Renewable Heating & Cooling

European Technology and Innovation Platform

2050
vision for 100 % renewable heating and cooling in Europe

www.rhc-platform.org

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THE VISION IN A NUTSHELL

100% renewable energy-based heating and cooling (100%RHC) in Europe **IS POSSIBLE** by **2050**.

The real challenge is to set up coordinated strategies at European, national, and local levels to reduce fossil fuels to zero by 2050. The narrow window of opportunity due to the long lifespan of heating and cooling (H&C) systems requires public authorities to maximise efforts in the next decade.

Solar thermal, geothermal, bioenergy, district H&C, and ambient and excess heat recovery -complemented with renewable electricity- are the backbone of a radically new, user oriented, carbon-neutral, efficient, reliable, and flexible energy system.

Such a system will harvest locally available renewable energy sources (RES) providing considerable employment and economic benefits to the local economies and the European Union (EU) and at the same time involve end users and counteract energy poverty.

Switching from the EU's over 400 billion cubic meters of fossil fuel imports to employment creation is hugely valuable.

The provision of 100% RHC in cities, districts, buildings, and industrial processes will be characterised by larger renewable energy (RE)-based DHC networks on different scales (from city wide systems to local micro networks) delivering cost-effective outcomes in high-density areas and self-supply through local RHC systems in rural and low-density areas. The latter will optimally integrate different RHC technologies into installation-friendly (plug-and-play) and easy-to-manage hybrid systems.

Long before **2050** in the EU it will be **utilised**:

- Legislation to phase out fossil fuel-based heating systems;
- Local energy from various RES technologies in concert to suit different opportunities and needs;
- Integration with the power sector to balance supply and demand;
- The drastic reduction of waste though reuse of excess heat and organic waste;
- Daily and Inter-seasonal energy storage of heat and cold, on large and small scales;
- Reliable and secure smart energy management systems based on real-time data, predictive algorithms, and artificial intelligence;
- Innovative business models, e.g. based on the H&C-as-a-service or Pay-As-You-Go;
- Citizens' and industries' engagement and participation with transparent publicity on the need to phase out fossil fuels.

Long before **2050** in the EU it will be **ended**:

- Subsidies for fossil fuel-based systems, reversing them in favour of RHC solutions;
- The belief that there is time for transitional investment;
- Installing fossil fuel-based solutions that can last until 2050;
- The dominance of centralised structures in favour of integrated, local, and user centric approaches;
- The belief that as individuals or corporations the fossil fuels phase down is optional.

RHC technologies are mature, commercial, and market ready, today. They will be continuously developed for increasing their performance and competitiveness. However, without strong political support to speed up the market uptake of these solutions, the 2050 vision will hardly become reality. The subsidiarity principle requires local leadership along with guidance at European and national levels.

It is unanimously concluded by the members of the European Technology and Innovation Platform on Renewable Heating and Cooling (RHC-ETIP) that this vision can only be reached with a very strong and resolute political will to change the H&C sectors towards 100% renewables and zero carbon dioxide (CO_2) emission sources – together with a persistent integration of the electricity sector under the terms of a level playing field.

Courageous political decisions are needed immediately to accelerate the ending of fossil fuels.

INTRODUCTION

This vision is intended to provide a clear path for 100% renewable energy (RE) heating and cooling (H&C) sectors in Europe by 2050. It highlights the principles, the drivers, and the challenges of the transition to RE and helps readers to understand the potential of renewable heating and cooling (RHC) technologies.

The **decarbonisation of H&C sectors is an essential milestone to achieve the ambitious climate and energy targets of the European Union** (EU). In fact, H&C accounts for about half of the total end energy demand in Europe and they are by far the largest energy consuming sectors. The annual consumption of thermal energy in Europe in 2017 amounted to about 5.600 TWh, against 2.700 TWh of electricity and 4.000 TWh used in the transport sector. However, in the same year only 19,5% of thermal energy was generated from renewable energy sources (RES) and considerable differences exist between EU Member States (EUROSTAT, 2019).

With the communication "an EU strategy on heating and cooling" (COM(2016) 51 final), in February 2016 the European Commission strongly emphasised the role of H&C in the decarbonisation process. This new attention led to the target of 1,3% annual average increase of RE in H&C, as mandated by the 2018 recast of the Renewable Energy Directive (Directive 2018/2001). **The Renewable Energy Directive set the target of 32% RE by 2030; overall, about 40% of this share is projected to come from the H&C sectors.** Thus, the evolution of climate related policies is giving new momentum to renewable H&C (RHC) technologies.

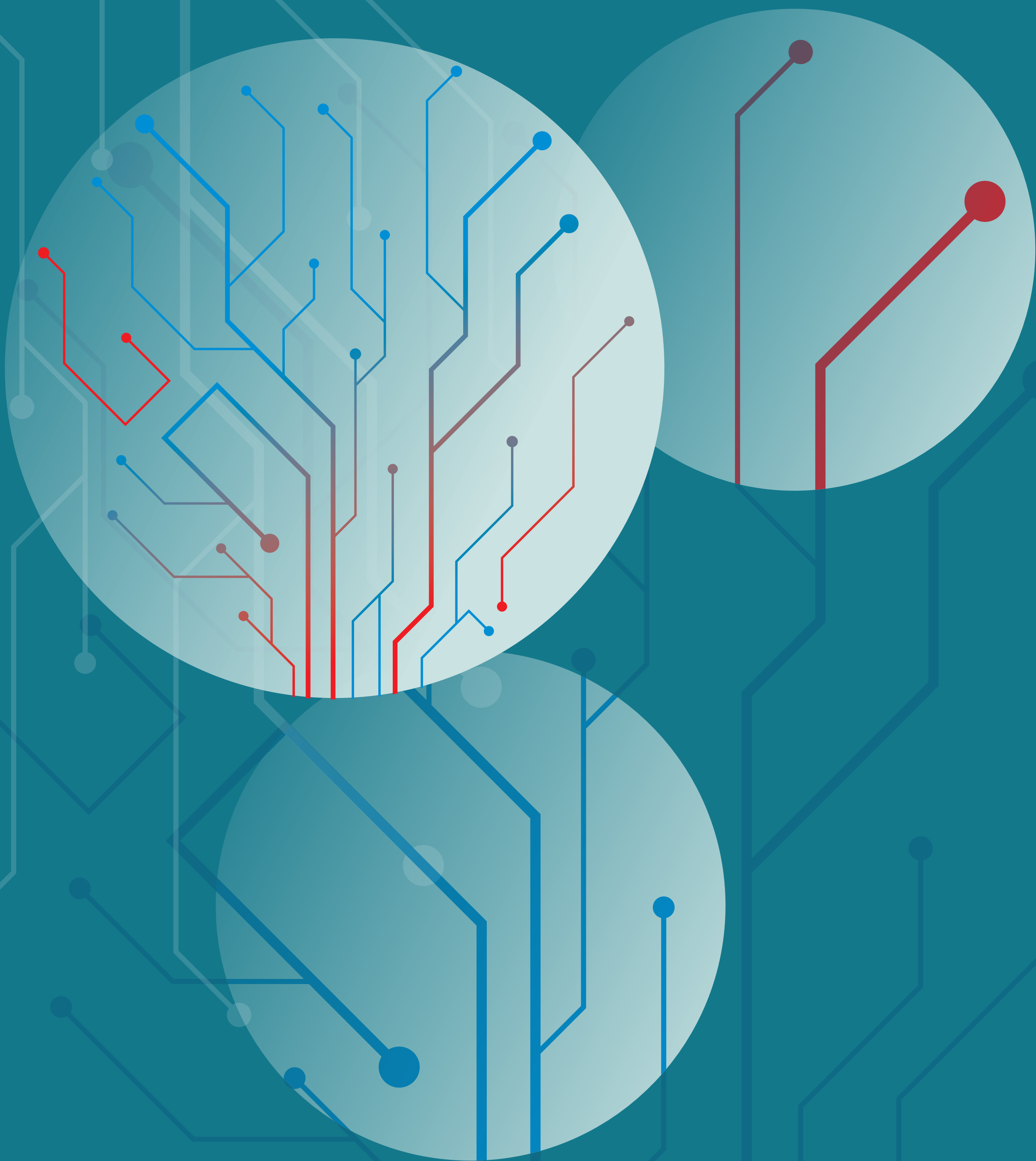
To effectively decarbonise H&C the EU, national governments, and the overall community of stakeholders need to act quickly, since the window of opportunity is quite narrow. In fact, H&C technologies (both conventional and renewable) have a relatively long lifespan, with an average of 15 to 30 years; therefore, the solutions in place by 2030 will deeply influence the sector's outlook by 2050. Considering the high level of decentralisation of H&C solutions, the low level of awareness of the alternatives to fossil fuel technologies, the lack of economies of scale, and the great variety of RHC technologies, fostering the energy shift is a challenging but feasible task. A shared view is needed among policy-makers, citizens, and stakeholders along the entire value chain on the main goals and pillars, in order to optimise efforts and resources. This is the rationale of this document.

