable energy production for H&C across the European Union. According to Eurostat's SHARES tool, heat pumps accounted for just over half the increase in renewably sourced H&C in the EU between 2016 and 2018, or 1.4 Mtoe (16.3 TWh) of the 2.5 Mtoe (29.1 TWh) increase (this number refers to all heat pumps, including industrial heat pumps, but industrial heat pumps represent only a very small share of the total) (Source: COM (2020) 299).

Considering the heating related heat pumps, the installed stock amounted to 14.8 million units in 2020, after a growth of 12 % per year over the last 10 years in the 21 European countries according to the European Heat Pump Association (EHPA), to reach 250 TWh of usable heat generation in 2020. Heat pumps have proven popular in northern European countries. Today, Norway has 1.4 million, Sweden 1.9 million, Finland 968,000, Denmark 390,000 and Estonia 179,000. If trends continue, the EHPA estimates that there will be some 600 million units worldwide in 2030, whereas in Europe they will reach approximately 72 million units.

Flexible heat pumps ideal for power grids congested by solar and wind

Smart heating systems and heat pumps that can be powered by solar and wind energy provide flexible electricity demand, particularly beneficial solutions in areas with high grid reinforcement costs where flexibility could provide a cheaper alternative.

3.2.3 Impact on the Power System

According to studies for the years 2030 and 2050, the share of electricity in buildings and tertiary heating demand should grow to 40 % and could reach up to 70 % respectively. Increased electrification of the heating sector will increase the number of hours of high demand in the Load Duration Curve and Peak demand in general as shown in Fig. 26. Based on a JRC study, Winter peaks could increase by 20 % to 70 %, with the biggest changes expected in Germany, Italy and the UK. In the future, ENTSO-E will most probably revise the abovementioned preliminary figures using its Seasonal Outlook and ERAA methodology.

The steep profile of the Load Duration Curve (Fig. 26) illustrates a highly variable energy demand, implying a small number of hours with a very-high demand. However, demand-side flexibility could reduce the number of hours with a very-high demand in the increased electrification scenarios, spreading out the peak demand more evenly. Under this frame, the mass adoption of the H&C sector solutions by consumers will require the design of new business models that facilitate flexibility provision.

Referring to the JRC study, Fig. 27 illustrates the threat of a capacity shortage in the future, due to the decommissioning of firm capacities as part of the power-system transformation towards its decarbonisation. The amount of energy which is not covered by the firm capacities (based on the capacities from the POTEnCIA central scenario) has been calculated on a country basis and then aggregated to the EU27+UK level. As shown for the electrification 100 % (EL100) scenario, the energy demand exceeding the firm capacity remains constant, between 1.5 and 3 %, up to 2030. In the longer run, however, it rises to 9 %. This indicates that, along its transformation, the likelihood of shortfalls increases as the firm capacity level could shrink notably due a stronger reliance on variable renewable generation after 2030. In the future, ENTSO-E will revise the abovementioned figures using its Seasonal Outlook and ERAA methodology.

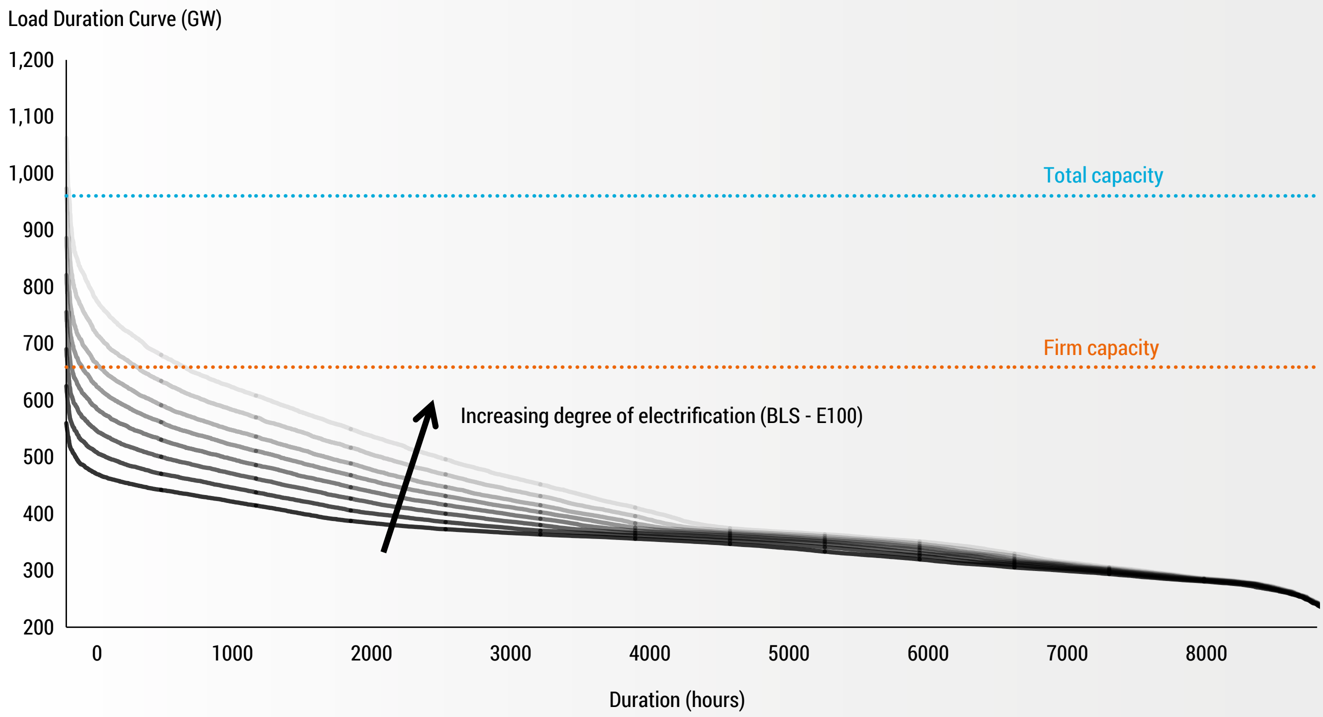

Figure 26. Load Duration Curve for the different H&C electrification scenarios (the firm capacity level for the year 2016 is indicated) (Source: Energy Policy, 148, 2021).