This vision was developed by the **European Technology and Innovation Platform on Renewable Heating & Cooling (RHC-ETIP)**; it is the result of the joint effort of a pool of experts from industry and research, divided in four multidisciplinary working groups, respectively focusing on individual buildings, cities, districts, and industries. This approach was adopted to look at H&C from a systems perspective, stressing the need for integration of different technologies and highligting promising solutions for different use contexts. The Platform's Technology Panels supported this exercise by providing relevant information on the technology state-of-the-art.

The European Technology and Innovation Platform on Renewable Heating & Cooling (RHC-ETIP) brings together experts on biomass, geothermal, solar thermal, and heat pumps, as well as the related industries such as district heating and cooling (DHC) and thermal energy storage (TES), to define a common strategy for increasing the use of RE technologies for H&C in Europe. Officially endorsed by the European Commission since October 2008, the RHC ETIP aims at playing a decisive role in maximising synergies and strengthening efforts towards research, development, and technological innovation, which will consolidate Europe's leading position in the H&C sectors. The scope and operational structure of the RHC-ETIP are intended to ensure balanced and active participation of the major stakeholders at the appropriate levels, including all concerned industries, scientific research organisations, public authorities, energy users, and civil society.

The European Technology and Innovation Platforms (ETIPs) are one of the main implementation mechanisms of the EU Strategic Energy Technology (SET) Plan, which was created to accelerate the deployment of low carbon energy technologies in Europe.

1. RENEWABLE HEATING AND COOLING AS KEY ENABLER FOR A SUSTAINABLE DECARBONISATION



RHC provides significant benefits to the EU society and energy system

Heating and cooling our homes and businesses, as well as generating process heat and cold, makes up more than half of the EU's energy demand. While nowadays heating dominates cooling in terms of energy demand, cooling demand is raising due to the effects of climate change (Kovats, 2014) and is expected to become significantly higher by 2050. The use of RES, as well as the re-use of excess heat and cold, are key elements in the path towards a sustainable society. These sources bring considerable benefits to the EU society and energy system, which can be outlined as follows:

- **System efficiency:** inefficiencies in energy generation by promoting a rational use of primary energy through RHC technologies. According to the exergy[1] analysis approach, energy waste can be minimised when supply and demand match. H&C applications usually require low exergy levels (except for some industrial processes), which can be easily matched with low-temperature thermal energy from RES and excess heat (e.g. by using low-temperature heat sources for low-temperature heating in residential and tertiary buildings). This leads to a more efficient energy use, allowing to use high-exergy energy carriers, such as electricity, for applications which need high-quality energy, e.g. mobility.
- **Decarbonisation:** RHC technologies play an essential role in developing a carbon-neutral building stock and industry in Europe, thus providing a fundamental contribution to the achievement of the EU climate targets. Existing technologies, including bioenergy, geothermal, solar thermal and ambient heat, have an enormous potential to support a carbon-neutral economy; these contribute significantly to the overall portfolio of RES.
- **Energy flexibility:** thermal energy storage (TES), the thermal inertia of buildings, and piping networks can compensate the temporal mismatch between H&C demand and source availability; thus, they provide a great degree of energy flexibility in H&C supply, allowing to cover demand on different size scales (building to city level or load profiles of industrial processes) and overcome temporal mismatches on different time scales (hourly to seasonal). Moreover, the benefits of TES go beyond the H&C sectors as such, since though sector coupling it can contribute to balance the electricity grid when high levels of RES are introduced.
- **Reliability and security of supply:** due to decades of technology development RHC solutions are reliable and require low maintenance and operation costs. These technologies can virtually be optimised for every climate condition in Europe. Consequently, RHC technologies permit to harvest locally available RES and to relieve EU Member States from fossil fuel imports in H&C, which currently amounts to 50-65 billion Euro per year for natural gas alone. Replacing gas imports with local RES will both benefit the European economy and help to secure the EU from geopolitical risks.
- **Socio-economic benefits:** most RHC technologies are made in Europe and the related energy sources are often locally available; their massive integration is resulting in a high socio-economic value due to the substantial employment opportunities arising by the need for skilled workforce required for technology development, production, installation, and maintenance. Furthermore, RHC technologies will allow the EU to take a strong leadership role in the global energy transition by successfully exporting sustainable products and technologies.

Planning and managing the energy transition

The transition from conventional (fossil fuel-based) energy sources to RHC must be carefully managed as it requires extensive planning and high-level expertise, along with significant investments in buildings' retrofitting, in industrial technology development, in installation, and in the development of storage capacities and transmission systems. The future mix of RHC technologies should be non-disruptive as much as possible, in order to guarantee a smooth and inclusive transition. In other words, it should focus on both ready-to-adopt and quickly deployable RHC technologies (in the short-term) and innovative RHC technologies and systems (in the medium-term). A high potential for RHC technology scalability is also essential to ensure the success of the EU's energy transition.

[1] Exergy is the energy that is available to be used. In heating applications, it is strongly related to the temperature level, as high temperatures result in high exergy content and low temperatures result in low exergy content.

Implementing the energy transition in the H&C sectors is challenging, since RHC strongly depends on local conditions and there are no one-size-fits-all solutions. However, with a strong political will, adequate planning, extensive training, high awareness levels, and a balanced mix of incentives and obligations, it is feasible to decarbonise H&C in Europe[2]. For this purpose, it is important to foster systemic changes, including:

- a **shift from large gas distribution networks to self-supply and local thermal networks** based on the systematic use of locally available RES. Where viable DHC networks should be the preferred option (high density areas), decentralised solutions should be favoured where they are more cost-efficient (low-density areas).
- the **optimisation of energy demand and supply**, through energy storage and smart energy management systems at production, distribution, and consumption levels.
- a **strong integration with the power sector** enabled by the persistent diffusion of coupling points (e.g. heat pumps and TES) together with the wide uptake of smart energy management systems.

Hence, EU Member States should develop plans and strategies for boosting the implementation of RHC in a safe way and developing suitable transformation strategies for their existing energy systems.

Great technology variety: a solution for all tastes

The wide variety of RHC sources, including solar thermal, geothermal, bioenergy, ambient energy sources (e.g. surface/ waste/ drinking water/ sewage water/ outside air) and excess heat from industrial or commercial processes (e.g. data centres), complemented with renewable electricity, will allow planners, developers and operators to choose the most competitive and sustainable solutions in all European regions. These technologies should complement each other, as diverse sources and components are needed to create a cost-efficient, robust, and secure energy system. In fact, different RHC technology applications will allow the EU to properly meet diverse profiles of energy demand. The technology mix will differ from city to city (local level), region to region (regional level), country to country (national level), and across specific economic sectors (sectoral), depending on the availability of local RES, the demand mix, regulatory conditions, and the existing infrastructure. Regulation ought to ensure in general that the most efficient RHC technologies in any given region should be preferred.

The key role of hybrid system solutions

By 2050 RE hybrid systems will play a central role in the energy mix. In fact, the integration of different RHC technologies in a system could overcome technology-specific limitations and therefore achieve higher performances. Hence, hybrid systems will be key enablers for year-round reliable and affordable H&C in buildings and industrial process, at different scales. Energy- and cost-efficient, user friendly, and competitive off-the-shelf products and services will boost the demand for RHC technologies.

Eliminate waste and inefficiencies

Excess heat from industrial processes and commercial buildings (e.g. data centres and other urban infrastructure, such as sewage channels, that are currently in large part dissipated in the atmosphere or water), will be used to complement other RES for space heating and cooling either directly (where possible) or indirectly via heat pumps. Circular economy approaches will be widely employed, including the surrounding buildings to efficiently utilise excess heat and cold in DHC networks, thereby creating added value for the local community. Excess heat can be used both for heating and cooling purposes (e.g. by converting it into cold through adsorption chillers). Additionally, bioenergy has the potential to eliminate industrial, agricultural, silvicultural, and food waste and transform it into H&C and electricity, thus reducing the waste of resources while fostering local circular economies. A special role will be played by seasonal thermal storage, as they help to cover the higher heating demand in winter using solar thermal or excess heat harvested in other seasons.

TES: a key enabler for RHC technologies uptake

TES will be a key enabler for the deployment of RHC, both in DHC, industries, and buildings, be it at small or large scales. The use of high-capacity underground storage shared by several heat or cold generation systems, instead of a high number of small decentralised storage, can unlock further potential. Additionally, the combination of TES and predictive control algorithms will help to increase the share of renewables and at the same time stabilise the electric grid by integrating coupling points such as heat pumps. In fact, such technologies enable the cross-utilisation of energy flexibility potential to manage and mitigate temporal imbalances of supply and demand in the electricity grid with a high share of variable renewables (e.g. wind, PV). As a result, improved reliability, security of supply, and higher efficiency can be reached.

EE is part of the solution and shall be integrated in H&C planning

Efficiency shall be promoted not only on the supply side, but also on the demand side. Decreasing final energy demand by improving the energy performance of existing and new building stock, and by the densification of urban areas rather than creating scattered areas with very low heat densities, will increase the likelihood of meeting the target of 100% RHC by 2050. Additionally, energy efficient buildings can effectively shave expensive peaks and improve the performance and feasibility of thermal energy networks. Therefore, H&C planning shall be closely related to national and local EE plans.