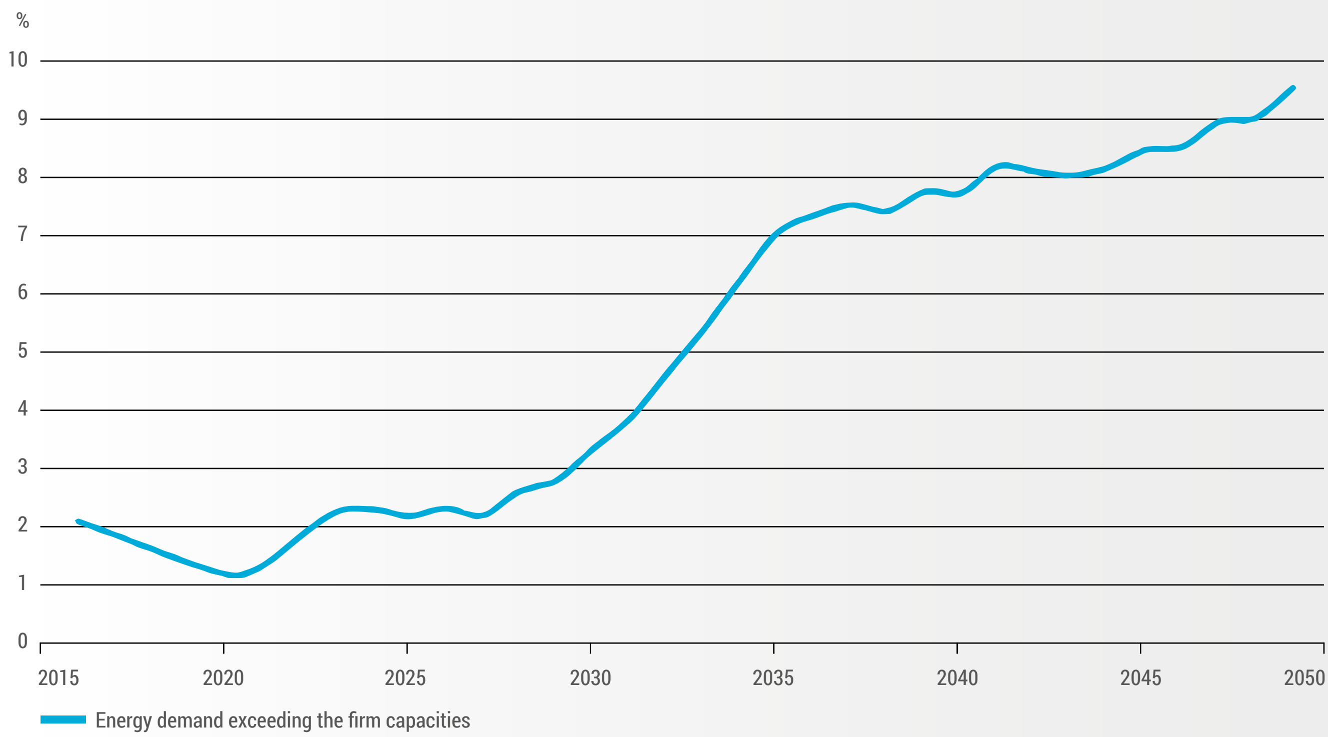

Figure 27. Development of the energy above the firm capacities for the EL100 scenario for the EU27+UK. Future capacities (2020–2050) based on the POTEnCIA (Policy-Oriented Tool for Energy and Climate change Impact Assessment) central scenario (the Central scenario was developed with the JRC´s energy model POTEnCIA and serves as a reference point to which policy scenarios can be compared)[11].

11 Source: "The decarbonisation of the EU heating sector through electrification: A parametric analysis", Energy Policy, 148, 2021

According to the JRC study, a comparative analysis of the situation in the EU in terms of the currently feasible electrification scenario, firm capacity, emissions' reduction, differential and abatement costs is presented in Table 6.

	Currently feasible scenario	Capacity [GWth]	Differential costs [bn.€]	Differential emissions [$MtCO_2$]	Abatement cost [€/tCO_2]
AT	None	0.0	0.0	0.0	–
BE	None	0.0	0.0	0.0	–
BG	EL100ALL	36.0	0.0	– 4.9	– 10.0
CZ	EL100	53.7	1.8	– 6.2	283.6
DE	EL20	121.7	3.8	– 11.1	344.0
DK	EL100BIO	20.6	0.5	– 2.0	254.6
EE	EL100	4.6	0.1	– 0.6	171.1
EL	EL100ALL	78.8	1.4	– 5.1	281.1
ES	EL100ALL	193.5	2.1	– 19.7	107.1
FI	None	0.0	0.0	0.0	–
FR	EL20	68.1	1.6	– 10.0	164.2
HR	EL100	14.8	0.5	– 1.4	372.5
HU	None	0.0	0.0	0.0	–
IE	EL100ALL	20.6	0.2	– 3.5	47.4
IT	EL60	202.3	7.4	– 21.1	351.4
LT	EL100	4.7	0.1	– 0.4	285.1
LU	EL100ALL	7.4	0.2	– 1.0	239.4
LV	None	0.0	0.0	0.0	–
NL	EL80	89.6	4.1	– 9.8	420.4
PL	EL40	66.7	1.7	– 5.5	300.4
PT	EL100ALL	30.7	– 0.3	– 3.0	– 99.9
RO	EL100	47.5	2.0	– 4.1	481.3
SE	EL100BIO	42.8	0.3	– 5.4	53.7
SI	None	0.0	0.0	0.0	–
SK	EL40	9.3	0.4	– 1.0	362.4
UK	None	0.0	0.0	0.0	–

Table 6. Electrification potential and cost under the conservative assumption that load needs to be completely covered by today's power system firm capacities and inflexible demand. The analysis is based on scenarios developed by JRC. (Source: Energy Policy, 148, 2021).

It is therefore clear that the European countries are moving towards decarbonisation at significantly different paces. Specific applications/use cases, on a local or national level, can provide very important "lighthouse" examples for broader implementation among the European countries, especially regarding the impact on the electricity sector and the transmission systems' operation. Finally, overall emissions of power and heating sector are expected to drop by only 5 % because the power mix of some countries is not sufficiently clean and efficient, and it may even increase the emissions in some cases.

3.2.4 Impact on TSO practices and data exchanges

Interconnectors, which are used to increase the transmission capacity between two countries, aim to support RES integration, improve security of supply and boost market efficiency in the social interest. They directly contribute to reducing RES curtailment (by enabling renewable energy surpluses generated in one country to be transported to another). Figure 28 presents the impact of a full electrification scenario (E100) compared to the baseline scenario (BLS) in 2050 (as these have been defined by JRC) on the interconnections among different countries. It is interesting to note that while in some cases the full electrification will reduce the congestion (max −20 %) in others it will increase it (max +23 %).