Not only buildings: industrial H&C processes are of paramount importance

Industrial H&C processes are a crucial part of manufacturing in a broad range of industrial sectors, with various temperature requirements. Process H&C can either be based on fuel, electricity, or a distribution network using liquid (water, thermal oil, refrigerant) or gaseous (steam, air) working fluids. Regardless of the method, heat and cold generation requires a high amount of energy. On the one hand, technologies are needed to employ lower process temperatures for heat and higher temperatures for cold, as this saves energy, simplifies the design of the supply side, and reduces running and investment costs. On the other hand, radically innovative and advanced technologies for high-temperature H&C supply could meet the demand of energy intensive industrial sectors. Companies are encouraged to rethink their current process design within the framework of the transition to novel and emerging RES technologies, resultant in the usage of hybrid RHC solutions.

Cooling is not just the low-temperature counterpart of heating; it needs specific attention by due diligence and care

Wherever possible, H&C demand should simultaneously be matched in an integral way (e.g. by wide use of heat pumps). Nevertheless, artificial cooling, in most cases, represents a distinct economic sector with numerous specific features. Thus, innovative integrated processes and systems of renewable cooling and power supply should be a major focus in order to build a decarbonised Europe by 2050.

Smart energy management and new business models

Smart energy management systems will be widely adopted both at centralised and decentralised levels. Such systems are capable of optimising production and operation in H&C systems and networks. Local H&C markets connecting private, commercial, and industrial consumers, producers, and prosumers[3] will enable all these market actors to actively participate in and make best use of local heat and cold generation and storage capacities. Moreover, radically new business models (e.g. heat-as-a-service, pay-as-you-go) have good chances to be adopted by H&C providers. Market operators will likely sell integrated services rather than components, thus spreading upfront costs for customers over long timeframes (through instalments or leasing schemes) and creating a win-win situation for building owners and energy service providers. Companies should engage in partnerships to provide a stronger combined "package/bundle" of products and/or services.

Why research and innovation?

Research and innovation on all technologies, infrastructures and system aspects, including digitalisation and planning of RHC systems and networks as well as standardisation, is needed for large scale adoption of RHC applications. Technology advancements will lead to radically lower costs, higher efficiency, better system design and integration, enhanced operations and increased resilience, as well as security of supply. With regard to the energy system as a whole, research on system integration is needed. The future RHC systems consist of multiple technologies (generation as well as storage) and this will lead to strong interdependencies, which require smart monitoring and control for optimal and efficient operation. For this purpose, an integrated approach is needed, taking into consideration all relevant actors (including energy suppliers, technology experts, politicians, city-planners, industry, intermediaries, and consumers), their interactions and interdependencies.

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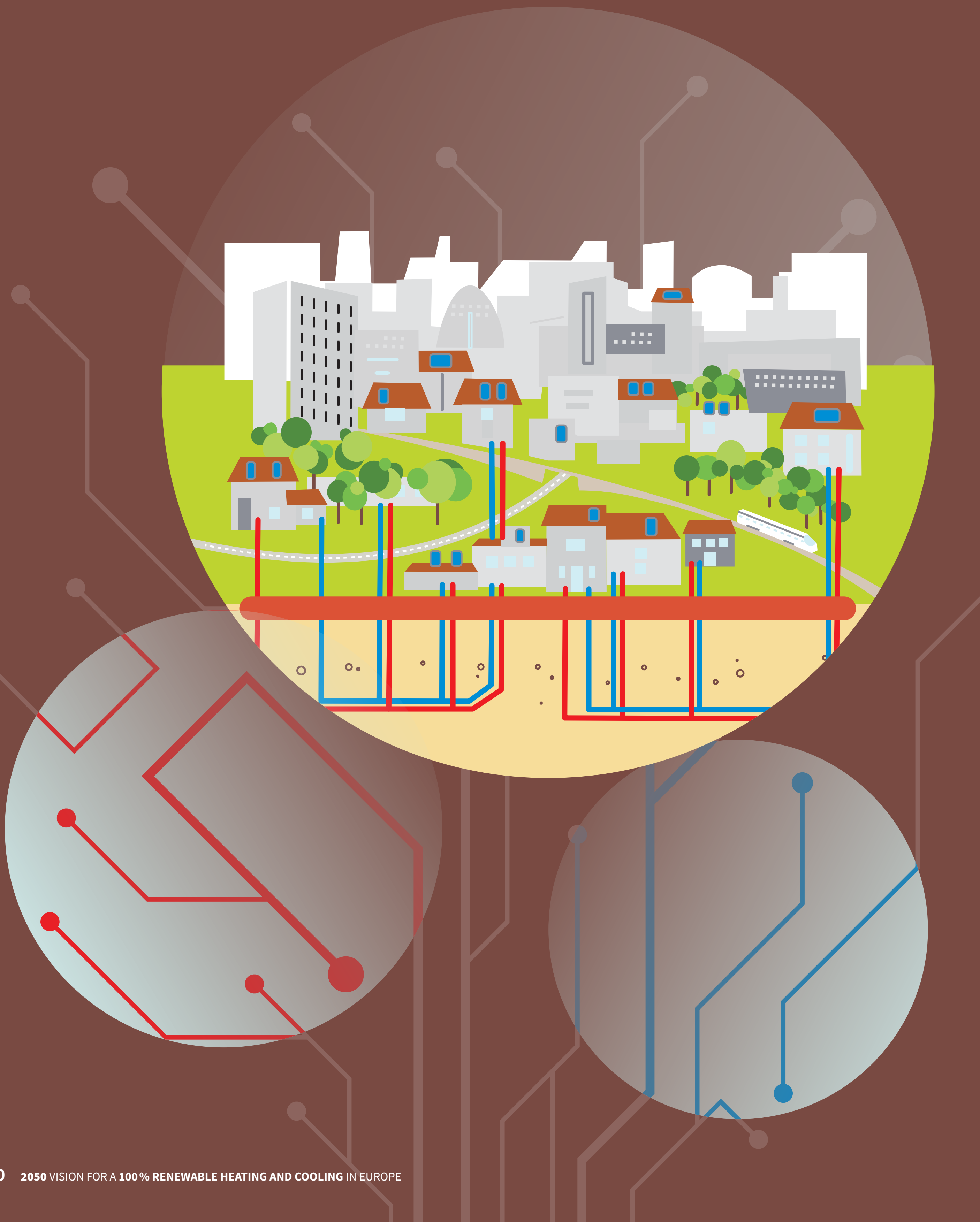
[2] The Heat Roadmap Europe project developed scenarios clearly showing that by 2050 CO_2 emissions in the H&C sectors can be reduced by 86% compared to 1990 levels, while the RE share can be raised to more than 87%. Project reports are available at: https://heatroadmap.eu/. Last time accessed on 13 September 2019.
[3] Prosumers is here intended as energy users who consume, produce, store and share energy with other grid users.

2. THE STRATEGIC ROLE OF CITIES IN THE ENERGY TRANSITION



The city of the future

Considering that 72% of the European population (EU28) lives in urban areas - defined as cities, towns and suburbs- cities play a key role in driving the sustainable energy transition. Smart cities are those cities taking a holistic approach to their energy management, by creating integrated energy systems. A smart city approach is built on the synergies of the most important sectors involved (electricity production, H&C, transport) and aimed at substantially increasing EE, while simultaneously supplying sustainable energy.

By 2050 cities will likely be based on a combination of RES for local electricity and H&C supply, and electrical transport integrated into the energy system. We envisage local H&C networks fed by RHC, with the intelligent exchange of energy occurring between houses and the H&C network. In the city of the future, which is 100% RES-based and has zero negative impact on the environment (no pollution, no GHG emission), citizens will act as prosumers in a smart and sustainable system.

H&C supply in cities

Cities and towns that have often been developed along rivers, lakes, and seashores, which provide access to substantial heat sources. All these sources make both high and low temperature RE available, and their usage is highly replicable as it is accessible right where it is needed. In order to use local sources, municipalities, energy utilities, and the industry must collaborate across sectors.

A single RES technology can never meet the high energy demand of cities alone. Each alternative has its specific advantages and disadvantages and needs to be applied intelligently, targeting those places where it can deliver its optimum capacity in synergy. In fact, cities are characterised by a variety of different settings, each of which require different technological solutions and management approaches for the supply of RHC.

Local leadership and the subsidiarity principle

In 2050, the subsidiarity principle will likely be applied to the European energy systems. This refers to cases when the monitoring and control of generation, conversion, storage, and consumption in all energy sectors are done in an integrated, highly automated way. The subsidiarity principle entails a paradigm shift, whereby energy systems are operated in such a way that actions are primarily taken at local and regional level (at the most immediate level). Only actions that cannot be properly addressed locally are handled at a wider governmental level. While this is a macro-trend for the whole energy sector, the inherently local nature of H&C supply means cities must play a leading role in developing and implementing strategies for their decarbonisation.

Improving the framework conditions

Four key non-technical areas have been identified as important to reach the goal of 100% RHC in Cities:

- establishing consistent energy strategies aiming to decarbonise the H&C sector;
- removing regulatory and market barriers, and simplifying procedures;
- developing innovative financial models for large, medium, and small-scale RHC projects, which are all quite capital intensive;
- training technicians, civil servants, and decision-makers from regional and local authorities, in order to provide the technical background necessary to approve and support RHC projects.

The ability of local governments to implement effective sustainable energy policies should be increased, including extending the legislative power of regions wherever appropriate. Cities can and must show leadership in this area and decisions must be taken locally. However, cities' efforts will only have the desired impact if they are complemented by compatible regulatory frameworks and favourable investment mechanisms established at European and national levels. Therefore, regional, national, and European governments should define targets and provide clear direction to the local actors. How to enable energy leadership at local level, while at the same time coordinating the different local dimensions over the entire continent from a system and market perspective, remains an important research, development, and innovation (RD&I) topic to be solved well before 2050.

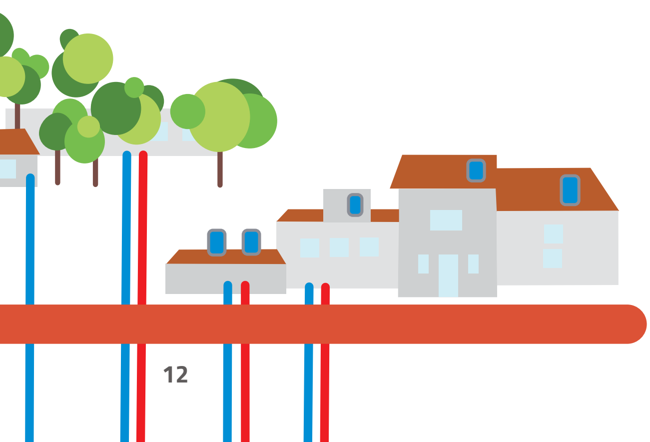
H&C planning as a prerequisite for the energy transition

H&C planning should be compulsory for cities. These obligations should be complemented by regional and national support schemes. Long-term climate and energy targets must be translated into adequately ambitious short-term actions through policies that facilitate the energy transition. In addition, cities should be allowed to autonomously carry out zoning planning, in order to empower them to implement the changes they need. Several simulation tools and dissemination platforms are already being implemented to support city planners to develop suitable H&C plans.

Technological objectives

The integration of the different components and actors of the local energy system and the building of synergies to reach 100% RHC in cities are required. The objectives in terms of technological development are to:

- improve smart appliances and energy management systems of buildings and districts for a full integration into the overall energy system. These should be capable of handling in a smart way the H&C supply, thermal energy storage, renewable electricity; and electric transport;
- develop the necessary interfaces/technologies to connect (Nearly-)Zero-Energy-Buildings to create zero-energy blocks of buildings and energy positive districts;
- provide cities with information on available RHC technologies and systems for all heating, cooling, and hot water needs (new and refurbished buildings, districts, industries), which will help to decarbonise cities.



3. A FURTHER STEP TOWARDS POSITIVE ENERGY DISTRICTS

The ambition: 100% RE districts

Bringing robust, reliable, and sustainable H&C to European cities is far more than a vague aspiration, it is a basic and entirely achievable necessity. By exploiting the potential of existing technologies such as efficient DHC networks, renewable heat generation, excess and ambient heat recovery, and fossil-free cogeneration, it is possible to move away from dependence on imported fossil fuels towards a more sustainable energy supply in highly populated areas.

Energy integration as a driver for renewable, circular, flexible, and efficient districts

It is vital to take an integrated approach towards the energy systems' planning, development, and operations across all energy infrastructures. Building and district systems can work together to optimise temperature levels, time of use tariffs, and storage opportunities so as to minimise total life cycle cost, recording input from load profiles, weather predictions, and future utility costs. Appropriate cross-sectoral software interfaces need to be established to achieve interoperability. EE and the use of RHC should be maximised and the synergies between them optimised by tapping into existing local RES and associated innovative technologies. Planning tools and methodologies specific to the DHC sector are necessary, in order to coherently model, analyse, and design H&C systems as an integral part of the entire energy system.

An integrated approach implies better exploitation of the potential of TES. The cost-effectiveness of all types of TES, including combined storage, long-term and seasonal solutions, should be identified and unlocked. Beyond traditional heat storage, cooling storage will provide flexibility and improve efficiency in cooling production. TES will reduce the electricity peaks, while providing a smart and cost-effective way to store electricity for consumption during off-peak hours. This will prove crucial in a system which includes a high share of variable RES.

To minimise the discrepancy between load and supply profiles of alternative heat sources (including power-to-heat), and to reduce the use of fossil fuels in peak load and wintertime while avoiding supply competition in summer, it is essential to develop and demonstrate technologies, systems and solutions to increase the short (hours to days) and long term (weeks to months) flexibility of DHC networks. Such solutions should improve the cost–benefit ratio of storage options and/or improve the demand side integration, where smart buildings learn and offer financial savings due to the available energy flexibility of existing customers.

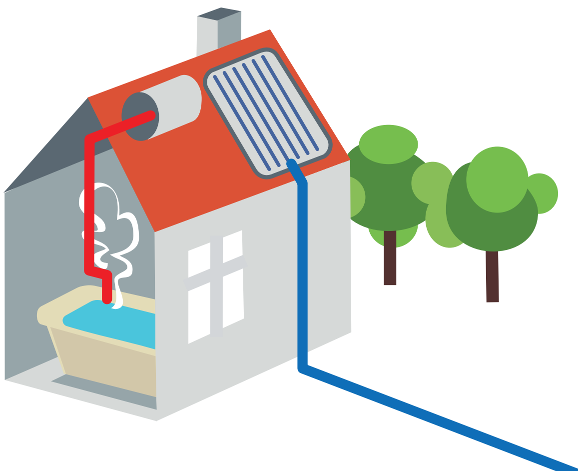
RES integration at district level

In the vast majority of urban areas, DHC is technically and economically more viable than other network and individual based solutions and can be 100% decarbonised through the use of renewables (biomass, solar thermal, and geothermal energy), excess and ambient heat, and fossil-free generation (Heat Roadmap Europe, 2018).

By 2050 the next generations of district heating (DH) systems will substantially provide the heat supply to buildings with low grid losses from low-temperature renewable heat sources. Due to raising temperature and comfort needs, district cooling (DC) has enormous potential and it will rapidly grow all over Europe. DC can be produced from local natural resources like sea water, or from renewable or excess heat sources. Already today, DC is 5 to 10 times more energy efficient than conventional machine cooling and can reduce cooling energy consumption by 50%. Switching to DC also contributes to reducing electricity demand, which is extremely useful especially in peak demand periods.

Efficient DHC systems improve EE and enable an increased share of local renewable and recycled energy for H&C. Clear and effective policy instruments for efficient and RHC networks provide stable framework conditions and will also create risk sharing schemes between investors, utilities, and public administration, thus increasing attractiveness to private investors. Therefore, it is of the utmost importance to develop and implement measures for:

- integrating additional RE heat sources of various sizes into existing DHC networks in a cost-efficient manner;
- targeting the combination of variable and invariable energy sources.



The successful integration of RES into DHC systems requires the development and demonstration of solutions for:

- matching system temperatures with locally available carbon-free and low-carbon energy sources, including the setting up of new DHC networks with low and very low supply temperatures and the reduction of the temperatures in existing DHC networks. The system design and operation should also be adapted to the lower temperatures, as well as to the integration of heat pumps, cooling options, and storage. Suitable business models involving building owners and end customers should also be addressed.
- efficiently providing, hosting, and utilising high shares of renewables up to in the local or regional supply, by following a holistic view on the energy system, i.e. linking different energy domains (electricity, heat/cold, green gas, mobility) at different scales.

The fundamental contribution of excess heat

Small- to large-scale excess heat sources could cover about 25% of the DH demand in many cities (Heat Roadmap Europe, 2018). Increasing the awareness and knowledge level of urban excess heat recovery among technicians, local administrators, investors, and sectors which could provide excess heat (e.g. data centre owners, sewage managing authorities, and service sector operators) is an important milestone to achieve 100% RE districts.

Digital innovation at district level

Simply put, digitalisation is about more and better communication, resource optimisation, and energy flexibility. This is how it could be interpreted at different levels:

- **Production level:** digitalisation is not a goal per se but a very interesting means to get a more renewable and efficient energy system while also saving costs. Advanced solutions such as smart network controllers integrate variable RES such as solar heat. Peak shaving, a form of smart control, can maximise the operation of RES.
- **Distribution level:** cost-efficient, robust, and scalable data collection and communication systems will enable the management of real-time energy data, which in turn will fuel digitalisation through machine learning and data mining technologies. This plays a key role in optimising the energy distribution and in maximising the performance in relation to temperatures, flow, pressure levels, thermal demand, and losses throughout the grid.
- **Consumption level:** digitalisation gives an opportunity to engage end-users in the awareness of their energy use and in turn their potential energy flexibility. By means of visualisation tools using real data on e.g. hourly intervals, energy end-users gain insights into their energy use; thus benchmarking with other consumers becomes possible and energy savings can be suggested. Tools for customers helping to control and monitor energy usage may streamline and help the customers to make DH much more efficient and allow 4th generation DH.