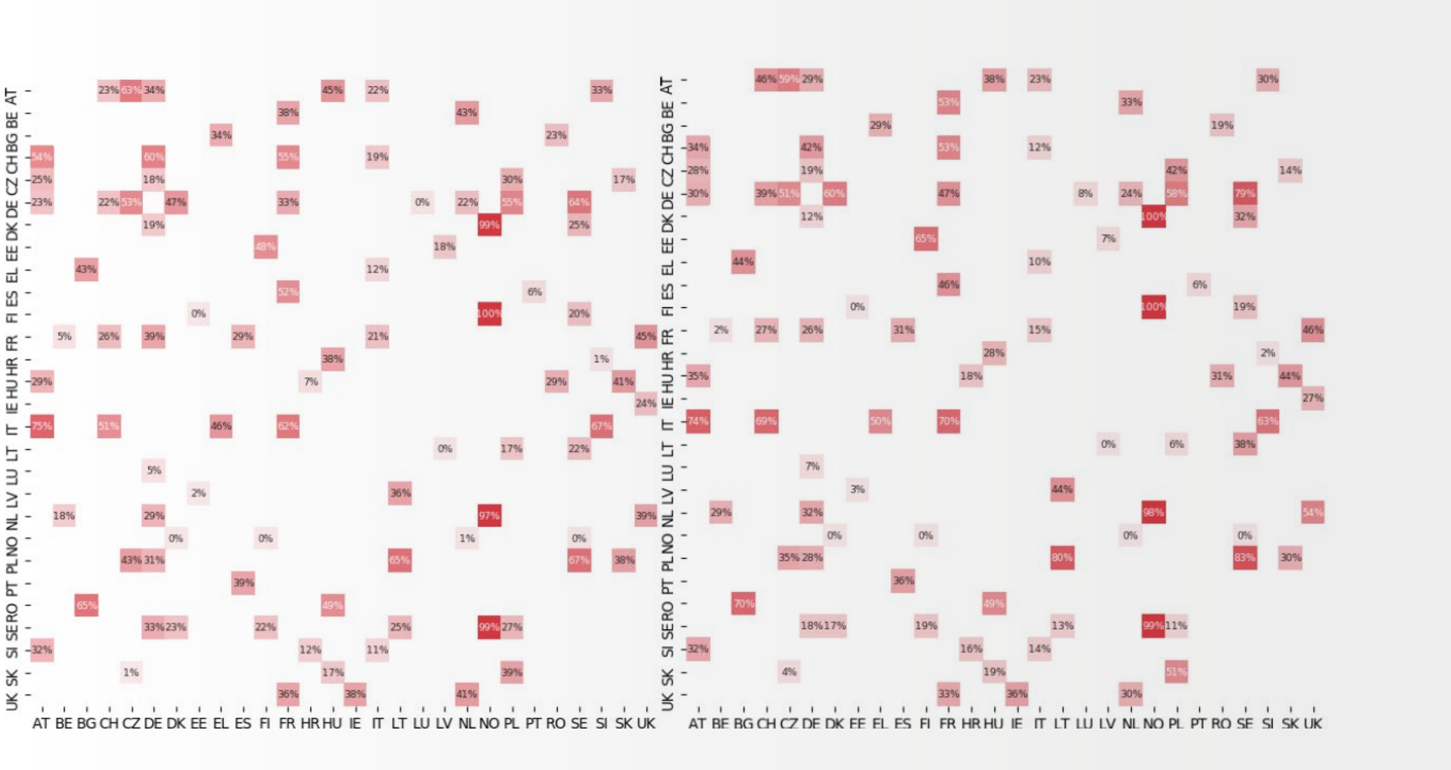

Figure 28. Differences in the interconnection congestions among different countries if the EL100 scenario prevails compared to the 2050 BLS baseline scenario. The numbers represent, in a percentage, the increase (red) or decrease (green) of the number of hours that a specific interconnector is congested (Source: JRC Technical Report, EC, 2019).

Based on the power system needs analysis carried out by ENTSO-E as part of its Ten-Year Network Development Plan (TYNPD) in 2020, the 93 GW of cross-border capacity needed by 2040 will enable the integration of 110 TWh of RES generation (which would otherwise have been curtailed) – and avoid 53 Mton of CO_2 emissions per year. The increase in cross-border capacity would cope with the congestion challenges that may occur with the high electrification of the heat sector.

The various other forms of impact on TSO practices are summarised below.

- Ideally a pool of heat pumps can shift its electrical load to other points in time without any drawbacks for the customers. The flexibility resulting from those load shifts can be marketed at electricity markets or used to actively support the electric grid. To exploit that flexibility, however, a pooling concept must be developed, including the analysis of the existing heat pump, storage system and building landscape, the potential operation strategies for the pool and the technical concept that enables signals' exchanges between an aggregator and the single heat pump.

- In general, to control a high number of different demand facilities, a suitable technical framework should define the exchange of signals and data between the single pooling unit and the aggregator. The implemented technical concept should be low cost/attractive, secure and in line with certain grid codes to provide reliable ancillary services. The requirements for the information and communication technology (ICT) infrastructure depend on the chosen operation strategy. Although the optimisation of the heat pump schedule is less complex, the participation in balancing markets must be in line with the requirements of the TSO.

- The controllable devices (heat pumps or heat pumps and storage combined) must be able to track a signal of the TSO to provide ancillary services. An indicative scenario aiming to highlight those specific processes has to be defined and adapted to the electrified heat situation to pave the way for smooth integration of heat pumps in TSO practices and can be considered as follows: In the case of tertiary reserve, an electronic communication device is necessary to offer the minimum bid size of i.e. 5 MW in line with IEC 60870-5-101. A point-to-point fixed line should be used, and the components must guarantee a time for data exchange of a maximum threshold 5s and a high availability of 95 %. Every 2 seconds measured data have to be sent to the TSO. In addition, during the times when no balancing energy is called, data exchange must be ensured. The actual electrical consumption as well as the operating point must be sent to the TSO.

- According to studies (Source: Aggregating the Flexibility of Heat Pumps and Thermal Storage Systems in Austria, SMARTGREENS 2016), the heat pump load shifting potential for 1000 households can be around 1.3 MW, however these values are still to be closely investigated and strongly depend on the specific combination of building, heat pump and thermal storage system. These indications can be very helpful in outlining the future picture of electrified heat. Moreover, the different technical characteristics of the devices forming the flexibility pool are of high interest for an aggregator. Large scale heat pumps (around 0.25 MW) are expected to be more favourable in terms of aggregation. This type of assets has a derating factor that has strong implications on the aggregator side reducing the available flex capacity for the TSO.

- In times of low market prices, electric heaters (such as heat pumps) can be switched on and eventual excess heat can be stored to connected thermal storage systems, though in most cases thermal storage is limited by the thermal comfort of the environment where the asset is working.

- Space and water heating are related to customer comfort as the primary driver of when these loads are used. Integration with storage can reduce peak demand, along with incentives and strategies to mobilise demand response and time-based pricing. Moreover, increased levels of surpassing the firm capacity will either create the need for more RES as well as cross border exchanges or the need for different capacity mechanisms.

4 Market Situation and Prospects

4.1 Current Situation

The heat markets differ from the electricity and gas markets. They are legislated and regulated in a wide variety of ways across Europe. EU's energy legislation provides limited guidance on preferred market rules. Thus, developments in district heat are driven mainly by national policy and regulation, with country-specific historical and political foundations.

As DH networks are organised at a local level, such as in city-wide schemes, the establishment and operation of a network and the sale of heat is usually organised in a single company or utility that serves a specific district heating network and supplies the heat at long-run lowest average cost, compared to a competitive market.

The DH sector has both monopolistic and competitive characteristics and could be treated as a normal utility business that needs to be increasingly customer-oriented and efficient. Both sunk costs and new economic CAPEX in district heating operations should be recouped and become eligible for risk-adjusted profits. Risks and complexity in a DH system seem to be higher than for other network-only businesses such as water, electricity and gas networks due to higher seasonality, input volatility and the need for more optimisation.

In the electricity sector, the solid EU framework protects consumers benefits across Europe. As DH will follow the decarbonisation pathway, it is likely that an improved framework for DH which can be local, national or EU if necessary could provide significant benefits for consumers.

Electrifying the heating sector is in line with the principle "energy efficiency first". Compared to other sources of primary energy, a heat pump, the main technology for electric-driven heating, is 3–5 times more efficient than a typical gas boiler. This is reflected to the cost of the end-user as they need to spend much less final energy to satisfy their thermal comfort.

4.2 Business models

Consumer-focused business models are the **key-enablers** for the successful widescale P2Heat integration; people are to be using more electrified appliances for thermal comfort increasing the overall cooling/heating duration curve" (a particular opportunity for heat pumps). These trends also increase the need for further integration of heat and electricity systems.