  Modern DHC systems are demand driven. The building level, manifested by the substation, establishes this demand. At the same time, building and apartment level solutions can help mitigate supply side challenges such as intermittent production. From a technical point of view, the building acts as the mediator between the grid and the indoor climate. By using smart meter technologies and remotely controlled devices, high temporal granularity of data is possible. Bi-directional data flow between the DHC operators and customers is one key to operational excellence and facilitates reaching the next level of indoor comfort for the end users.
- **Design & Planning:** the planning process of districts by municipalities can be optimised through the development and application of various digital solutions, including big data approaches for data analysis (e.g. utilisation of metering data for design processes), mapping algorithms (e.g. renewables, retrofitting potential), process planning tools, sophisticated optimisation and co-simulation methods, etc. Development and testing of technical and operational modelling, simulation and optimisation of multi energy technologies and systems is required to identify the technological and systemic constraints.

Coupling thermal networks with electricity grids

Technical interoperability between DHC technologies, automation, and electricity market standards will enable coupling points (e.g. heat pumps, EV loading stations, etc.) to be seamlessly integrated into a wider system.

Beyond technological, also socio-economic challenges need to be addressed

100% RE districts can be achieved only if innovations are not merely related to technological aspects, but rather also to societal changes with respect to sustainable finance, market uptake measures, and citizen engagement. In doing so, an orderly and highly cost-effective transition to a fully decarbonised H&C sector by 2050 can be ensured; subsequently creating smarter, greener, and more liveable cities along the way.

4. 100% RE BUILDINGS

Buildings are the largest energy consumers

Buildings represent almost 40% of total final energy consumption in the EU, with transport accounting for 28% and industry for 23% (EC, 2016). The main use of energy by households in the EU in 2017 was for heating their homes (64 % of final energy consumption in the residential sector), with RES accounting for almost a quarter of EU households space heating consumption. In EU households in 2017 heating and domestic hot water (DHW) alone accounted for 79% of total final energy use (EUROSTAT, 2019).

What to expect from the future?

The expected H&C demand (final energy use) in Europe in individual buildings depends on a number of factors, including evolving demographics, building standards (refurbishment of old buildings), typology (residential – including single-family, multi-family or blocks of buildings – and commercial), square-meter usage per person, and climatic conditions. The increasing population in Europe will likely raise the overall H&C demand, but more energy-efficient buildings can more than compensate for this. Warmer climates will decrease the heating need while increasing the cooling need, and improved standards of living will likely raise the fraction of the population being willing to pay more for H&C comfort. Towards 2050, a large increase in cooling demand can be expected in the residential sector, and heating-related comfort will become increasingly important as new and highly insulated building stock becomes more common in Europe.

Regional and local disparities of energy availability, costs, and demand in individual buildings requires feasible and sustainable solutions covering the wide range of needs of individual energy consumers. Hence, for individual buildings especially, the individual consumers will increasingly shape the future of H&C; a sustainability-first approach should be promoted and prioritised to the highest possible extent.

The decarbonisation of H&C in buildings is a challenging, but feasible task

When it comes to H&C, a shift to 100% RE for individual buildings is a huge undertaking. From the consumer perspective indoor comfort is central, which may lead to non-optimal solutions, if consumers have a low awareness level of RHC available to them. Commercially competitive technologies already allow the heating of buildings with RES only. These technologies will further develop, as will the insulation level of buildings, so that 100% RE for individually heated and cooled buildings by 2050 is both technologically possible and economically attractive.

The strength of H&C sectors today depend very much on regulations and geology of countries and regions, as does the market share covered by RHC. Going from north to south in Europe, the potential for active solar based H&C increases. Shallow geothermal H&C possibilities are numerous and deep geothermal systems are more geologically viable and less country and region specific. The H&C market share in2017 covered by renewables (not including electricity) in the different European countries ranges from 1.5 to 46.3%, with an average of 17.5% for EU-28. To reach the 100% RE target within 2050, a total phase-out of heating oil in the residential H&C sector is needed, which is already enforced in some European countries. Using solid fossil fuels will also likely become history. However, the extensive use of natural gas for H&C will be much harder to eliminate and replace; a gradual replacement of or mixing with RE gas is foreseen, as well as the substitution of natural gas with other RHC technologies.

Exploiting existing infrastructures to facilitate the RHC transition

Most privately-owned residential and commercial buildings in Europe are not connected to a DHC network, they are individual buildings (with individual H&C systems). Today, these buildings are often equipped with fossil fuel boilers (mainly natural gas, heating oil), although 100% RHC solutions are already available and competitive, such as biomass boilers, solar thermal collectors and geothermal and ambient heat-based heat pumps. These buildings that are not connected to a DHC network are, however, connected to a natural gas grid, hence enabling the use of natural gas for heating. This natural gas has the potential to be replaced by biomethane (a RE-based synthetic natural gas), making it possible to utilise the well-developed natural gas grid infrastructure to facilitate the RHC transition. However, due to EE consideration this should be avoided in the long-term.

The large variety of H&C technologies can provide optimal solutions for any context

Several cost-efficient technologies exist for H&C with RE sources in individual buildings, while some promising technologies are in the pipeline and need further development. The best technology or combination of technologies in a system to provide heating, DHW and cooling, as well as electricity, depends very much on the type, size, and architecture of the building, its insulation levels and its geographical and physical location.

When considering investments into H&C technologies, it should be considered that the final goal of H&C systems in individual buildings is:

- to minimise their needed size/power/capacity with EE measures;
- to apply solar thermal or passive geothermal H&C where possible;
- to supplement H&C provision with bioenergy sources or renewable electricity, when needed.

In the end, all H&C systems are part of a value chain, where in principle the sustainability of the whole energy value chain should prioritise the choice of RHC technologies and systems over less renewable options.

Sector coupling and energy storage are key elements enabling 100% RE in buildings

TES is a key enabler of 100% RHC in individual buildings, allowing for optimum utilisation of a combination of different RES over a day or even a year. Hybridisation and heat storage can significantly mitigate problems related to the intermittency of variable RES, such as solar thermal heating. Therefore, increased focus on thermal storage is extremely important.

Another key to a well-functioning energy system based entirely on RES is their optimal integration in the European energy and electricity systems. For individual buildings, it can be important to couple on-site H&C production, energy storage, RE-based electricity generation, and to some extent a RE-based gas grid; this will enable the provision of improved energy services that are more sustainable and deliver increased customer satisfaction. Using heat pumps to provide space H&C, while combining them with solar thermal for DHW and space heating, is an interesting option.

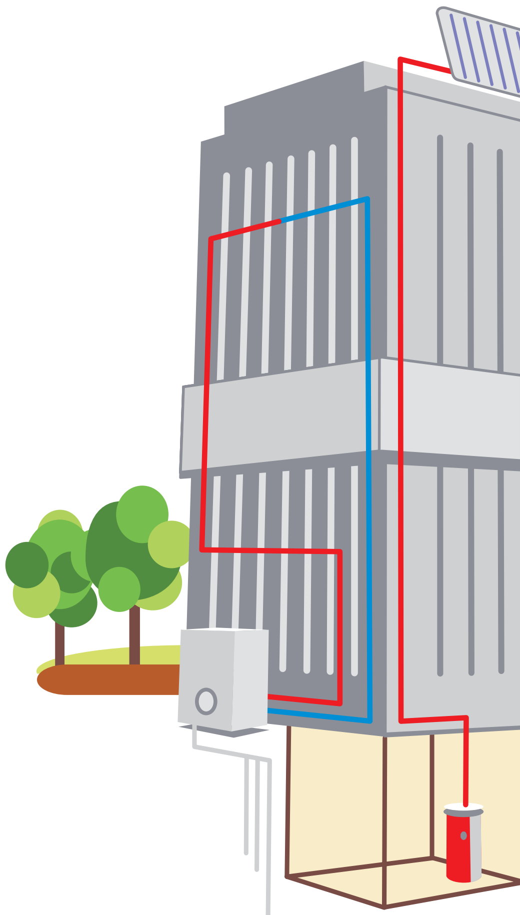
System solutions and consumer participation

Well before 2050 customers will be increasingly aware of their choices regarding RHC for their H&C demand in individual buildings. H&C will move towards building integrated system solutions, i.e. optimised with respect to the design criteria of the building. RHC systems will become more intelligent and user-friendly, allowing e.g. remote operation and control. This does not automatically exclude certain types of RES or H&C technologies, as the H&C sectors will strive to adapt to this future and will provide technology combinations and solutions satisfying consumer expectations. Increased participation of consumers in the energy system thanks to IoT (Internet of Things) and benefits from self-consumption of energy prosumers, and new technologies including smart meters and smart Building Energy Management Systems (BEMS), is foreseen.

Drivers for further RHC market uptake

Even though there is significant technological improvement potential for some of the existing individual RHC technologies, other aspects of technology adoption become even more important for the further deployment of those technologies:

- **Optimal system integration:** this includes the integration of an array of technologies that together perform the services that are expected, i.e. covering the H&C needs of individual buildings, in order to reach 100% RHC throughout the whole year. As there are large differences in Europe regarding H&C demand, it is essential to find the best system integration for specific climatic conditions.
- **Installation friendly systems (plug and play)** are needed, in order to provide H&C with minimum disruption for the user, especially when it comes to the refurbishment of old buildings. In this respect, the automation of technologies and systems are also needed. Finally, effective control systems and algorithms are needed to enable the optimum scenarios in terms of operating conditions. These considerations should include integrated artificial intelligence (machine learning) to continuously improve upon the operational efficiency and have integrated automatic inspections for malfunctions and therefore prevent equipment break down.
- **Relativise the high upfront capital costs throughout the system lifetime.** For many RE systems, the high upfront capital required during initial investment (CAPEX) represents a barrier against the implementation of 100% RHC in individual buildings, although the lifetime costs are often very competitive. Upfront capital investment reduction must therefore be a focus. Increased energetic performance of the RE system, including e.g. increased seasonal coefficient of performance (CoP) for heat pumps, will also contribute to a decrease in operational costs (OPEX). Emerging RHC technologies will become more cost-effective, more effective, and offer higher capacity.
- **Reducing the time needed for installing RHC systems** is an essential milestone. When an oil or gas boiler breaks down there is often very little time to replace it. There is a need for modularised RHC solutions which can be installed in less than one week. This may be also done by applying innovative renovation concepts, where e.g. a complete façade or roof elements are prefabricated and manufactured in a highly automated way in a factory and installed on the building in just a few days.
- **Modelling and simulation tools** considering the dynamic behaviour of energy systems will need to be developed and actively used to ensure optimal performance and resilience of RE systems. Individual buildings will increasingly become active parts of the overall energy system, delivering e.g. PV electricity to the grid, and using RE electricity or gas to cover the energy needs for several purposes and time periods. Emphasis should be put on the development of cognitive platforms for the monitoring of RE system operation (by analysing the information deriving from workflows and the surrounding built environment), with the goal to increase cost effectiveness. This includes the development of BEMS able to effectively control multi-generation systems with high RES integration. Data and communication security should also be taken into account.

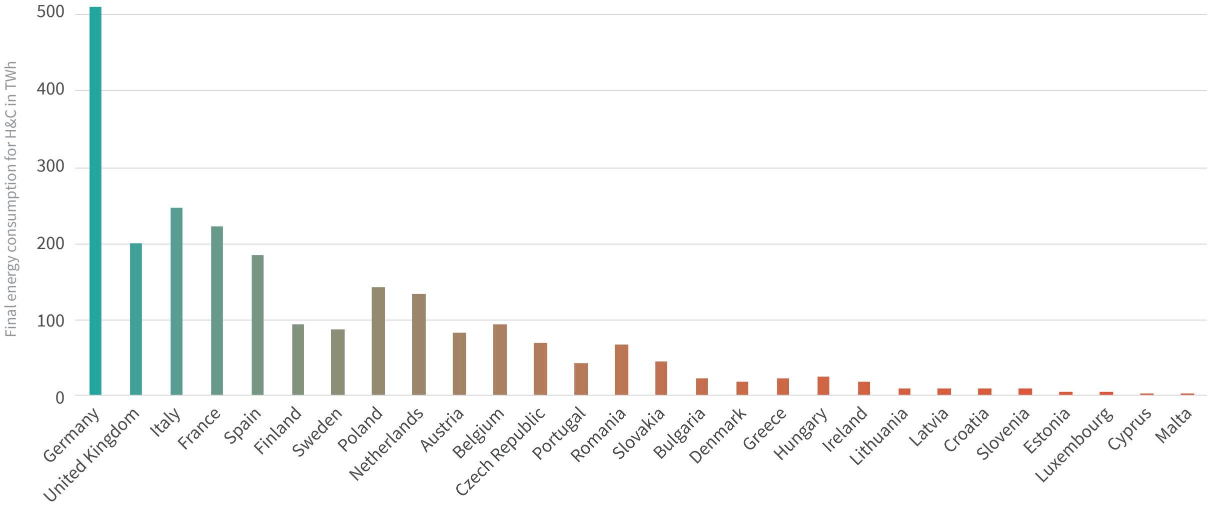


5. EUROPEAN INDUSTRIAL LEADERSHIP BASED ON A 100% RE SYSTEM

Industry is heating up

The final energy consumption in EU28 was about 11,900 TWh in 2015 (Eurostat, 2019), of which approximately 2,400 TWh came from the industrial sectors (e.g. manufacturing, construction), representing a share of 20 % of the total final energy consumption. The 15 countries with the highest consumption of H&C in industry (Germany to Portugal) accounted for 93 % of the overall final energy consumption in EU28 (Fleiter et al. 2017), as displayed in Figure 3-1.

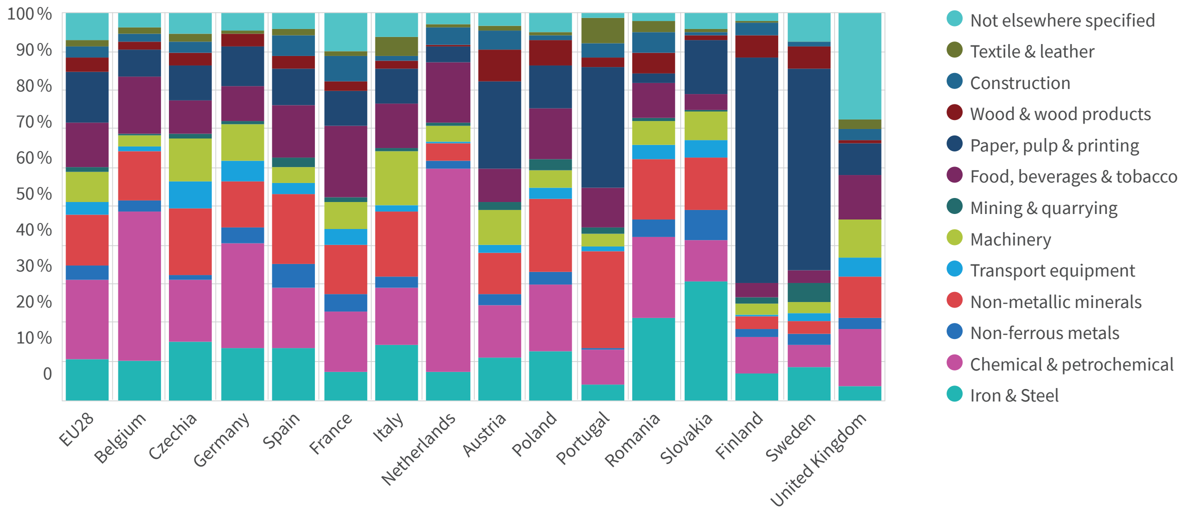
FIGURE 3-1: OVERALL FINAL ENERGY CONSUMPTION FOR H&C IN INDUSTRY (2015) (FLEITER ET AL., 2017)



There is a considerable demand for H&C in EU industries and this trend is expected to continue in the future. However, the share of energy carriers for industrial energy supply is still dominated by fossil fuels (see Figure 3-2). gas and coal are the most dominant energy carriers, whilst biomass is the most important RES with a share of 9% (Fleiter et al., 2017).

Figure 3-2 shows the relative share of the final energy consumption of industrial sectors in the EU28 as of 2017, and the 15 (of EU28) Member States with the highest final energy consumption for H&C. The most energy-intensive industrial sectors are chemical & petrochemical (20 %). They are followed by paper, pulp & printing (13 %); non-metallic minerals (13 %); food, beverages & tobacco (12 %); and iron & steel (11 %). With a few exceptions, the final energy share of the industrial sectors is similar for most of the depicted countries (Eurostat, 2019).

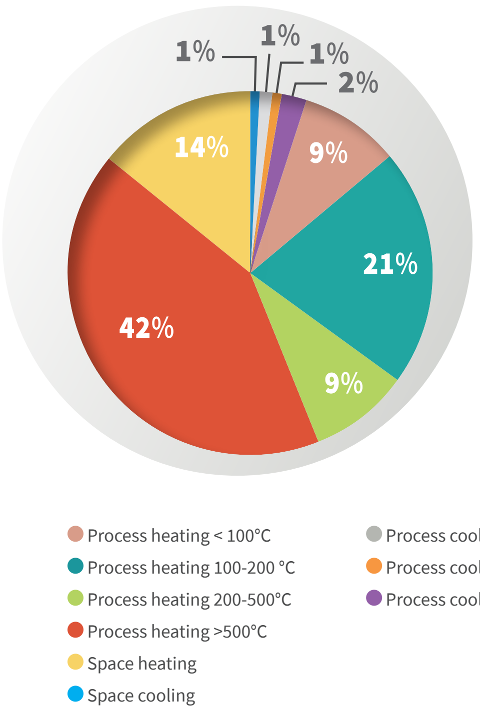
FIGURE 3-2: SHARE OF TOTAL FINAL ENERGY CONSUMPTION OF DIFFERENT INDUSTRIAL SECTORS IN THE 15 EU28 MEMBER STATES WITH THE HIGHEST FINAL ENERGY CONSUMPTION FOR H&C (93 % OF TOTAL H&C) AS OF 2017 (EUROSTAT, 2019)



Huge potential for a decarbonised industry

Figure 3-3 shows that 51% of the final energy in EU28 industries is used to generate heat above 200 °C. Heat under 200 °C (process and space heating) represents 44% of the overall final energy consumption for industrial H&C, while the final energy consumption for process and space cooling accounts for 5% of overall final H&C energy consumption (Fleiter et al., 2017). This share of H&C temperature levels is similar for most European countries, especially those with higher final H&C energy consumption.