Regulating demand is one way to tackle current and future challenges such as volatile energy supply, decentralised generation, and critical energy grid situations. The goal of demand response is not necessarily the reduction of energy consumption, but the avoidance of high-power costs, costs for grid expansion or backup power plants and conventional energies due to demand following generation (instead of vice versa).

Demand response can be implemented as:

- **Incentive-based:** demand response programs that are based on giving monetary incentives (e.g. payments, taxes relief) to promote the reduction of consumer consumption when requested. These programs are usually implemented by aggregators or system operators.
- **Price-based:** demand response programs that are based on price signals (e.g. higher or lower tariffs, time blocks) sent to the consumers, intending to promote the modification of the consumer's consumption profile according to their cost reduction mentality. For example, the energy pricing for the next day can be made available to the consumer similarly to the previous timescale approach, thus inducing it to perform a scheduling for the next day to reduce its operation costs, focusing its consumption on low-tariff periods.

The demand side management environment is highly affected by **consumer awareness, consumer engagement** and **demand flexibility**. Consumers must be aware of the available efficient and cost-effective services that enable their smarter participation to provide flexibility to the system, under the current framework of energy markets. Consumer engagement is related to the approach of the demand response providers, power system's management and operation, towards the inclusion of consumers in energy markets and efficient energy use. Finally, the third step is the technical basis for the other two as it defines the capability of consumption-side assets adjustment based on the power system's operation. This is heavily dependent on the digitalisation level of heating and cooling on the demand side, as well as on the grid operator's side.

Consumer-Focused Business Models in the H&C Sector

- **Digital/Software Services**
  - Building Energy Management Systems (BEMS)
  - Building Information Modelling (BIM)
  - Digital Twin
  - IoT & Remote Control
  - Blockchain Technology
- **Demand-Side Management**
- **Heat Pumps, CHP, electric boilers' flexibility**

Potential Customers

Consumers (individual & DH) that are encouraged to make use of initiatives and technologies to optimise their energy use are: a) Residential consumers, b) Commercial buildings, c) Public sector agencies, d) Private sector companies, e) Research institutes

Created value of Digital P2Heat Technologies

For:
- Local energy system operators with electricity distribution network and DH networks;
- Consumers/Asset owners of P2Heat devices in integrated energy systems.

Competitive advantages:
- Planned or predictive maintenance;
- Prediction of the system's health;
- Heating and cooling become a service that the user enjoys and pays for (Energy-as-a-Service).

Potential financial savings/revenue streams

Management of the energy cost with more options available:
- Monetisation/selling of data (Software-as-a-Service) and making more revenue from service-level agreements (SLAs) or Premium support packages
- Time-varying pricing and energy management packages (Demand-Response)
- Revenues through provision of capacity and energy at the reserve markets, reduction of grid fees.

Smart Heat Demand Response Services. Energy concept for 2029, Finland

DH utility, Helen, could update the energy contracts of its customers and install control equipment at substations. The equipment gathers data and enables remote control of heating. AI and machine learning algorithms can then control and optimise the heat usage in the DH network.

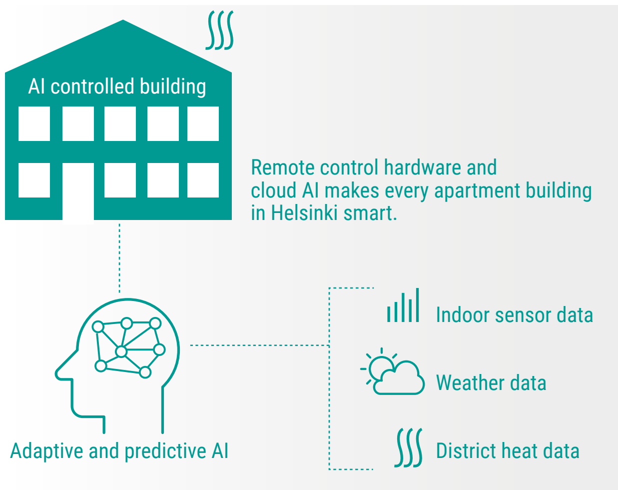

Figure A – System Diagram for Building with AI-Controlled Heat (Source: "Helsinki 's Hot Heart Storage', Helen Energy and Electricity Company)