FIGURE 3-3: SHARE OF FINAL ENERGY CONSUMPTION FOR H&C ON DIFFERENT TEMPERATURE LEVELS IN EU28-INDUSTRY (2015) (FLEITER ET AL., 2017)



The typical load profiles and temperature levels used for H&C in various industrial sectors determines the short- and mid-term decarbonisation potential of those sectors. Sectors using low temperature heat (< 150 °C) can already be decarbonised with renewable heat as there are several efficient RHC technologies available for low temperature demand. The higher the temperature of the heating demand is, the more limited the options are for decarbonisation by renewable heat. To estimate the short- and mid-term decarbonisation potential of industrial sectors and to identify the need of developments (especially for high temperature heat demand), it is important to cluster the industrial sectors regarding energy demand, load profiles, and temperature.

The steps towards the decarbonisation of H&C in industry

There are several ways to introduce renewable heat in industrial H&C processes. The first step is to investigate which renewable fuels are available locally, expecting that in most cases more than one fuel should be available. Examples include solar irradiation, ambient and excess heat (the former being mainly available in the form of water basins, the latter being excess heat from anthropic thermal processes), biomass in all its multiple forms (including biogas), and geothermal heat. The next step is to define the most suitable technology to make use of the renewable heat (each fuel can be utilised with specific technologies, generally more than one). In the case of biomass, for example, the fuel can be produced and transformed in gasified, liquid, and solid states and exploited accordingly through various thermal devices.

Seasonality in energy demand: once again, the solution is thermal storage

Seasonality is an issue for the supply of almost any renewable heat source. When it comes to industry, though, heavy fluctuations may occur also on the demand side. This is typical in batch production processes (daily, weekly, and seasonal fluctuations), but also occurs when manufactured products change, or a new production line is installed. In such cases, H&C demand may change in both quantity and profile. Nevertheless, fluctuations can be managed with thermal energy storage. The main challenge here is related to innovative high temperature storage, e.g. to store steam, such as Phase Change Material (PCM) or Thermo Chemical Material (TCM) storage, or even direct steam storage and underground storage can be used.

Eliminating waste by reusing excess heat

Several issues should be considered with regard to excess heat. Excess heat is usually available at low or medium temperatures (20-150°C), although higher temperatures are also possible (e.g. from exhaust gases). Depending on its temperature, excess heat can be used either for direct heating of lower temperature processes or as the heat source for a heat pump. Since relatively high temperatures are often required in industrial facilities, high temperature heat pumps have been developed and are commercially available (often custom-made). Finally, excess heat can also be used as a source for sorption chillers, given that their temperature level reaches at least 55-60°C. Excess heat could be used more effectively than it currently is in some industrial facilities where it

is generated, because it can also be shared or sold to neighbouring facilities via micro DHC grids, or even to neighbouring cities via large DHC networks.

Industries of the future

Changing the energy supply sources for industry requires a redesign of process technologies or, at least, an adaption of the conventional apparatuses. New energy systems based on RES can often only be integrated into low temperature heat distribution systems (e.g. heat from cogeneration plants or solar process heat). Continuous process management, which can be achieved through innovative process technology and which makes the use of renewable energy at low temperature levels (<120 °C) is possible and would lead to further significant reduction of the energy demand.

The use of thermal storage will be pivotal to integrate different heating and electrical solutions that cope with price fluctuations and seasonality, including among thermal technologies such as solar thermal, geothermal, and biomass. In 2050 industrial H&C demand could indeed be covered by RES, namely biomass, solar thermal, geothermal, green electricity, and gas for temperatures up to and above 250°C. The key challenge to achieve this, will be to convince industrials from a business perspective that taking concrete actions to switch to renewables and EE measures can be profitable.

Other energy vectors support the transition to RHC

Some energy vectors are likely to be increasingly used in the future for H&C (e.g. electricity and hydrogen). Depending on which energy source is used to produce them, they can be considered as RE, or not. Renewable electricity shall in the future be used mainly for high temperature applications, which cannot be easily covered with renewable fuels. Apart from that, growth can be expected in microwave drying, for example in pulp and paper production. It is also worth mentioning here that electricity consumption in industry will increase significantly due to the use of heat pumps. Hydrogen and ammonia are important energy vectors, but only if they're produced through RE. In the future, the use of these energy vectors is likely to become common in high temperature industrial processes (e.g. steel industry, cement industry).

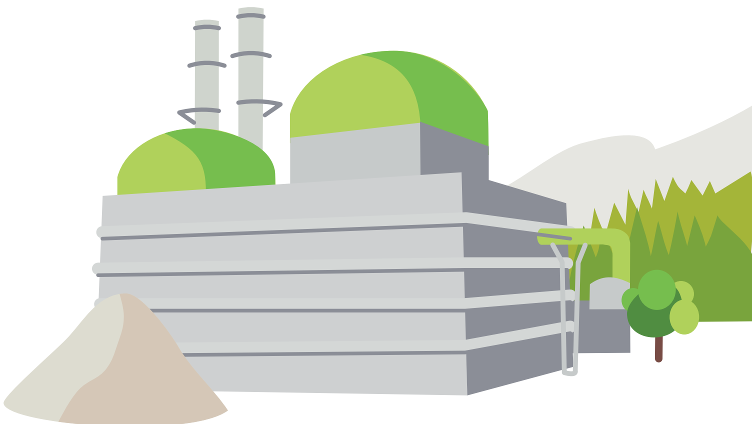
The impact of digitalisation

Industrial energy management systems for manufacturing are mainly designed for single supply technologies. They are not optimised for the fluctuations of energy demand and energy supply, and thus can only react to volatile demand and supply (thermal and electric) to a limited extent. Because of this, there is a need for support in redesign and optimisation of the operation of industrial energy management systems (demand and supply) so that they facilitate the interaction of both renewable (volatile) and conventional energy sources.

Fluctuating energy demand will be further increased by Industry 4.0 and the need to increase productivity. The flexibility of production makes it almost impossible for industry to plan and assess necessary adaptations and investment in the process and supply system. These challenges will increase significantly in the upcoming years.

In the future it will be important to support industries with the development of a methodology and software tool to optimise the operation and design of industrial energy management systems. The core of this challenge is the development of a holistic optimisation approach, based on (near-) real production data, historical data, and predicted data about the existing energy management system, both for the process demand and supply levels. Industry would then be supported with reliable solutions in terms of fluctuating, volatile, and renewable energy supply that is well designed for efficient process technologies. The methodology of the digital twin will be developed and validated for single use cases and more importantly implemented in the manufacturing industry (e.g. the printed circuit board industry).

From this, positive impact multiplication will be achieved and industries will benefit from a reduction of costs and risks, which will lead to a significant increase in the implementation of RE technologies that result in higher EE during industrial production.



6. SOCIAL AND POLICY INNOVATION

It is unanimous among the members of the RHC-ETIP that the 100% RHC in EU by 2050 vision can only be reached with a very strong political will to change the heating sector towards 100% renewables. Technologies are mature, commercially available, and market competitive already, and they will be continuously improved. However, without drastic political support, this vision will hardly become a reality. Courageous and effective policy instruments are needed to stepwise phase out any fossil H&C systems well in advance of 2050.

Political decisions and plans to phase-out fossil fuel-based heating systems

100% renewable in the H&C sectors by 2050 means that by that date any fossil fuel-based system in the sectors must have been replaced. If that should be reached, enormous efforts are needed within the next 30 years. Reaching this target is only possible with suitable policy instruments and ambitious plans to phase out fossil fuel-based heating systems.

Removing all fossil fuel subsidies

In some countries, the installation of efficient fossil fuel boilers (gas, oil boilers) is still subsidised if they replace old systems. These subsidies slow down the RE transition and need to be removed.

Introducing effective investment incentives

Direct investment subsidies for RHC systems can be a powerful tool to boost market uptake of RHC technologies. The principle behind this is that among the public benefits can drive actions better than penalties can. It is important that these measures are thought through carefully, that there is a clear objective, and that there will be enough funding available to achieve this objective. Subsidies need to be easy to understand for the beneficiary, and have a low level of bureaucratic hurdles. Most importantly, they need to be directed towards lowering the high upfront costs associated with many RHC solutions.

To reach this envisaged decarbonisation targets by 2050, the cost-effectiveness of RHC compared to fossil fuels must be increased dramatically. In order to enhance the competitiveness of RHC, a tax on fossil fuels should be progressively introduced, thus alleviating the majority of social and environmental costs. Alternatively, the extension of the Emission Trading scheme (ETS) to the H&C sectors could also be helpful. These revenues should be used for supporting schemes to incentivise RHC solutions.