4.3 P2Heat ecosystem

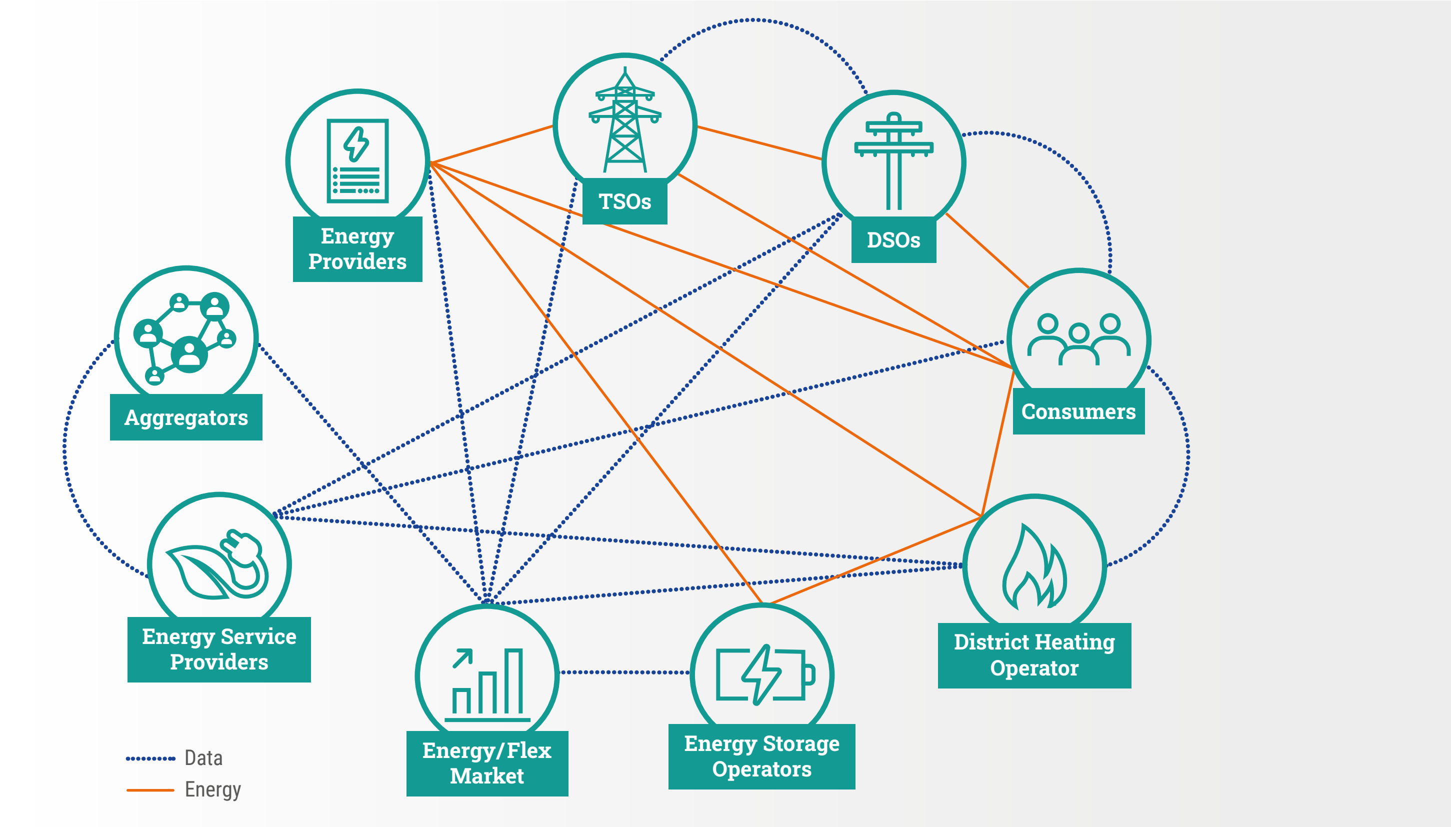

Figure 29. Data and energy interactions among H&C ecosystem actors

4.3.1 TSOs

TSOs have a multifaceted role in the P2Heat sector integration and can contribute to its realisation by:

- Providing adapted transmission grid tariffs that incentivise the optimal location of users (e.g. generators, large heating/cooling loads) in the grid, in order to promote a more efficient use of the transmission system, e.g. as done in Ireland[12]
- Accelerating the integration of thermal storage and demand side response (DSR) to cope with the short-term flexibility requirements of the electrical system and (in particular) structural RES overgeneration during the central hours of the day and the steeper evening residual load ramp.
- Enhancing grid operation driven by digitalisation (to maximise the availability of grid assets and minimise RES curtailment).
- Developing the electricity transmission grid to enable, among others, the large-scale integration of RES and of electrification in line with EU and Member States decarbonisation objectives. This in turn contributes to the provision of long-term investment signals for an efficient and effective build-up of resources and secured capacity to guarantee security of supply.
- Further integrating electricity markets across European countries, facilitating the cross-zonal trading of energy and ancillary services, and further increasing regional cooperation.

4.3.2 DSOs

DSOs own the smart meters and have responsibility for the measurement of production and consumption according to their national legislation. This ensures real-time knowledge of their system and allows for an efficient distribution of electricity.

12 https://www.eirgridgroup.com/site-files/library/EirGrid/Shaping_Our_Electricity_Future_Roadmap.pdf

4.3.3 District Heating Operators

DH operators procure heat from sources (any heat producer can connect to a DH network for offering heat for customers) that have availability at the most favourable prices at a time when the customers need heat. Real-time collected data allows the utility to optimise the temperature in the network – hence improving efficiency and reducing cost and emissions.

4.3.4 Aggregators

Aggregators[13] bundle the resources that can be traded at the flexibility markets, pooling and marketing generation facilities, flexible consumers, and storage systems. Through an aggregator, small plants, like heat pumps and electric vehicles (EVs), gain easy access to the markets and become able to sell **flexibility services to the DSO or ancillary services to the TSO**.

4.3.5 Energy Service providers

Energy Service providers integrate all the necessary steps from system design to integration, add the necessary sensors and control systems, and provide the required H&C service to the end user (e.g. via comprehensive energy packages, such as smart controls combined with heat pumps and renovation measures, aimed at delivering energy savings across a range of end uses).

Participating customers (residential, commercial and industry consumers –DH consumers included):
- Turn into prosumers;
- Become active players in heat and electricity market;
- Take out contracts and electricity tariffs for Demand Response;
- Enjoy and pay for the provided H&C services (Energy as a Service).

4.3.6 Local Energy Communities, cities and regions

Distribution networks, RES and storage capacity are increasingly seen as local resources that need a community approach. Local communities are well placed to identify local energy needs, take appropriate initiatives, and bring people together to achieve common goals. Digitalisation can enable community energy storage in a manner that stores excess local heat that cannot be consumed locally when produced and makes it available later when needed.

4.3.7 Storage Operators

Energy storage can be considered an activity that is mainly performed in the markets by generation plant owners (hybrid plants) or aggregators. The regulation for storage participation in markets is quite different among European countries.

4.4 Challenges and Opportunities

4.4.1 Key drivers/enablers identified

- Electrification of heat dominated by heat pumps offers flexibility at energy system/grid balance level and economic level.

- The energy service business models and smart energy trading platforms are attractive solutions to consumers and enable their engagement through the use of opportunities across the value chain, for retailers, product manufacturers, renovation businesses, networks operators and network investors.

4.4.2 Challenges identified

- As previously mentioned, unless a similar regulatory framework with electricity and gas is developed for the heat market that provides significant benefits for the consumers, the commercially available P2Heat H&C technologies cannot be exploited.

- Unless specifically tailored financial and taxation schemes are implemented to mitigate the high upfront investment costs that the various categories of consumers will face, the adoption of renewable energy in the H&C sector will not be accelerated.

- Unless market regulators and/or facilitators ensure that the flexibility deriving from P2Heat technologies is available to the market, the electrification of the H&C sector cannot be exploited to the maximum.

- Risks and complexity in a DH system seem to be higher than for other network-only businesses such as water, electricity and gas networks due to higher seasonality, input volatility and the need for more optimisation. Unless the DH sector is treated as a normal business utility that needs to be increasingly customer-oriented and efficient, heat networks will not be widely deployed, especially in regions with no such tradition.

13 The term independent aggregator is also used to refer to an operator that combines flexible resources outside the conventional electricity delivery chain, i. e., an operator that is not the electricity supplier or balance responsible party for the sites.

5 Conclusions

The H&C sector is responsible for 50 % of the energy demand in the EU and mainly relies on fossil fuels; thus the heat supply to the built environment and industry has been identified as a key pillar in the European energy policy to achieve a climate-neutral Europe by 2050. After a deep analysis and TSO pooling, ENTSO-E considers P2Heat integration to be a catalyst in meeting the clean energy targets but also in providing flexibility services.

P2Heat will unveil new **energy efficiency** opportunities through the use and development of various technologies such as heat pumps, biomass, solar-thermal, thermal storage, waste management and waste to heat, and waste heat recovery from industrial processes/data centres. Heat pumps are a very promising technology for H&C purposes. They have lower running and maintenance costs than combustion heating systems and can provide flexibility to the electricity grid following control signals. However, upfront costs and the required expertise for their design and installation are barriers that need to be overcome.

The H&C sector presents untapped opportunities to improve the **integration of RES** and, with the help of **thermal storage**, heat generated by electricity will be stored in a more economical manner and increase the flexibility capabilities of the energy system. Although normally the thermal impact is local, a wider impact is foreseen through power interconnections among different countries, attempting to utilise any source of flexibility of the whole energy system.

Digitalisation will be a key enabler for leveraging the flexibility resources from H&C assets: trusted and (cyber)secure access to data, data interoperability, and fast data exchange will facilitate the provision of congestion management, FCR, aFRR and mFRR services. A retrofit of the existing units, however, is required and its incentivisation is necessary. The availability and preservation of data for heat demand is essential to evaluate the respective energy needs and challenges and conduct common integrated studies with electricity and gas variables.

P2heat technologies are mature and commercially available. More **incentives** should be introduced to increase the use of RES through these H&C solutions for domestic and industrial consumers, as well as for the tertiary sector, to balance the upfront investment cost of these installations. It should be underlined that the heat markets differ from the electricity and gas markets. Developments in DH are driven mainly by national policy and regulation, with country-specific historical and political foundations. **Market regulation** should facilitate the participation of flexible heating resources into the energy mix with enabling measures, such as new market rules for optimisation and bidding strategies. Full implementation of the Clean Energy Package across EU countries will remove the remaining barriers for all types of flexibility, including those from P2Heat, to access the different electricity markets.

Finally, as the P2Heat **ecosystem** involves many actors, from system operators to DH companies and aggregators, TSOs will have to update their planning practices with a multisectoral approach and coordinated studies with stakeholders from other energy sectors, mainly gas. **Enhancing the cooperation** with DSOs, who will also face challenges from electrification of heat (network congestions and demand peaks), is a necessary step forward. A **supportive framework for innovation** is crucial to demonstrate and speed-up the time-to-market of the required technical and digital solutions, as well as that of new energy services and business models centred on consumer needs.

Appendix – Use cases

Project 1	ViFlex (Germany, 2022)
Project's scope	› Pooling of heat pumps to form a virtual power plant and provide flexibility for congestion management; › Maintaining comfort and efficiency for costumers' hot water and space heating requirements; › Provision of redispatch services to avoid RES curtailment and start-up of conventional power plants due to congestions.
Consortium	TenneT, Viessmann, Equigy
Functionalities	Flexibility through both aggregated, pool-level measurements and independent device-level measurements.
Ancillary services provided	Grid congestion management
Market maturity	The heat pumps (provided by Viessmann) use technology that can be operated with 100% renewable electricity and is able, with smart control, to respond flexibly to the demands of the electricity grid.
Energy carriers' coordination	Electricity and Heat (end-use)
Consumer engagement	The participants' heat pumps are optimised in such a manner that flexibility is provided to TenneT for congestion management without any loss of comfort. The customers will be able to save significantly on electricity costs if they participate in the ViFlex pilot project.
Scalability	The consortium of Swissgrid, TenneT and Terna will launch the Equigy Crowd Balancing Platform in the Netherlands, Germany, Italy, and Switzerland, using it to help balance the power system. Denmark's Energinet has formally expressed its intention to join the consortium, which will extend Equigy's European roll-out to five countries.
Replicability	TSOs can use the distributed capacity offered by small-scale consumer-based devices, such as heat pumps, water boilers and domestic batteries, in private homes EV.
Market uptake	The Equigy Crowd Balancing Platform has been tested through a number of pilots involving the use of decentralised flexibility from domestic batteries and e-vehicles, such as the collaboration with Sonnen and Vandebron and participation in the "Bidirectional Charging" consortium with BMW. The TSOs are engaging in this activity with no commercial interest while Equigy aims to unlock as many clean distributed energy sources for ancillary service markets as possible.
Sources	**https://www.tennet.eu/electricity-market/dutch-market/congestion-management/** **https://equigy.com/Your-Role/#tso** **https://www.smart-energy.com/industry-sectors/new-technology/european-tsos-platform-unlocks-flexibility-of-consumer-based-devices-electric-vehicles-equigy/** **https://www.tennet.eu/news/detail/equigy-platform-gives-european-consumers-access-to-tomorrows sustainable-energy-market/**

Project 2	FLEXITY 2.0 (Belgium, 2022)
Project's scope	Flexity 2.0 is an open demonstration project in which system operators join forces with flexibility service providers to demonstrate the participation of low-voltage flexibility in the balancing market (aFRR).
Consortium	Fluvius, Elia, ThermoVault & Flexcity (Veolia). The project is still open for new participants.
Functionalities	Real time control of residential boilers/ heat pumps/space heaters/ EV chargers
Grid services provided	Flexibility (aFRR)
Market maturity	Medium (aFRR already live for higher voltage, so no big changes foreseen)
Energy carriers' coordination	High coordination between TSO and DSO for data exchange to validate activations
Consumer engagement	High (press release led to dozens of people asking how to participate)
Scalability	Highly scalable
Replicability	High but coordination with each DSO requires effort
Market uptake	Many other companies interested but preferring to wait for the industrialisation
Sources	https://www.ioenergy.eu/flexity-2-0/

Project 3	P2Heat Applications for Large-Scale System Integration of Power-to-District-Heating in Berlin (Germany, 2019)
Project's scope	Using Wind and Solar Power instead of curtailing it in the Berlin DH Supply, thus contributing to the reduction of fossil fuels in heat generation. The focus is on integrating surplus renewable energy into the DH supply through innovative strategies for demand-side management and a coordinated response to grid congestion management.
Consortium	Part of WindNODE joint project, Vattenfall Warme Berlin AG
Functionalities	Small Power-to-District-Heating plants (5 MW) can reach full capacity within 10 seconds and thus provide grid-related system services extremely quickly before wind turbines must be curtailed. The large electrode boilers could conceivably be online within 15 minutes. The limiting factors (regarding grid capacity) in this context are the maximum starting current and the hydraulic feed-in of heat into the DH system as conventional generation plants must be shut down in turn.
Grid services provided	› Converting renewable electricity into "green district heating"; › Challenge: "using power instead of curtailing it" would require a change to the regulatory framework.
Market maturity	Commercial products: wind turbines, solar panels, DH system, CHP plant
Energy carriers' coordination	Focus on technical analysis of the interaction between CHP and Power-to-District-Heating plants at the same site, as well as on the derivation of the resulting energy marketing and balancing options
Consumer engagement	Attractive to consumers because it eliminates the need to install additional building services or make behavioural changes to obtain DH generated from renewable energy.
Scalability	If a large amount of renewable electricity is available, the plant will use it to generate 10 % of Berlin's total electricity requirements in summer (or the energy demand of 750,000 refrigerators). Vattenfall Wärme Berlin AG plans to construct a 50,000 m³ hot water storage tank (max. 95 °C) at the Reuter West site to facilitate the feed-in process.
Replicability	The Power-to-District-Heating plant will provide Berlin with a valuable tool for renewable energy integration. Vattenfall Wärme Berlin AG will design and build additional Power-to-District-Heating plants and deploy large heat pumps, for example using wastewater.
Market uptake	During tests with the WindNODE flexibility platform, it became apparent that flexibility bids based on the maximum power of the electrode boilers would have caused an increase in the grid fees paid by the DH power stations. Because the facility is connected to the distribution grid, it does not fully benefit from the compensation for disadvantages in grid fees under the SINTEG Ordinance (SINTEG-V), unlike comparable plants connected to the transmission grid
Sources	https://www.windnode.de/en

Project 4	Smart Systems and Heat (UK, 2014–2020)
Project's scope	› Address the technical, regulatory, economic and social barriers that block new low carbon heat products, services and business models getting to market. › Bring innovators, businesses, local authorities, networks, policy makers, regulators and consumers together to investigate new energy market arrangements that deliver low carbon heating solutions at scale. › Establish a range of platforms, capabilities, assets, modelling tools and insights to help innovators discover new low carbon heating solutions that consumers value.
Consortium	Catapult energy systems
Functionalities	Improved, accessible and easy to use interface design & heating control through the Home Energy Services Gateway (HESG).
Grid services provided	› Demand-side management business models for Distribution Network Operators (DNOs) to pre-heat homes ahead of high peak energy use times (through using the proposed time of use network charges). › Potentiality to reduce network peak loading, while modestly reducing and maintaining comfort outcomes for occupants. › Commercial incentive for providers to learn how to deliver the outcomes consumers want while spending as little on energy as possible (by using less or avoiding using energy at peak times).
Market maturity	Commercial products: Smart, wireless digital control devices and sensors monitoring temperature, humidity and energy use (via HESG).
Energy carriers' coordination	› Integrating Tidal Energy into the European Grid (in Orkney, Scotland, an 11-million-euro Interreg North-West Europe (NWE) project). › Energy sector regulator Ofgem has now included LAEP in recommendations in its latest RIIO-2 Business Planning Guidance for energy networks.
Consumer engagement	SSH1: Devices included individual wireless temperature and humidity sensors for each room, individual wireless radiator controls, utility meter readers, water pipe temperature sensors and boiler controls installed in 30 homes. SSH2: A "Living Lab" of over 100 owner-occupied homes in Birmingham, Bridgend, Manchester and Newcastle tested the new service-based business model for the delivery of energy services to domestic customers (HaaS concept), marketed to consumers as a Heat Plan.
Scalability	The Planning modelling processes and modelling tools, such as the LAEP, can help streamline the collaborative dialogue between stakeholders and local government/authorities; representative examples of different but typical urban areas are Newcastle, Bridgend and Bury in Greater Manchester.
Replicability	› EnergyPath® Networks (EPN) provide a firm analytical and empirical grounding for the exploration of future scenarios and formulation of plans. › Local Energy Asset Representation (LEAR) tool enables planners and innovators to strategically decide how they might deploy and grow low carbon businesses.
Market uptake	› Launch of a low-carbon, hybrid heating offering (air source heat pump) for households that are not on the gas-grid and use oil or LPG heating (by EDF). › Successfully trialled selling "Heat as a Service", in a move that paves the way for the low carbon retrofit revolution (by Baxi Heating UK). › Invention of an "intelligent air-brick" (by AirEx), which uses temperature, humidity and air quality home sensors and smart algorithms to selectively open and shut air vents, reducing fabric heat loss. › Launch of B-Snug, a smart hybrid heat pump subsidiary (by Shell and Passivsystems) that uses advanced technology to manage a combination of an air source heat pump and a traditional boiler.
Sources	**https://es.catapult.org.uk/case-studies/smart-systems-and-heat/**

Project 5	Optimising Locally Produced Energy on the isles of Scilly (UK, 2016–2019)
Project's scope	› Supporting the energy transition with the IoT. Optimising locally produced energy on the Isles of Scilly (IoS). › Demonstrate how domestic energy technologies, managed by an IoT system in conjunction with a smart energy trading framework, could support the transition to the DSO model.
Consortium	Hitachi Europe Ltd (leader), Moixa UK, PassivSystems UK, Council of the Isles of Scilly, The Duchy of Cornwall, Tresco, The Islands' Partnership, The Isles of Scilly Community Venture, part-funded by the European Regional Development Fund
Functionalities	› On a household level: heating and hot water at the lowest possible cost to the household, making best use of behind the meter solar PV and the Economy 7 tariff (AI-based algorithms) › On an island level: The project explored whether curtailment of local PV generators could be mitigated by turning up demand at the time of surplus generation, in collaboration with Western Power Distribution (WPD). Hitachi's IoT platform was able to receive curtailment signals from WPD's Active Network Management, translate it into a flexibility request that two separate aggregators, PassivSystems and Moixa, could respond to, obtain a confirmed order and ultimately deliver the required flexibility from multiple devices (EV, ASHP, Batteries and Hot Water). The aim was to absorb the surplus generation and enable the local PV to continue to produce, thus making better use of locally generated electricity
Grid services provided	› Active Network Management › Avoidance of RES curtailment Impacted voltage level: LV (directly), HV (indirectly)
Market maturity	TRL 9 (actual system proven in operational environment) Commercial products: Home Energy Management Systems, rooftop PVs, air source heat pumps, hot water tank controls, domestic/storage batteries, EV charger
Energy carriers' coordination	The distribution network operator in the southwest of the UK.
Consumer engagement	The households participating in the Smart Energy Islands project were asked to sign up to a Behind-The-Meter (BTM) billing agreement with the Isles of Scilly Community Venture and the response was very positive, with only 3 out of the 82 prosumer-households opting out.
Scalability	In a larger scale system, an aggregator would likely manage its risk profile differently, retaining a percentage of availability in order to balance the opt-out risk; thus delivery would usually be closer to 100%.
Replicability	Smart Energy Islands has demonstrated that in locations with strong community ties, consumers are willing to pay for BTM self-consumption in the knowledge that their contribution benefits the community.
Market uptake	ICT solution, USEF-based flexibility trading system, BTM billing service, Energy Profile Manager, Operator's Web portal for monitoring and management of the Energy Flex Trader. Technologies installed: solar PV generation and heat pumps, batteries, hot water tank controls and an EV charger.
Sources	–

Project 6	Power to Heat Salininkai (Lithuania)
Project's scope	The Power to Heat Salininkai project is the first of its kind in Lithuania. The aim is to develop a working P2H system and assess its feasibility as a mFRR and perhaps even as an aFRR service provider. The system will be comprised of a 1 MW heat pump, a solar collector array and a suitably sized heat storage. This will allow the heating service provider to gain additional income from participating in the balancing market, as well as increase the electricity grid stability.
Consortium	LITGRID AB, EPSO-G, Vilniaus Šilumos Tinklai
Functionalities	P2Heat would not only bring more cost competitive DH and hot water production solutions but it would provide frequency regulation services from mFRR to eventually aFRR. Thus, it would increase an overall system's stability.
Grid services provided	LITGRID AB
Market maturity	First P2Heat system in Lithuania, balancing market of low maturity on national level
Energy carriers' coordination	The P2Heat concept would employ electricity and thermal agent (circulating within enclosed heat generating system) as main energy carriers. The coordination would be achieved by implementing control logic between two heat energy generators: Heat pump and thermal solar collector array.
Consumer engagement	No significant consumer engagement is yet expected in an undergoing pilot project
Scalability	The concept can be applied to other DH, service providers in Lithuania. Moreover, a broader spectrum of Power
Replicability	This project could be easily replicated in other Lithuanian regions as most of them have been using natural gas to generate heat. This pilot project also serves as a showcase to promote district heat and how water production using renewable electrical energy.
Market uptake	The purpose of the P2Heat pilot project is to promote sector coupling technologies that would enable a more flexible and stable energy system, able to accommodate large quantities of integrated VRES. This pilot project should also have financial, environment and technology related benefits, thus encouraging energy system stakeholders and large energy consumers to adapt Power to X technology on a larger scale.
Sources	–

Project 7	Electric Boiler and Heat Pump for District Heating in Aarhus (Denmark, in operation)
(Denmark, in operation)	The city of Aarhus in Denmark expanded the capacity of an existing combined heat and power plant by adding an 80 MW electric boiler in 2015 and a 2 MW electric heat pump in 2020 to provide DH to the neighbourhood.
Consortium	› AffaldVarme Aarhus (AVA): DH company, owns and operates most of the DH system in the city of Aarhus, Denmark. › Part of READY Project (80 MW electric boiler)
Functionalities	› Heating electrification (P2Heat technology implementation). › Integrating DH and electricity systems › Direct use of windmill electricity › The electric boiler generates heat to the DH grid; operates whenever the electricity price is low (when it is very windy, and the wind turbines generate more electricity than required). › The city's use of variable renewable electricity for heating – together with other measures – is motivated by the municipality's ambition to become carbon neutral by 2030. There is also a national target to meet 50 % of electricity demand with wind power. › Seawater is used as a heat source. Its temperature in winter is thereby lowered from 4 °C–6 °C to 0 °C–2 °C (with up to 14% ice in the discharged water)
Grid services provided	Important synergies: › Grid connection with a high voltage is available. › The plant's pressurised storage tank (short-term heat storage (~1000 MWh)) can act as a buffer between heat generation and demand. › Wind power production is greatest in winter and thus well correlated with heat demand in Denmark. This means the electric boiler is expected to primarily replace oil-based peak load boilers installed at the same power plant.
Market maturity	Commercial products: Electric Boiler and Heat pump
Energy carriers' coordination	› Wind-power/electricity production companies › DH operators
Consumer engagement	City's DH customers
Scalability	The inherent modularity of the heat pumps allows capacity to be continually expanded. The heat pump's capacity is planned to be expanded up to 14 MW. At their full planned capacity, the heat pumps will be able to take the entire heat demand of the neighbourhood, thereby replacing oil boilers.
Replicability	› The Danish ambitions for introducing heat pumps in the DH supply is significant and the Aarhus' heat pump and its achievements is followed with great interest. › Denmark has shown a potential way to integrate a high share of RES into energy systems with large-scale heat pumps supplying DH.
Market uptake	› It is the ambition of AVA to have a digital twin – an online and interactive data-driven model – of the sea water heat pump to help facilitate the overview needed to manage it cost-optimally and to decide whether to increase the installed heat pump capacity for DH production in the future. › The large-scale heat pump contributes to a better integration of the DH system with the electricity market. › Heating and electricity Taxation
Sources	https://www.dtu.dk/english/news/Nyhed?id=%7BAB086B1B-8782-4CDB-AD18-26FD88CC6A0C%7D

Project 8	Katri Vala Heat Pump Plant (Finland, in operation)
Project's scope	The Katri Vala heating and cooling station (under the Katri Vala Park in Sörnäinen) uses heat pump technology to produce DH and cooling at the same time.
Consortium	Helen Ltd, energy operator, Finland's second-largest energy company, owned by the City of Helsinki.
Functionalities	Currently: The heat pump integrates electricity, wastewater, DH and district cooling systems to produce up to District heat: 105 MW District cooling: 70 MW (Installed capacity). The control and logic system are based on the latest Siemens PLC equipment. New Heat pump: The district heat output of the new heat pump is 18 MW and the cooling output 12 MW. The investment will raise the thermal output of the Katri Vala heating and cooling plant to a total of 123 MW and the cooling output to a total of 82 MW.
Grid services provided	› System level efficiency › Katri Vala is among the best solutions to replace the Hanasaari coal-fired power plant by 2025. › With the new pump, heat will be recovered from the heat of wastewater that has already been utilised, which will significantly improve the efficiency of recycling thermal energy. › Moreover, this will substantially reduce the thermal load ending up in the Baltic Sea along with wastewater. › The new pump will also improve the plant's year-round availability. Consequently, it will be possible to operate the plant in the coldest periods more often than at present. › As a result of the new investment, the annual energy generated by Helen's heat pumps will increase to almost 1TWh, which corresponds to the heating need of a city the size of Kuopio or half of the heating need of Espoo, Tampere or Turku.
Market maturity	Commercial products: Heat pumps, DH networks
Energy carriers' coordination	Fingrid TSO, Helen's Development programme
Consumer engagement	Residential and commercial customers in the city of Helsinki
Scalability	› The plant already has 5 large heat pumps, and it has been possible to raise their production volume each year by developing the production process. Extra space was excavated for the Katri Vala heating and cooling plant already in its construction stage with a view to any future expansion. › Helen is continuing its investments in the recycling of excess heat by building a new heat pump to complement the underground heating and cooling plant located in Sörnäinen. The plant was commissioned in 2006. It will now be easy to install the new heat pump in that space.
Replicability	› Efficiency to cover a wide area › Model example of eco-efficient utilisation of manipular waste energy in urban conditions
Market uptake	Sale of the DH and cooling
Sources	**https://www.youtube.com/watch?v=iVgOLyeEK90&t=25s**

Project 9	Large-Scale Underground Heat Storage (Finland, estimated launch 2019–2021)
Project's scope	A large underground oil bunker (in the old oil rock caverns in Mustikkamaa) has been converted into to a heat storage facility, that will allow reduction in the use of fossil fuels. The stored energy is from DH.
Consortium	Helen Ltd, energy operator, Finland's second-largest energy company, owned by the City of Helsinki.
Functionalities	› Applicable for long term storage › Rock cavern storage (volume is 260,000 m³), pumps, heat exchangers and water. › The charging and discharging capacity of the facility is 120 MWth, which enables discharge or charge for about 4 days when the accumulator is full or empty (11.6 GWh/4 days, annual heat storage 140 GWh). › District heat will be stored in the caverns for use at another, more suitable time. On discharge, the heat can be utilised as district heat.
Grid services provided	› The heat storage facility will provide P2Heat flexibility to the energy system as it will balance variable heat consumption. › Energy production optimisation › Indirectly impacts electricity consumption and electricity balancing. › The use of fossil fuels in separate heat production will be reduced with the heat storage facility, and the use of renewable fuels and CHP generation will be increased at the same time. The heat storage investment will support the functioning of the electricity market and the increase of renewable energy in the entire electricity system. It will also increase CHP. The Mustikkamaa heat storage facility can be used for increasing profitable operating time in CHP and improving its possibilities of operating on the market also in the future to safeguard the security of energy production and supply.
Market maturity	TRL 9 (actual system proven in operational environment); Commercial products: Heat pump, DH network, underground thermal storage
Energy carriers' coordination	Energy operator, DH operator
Consumer engagement	Residential and commercial customers in the city of Helsinki
Scalability	Vantaa Energy is planning to implement the world's largest cavern thermal energy storage in the city of Vantaa. The amount of heat contained in the facility, 90 GWh, would meet the heating need of a medium-sized Finnish town and it also corresponds to about five per cent of the annual heat consumption of Vantaa. Among the largest heat storage facilities throughout the world until now have been the Vojens (200,000 m³) and Marstal (75,000 m³) storage facilities connected to solar heat systems.
Replicability	› Helen also has heat storage facilities at the Vuosaari and Salmisaari power plants. › Helen is also planning a heat storage facility in Kruunuvuorenranta. This seasonal energy storage facility would operate according to a different principle than the Mustikkamaa heat storage facility.
Market uptake	Heat storage and utilisation: The Mustikkamaa heat storage solution supports the implementation of the national energy and climate strategy. It will improve the energy efficiency of the energy system and reduce the use of fossil fuels. It will support the reduction of coal use and the replacement of coal with other production methods.
Sources	https://www.vantaanenergia.fi/en/the-role-of-a-cavern-thermal-energy-storage-as-part-of-an-evolving-district-heating-system/

Contributors

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