Supporting the ESCO models

An energy services company (ESCO) is a recognised business model that drives the penetration of RHC solutions, but it has not yet reached its full potential throughout the EU. The core stakeholders of ESCOs are usually small and medium sized enterprises (SMEs). Increased adoption of the ESCO model throughout Europe will be very important to drive performance expectations of the RHC sector, as the ESCO model dictates that the earnings of the professional stakeholders when designing, installing and maintaining energy systems, are directly related to performance/energy revenue criteria of the systems installed. However, at present there is no simple method for an SME to raise the initial finance to initiate an ESCO contract. There is a need for suitable framework conditions allowing the further uptake of this business model.

Gaining the trust of the mainstream market

Transparency is a necessity to gain the trust of the consumers, as previous RHC experiences over the last 30 years have somewhat damaged the image of RES. To ensure mainstream uptake and solid growth in the RHC sectors, installed systems should be guaranteed to function according to the expected performance. To enhance trust in RHC solutions, dissemination platforms should provide historical data of RHC systems (including hybrid variations). This data should be integrated with a method to compare performance and installation cost, therefore providing guidance to businesses and decision-makers. Once this comparison tool has evolved, businesses can establish benchmarks for cost, performance, and emissions savings. Presently, there are disruptive open source control platforms already established and available that provide methodologies for comparing such historical and real data. The application of these platforms will be required to build the benchmark data, with the goal of establishing effective RHC business models.

Moreover, in order to ensure the installation of systems that fulfil at least the minimum of quality requirements, appropriate product certification schemes (e.g. the Solar Keymark certification for solar thermal products or the Heat Pump Keymark for heat pumps) should be established for all kinds of RHC systems. Only the installation of certified products should be eligible for public subsidies.

From "heat as a commodity" to "heat as a service"

Extending the ability of cities to generate revenue and access financing at lower opportunity costs will support their efforts to undertake sustainable energy programmes and infrastructure projects.

There is a need to develop business models that move from the conventional approach of "heat as a commodity" towards the emerging concept of "heat as a service", in order to increase the RHC investment desires of institutional investors. Business models and tariffs should benefit consumers who want to contribute to demand-side management. To scale up investments, innovative approaches must be found, enabling investors to understand how RHC contracts can be built and how the investment risk shifts from low investment and high operation cost to high investment and low operation cost for RHC usage.

Moreover, there is a trend of decreasing public funding availability so there is an imminent need for an increased leverage of private funds to support RHC growth. In light of this, the setting up of new schemes and mechanisms to lower the risks on investments, such as a more standardised contractual framework at European level (e.g. energy performance contracts), is necessary. The development of innovative financial schemes could support the attraction of private investments for RES in DHC. The creation of one-stop-shop business models and a broader use of revolving loans or new financial products such as green bonds are two examples. Lastly an enhanced participatory approach in financing for RES has showed in many cases the potential benefits for all involved stakeholders. For example, crowdfunding as well as initiatives led and financed by citizen cooperatives can have a major role in adding new sources of finance and raising capital from widespread investors.

Need for structured plans to phase out fossil fuel-based heating systems

The fulfilment of the objective of 100% RHC sectors by 2050 requires clear plans at both EU and national levels to phase out fossil fuel-based heating systems. Considering the lifetime of boilers being 20-35 years, this plan must be implemented as fast as possible and should include both new buildings and infrastructures, as well as the existing building stock. Some European countries (e.g. Netherlands, Norway) followed the Danish example of banning the installation of new fossil fuel-based boilers. From a given date onwards, it is forbidden to install new fossil fuel-based boilers. Also, the replacement of existing boilers with RE systems could be requested within a given transition period. This is a rather simple but extremely powerful mechanism. Such bans could also be accompanied by incentive schemes, in order to mitigate the risk of energy poverty.

Developing national building codes

One of the key elements to achieve the target of 100% RHC in buildings will be the application of binding RHC targets for the building stock. National building codes throughout Europe are recommended for the refurbishment of existing buildings. For new buildings there is a variation of building codes throughout Europe. To reach 100% RHC in buildings by 2050, we need building codes and legislation with crystal clear requirements and ambitious targets for the use of RE-based systems.

Valuing energy performance certificates

Presently energy performance certificates, rolled out as mandatory in Europe by national governments, have been treated by the 'mainstream' as another bureaucratic hurdle to overcome when selling a property. The certification process is not yet used for any specific purpose, but it could be a vehicle to invigorate the use of RHC. For buildings, as the energy performance certificates have been sufficiently accepted by EU countries, there is an opportunity in using them to drive a methodology of tax incentives or penalties on the municipal building taxes.

Enhancing stakeholder awareness

The main challenge of achieving the 2050 100% RHC target will be to inform stakeholders about the beneficial uses of RHC applications. All building owners should be engaged because tenants/renters typically won't invest in RHC for properties/buildings that they don't own . The motivations of building/property owners to invest in RHC technologies is often low due to high investment costs, which can lower profitability in the near term. In order to also upgrade rented buildings to 100% RE, suitable legislation and national targets are needed, which will clarify the role of tenants and building owners in changing the heating systems.

Another important action is mainstream awareness raising through fact-based and proactive communication, with experts enabling the creation of transparent regional/national internet portal hubs, that could potentially evolve into self-funding platforms. These platforms should include information on loan distribution related to energy savings, technical validation with all the 'checks and balances', demonstration and dissemination of financed projects, information such as design to metered energy, and CO_2 savings. This will foster the engagement of professionals and building owners.

European wide application of RHC solutions, and mainstream education, will need to take into consideration the wide range of 'engagement variables' such as geographical location, economic levels of development, building characteristics, local environmental conditions over an annual cycle, and cultural differences.

Support informed consumer decisions

The breakdown of old heating systems often occurs suddenly and at times with high heating demand. Thus, spontaneous consumer decisions for heating systems must be considered; system breakdowns usually lead to "like-for-like" replacements because there is little time to make an informed decision. Support must be given so that consumers as well as intermediaries have the required knowledge to take an informed and optimal decision. There should be a mandatory consultation (e.g. the "Feuerstättenschau" in Germany) with the goal to setup a master plan for the deep renovation of building(s).

Citizen engagement and participation

Modernised H&C sectors empowers local communities, small businesses, and citizens, giving each citizen the possibility to take part in the energy transition as a consumer, worker, investor, or even producer. Citizen engagement and participation in decision-making processes should be enhanced through:

- a transparent and inclusive framework for public participation in decision-making processes (public consultation procedures and consultation meetings);
- the involvement of enthusiastic community members, who often function well if engaged as local/regional "ambassadors";
- initiatives for local/regional communities to increase and sustain acceptance (i.e. creating reliable "win-win" solutions);
- strategies to dismantle local/regional initiatives that seek to prevent progress in decarbonisation.

Energy communities can be the entry point for a change in the traditional RHC business model in which operators own the assets, to a new one in which citizens take up this role. Community-based projects should be prioritised over sole ownership under the premise that community-owned solutions have higher targets for decarbonisation and indoor air quality improvement considering the volume of people being affected. As investment plays a key role in final energy prices when using renewables, this new approach will provide better prices for end users, while operators can concentrate their efforts on what really is their core business (managing the production and distribution of energy). Consequently, many small and medium low temperature DHC networks will emerge, so digital tools must be created to manage operations under these conditions.

In this community-ownership scenario, RHC end-users can assume both the roles of energy consumers and producers, thus becoming prosumers. Business models will be developed with energy users as the focal point, trying to gather social acceptance and triggering the wide adoption of the solutions implemented within this framework. The financial benefits for prosumers should be structured to reflect the needs of the overall energy system. Moreover, policies and price signals should encourage flexible interactions for prosumers to help balance energy grids instead of simply maximising the owners' self-consumption.

Engaging professionals

Several analyses of H&C consumers[4] show that certain professional groups, such as architects and engineering consultants, still consider RE as a potential risk to their clients. This is due to the complexity of design/installation compared to existing HVAC systems available in the marketplace. These reservations from such professional groups must be considered and dealt with, using transparent platforms for providing and disseminating information on the design and performance data of installed systems. Environmental and financial savings should demonstrate to the professional groups the necessity of engagement.

Due to the high number of RHC system installations needed to reach the 100% RHC target, the need for engagement of both technician and professional groups cannot be underestimated. Again, the dissemination of RHC systems design, installation, and performance data will enable these stakeholders to engage with the marketplace. The use of professional certifications would also be beneficial but should not be mandatory at the initial stage of the RHC transition.

The role of intermediaries

Consumer decisions are usually made based on recommendations of intermediaries such as installers, chimneysweepers, and even architects. Currently, the installation of oil or gas boilers is often the simplest solution for the replacement of old or broken heating systems. Intermediaries often recommend the installation of oil or gas boilers as it is a low risk technology with low maintenance efforts and generally high consumer satisfaction. Thus, these intermediaries must get the necessary support to be motivated enough to promote RHC solutions instead of fossil fuel-based systems. This support can and should likely be monetary (e.g. by tax reductions, training, etc.).

Need for new skills

New skills will be required from energy planners, heating system providers, and installers as emerging EE, automation, IT solutions, and services become prevalent in the H&C sectors. A mix of interdisciplinary skills, including control engineering, energy engineering, and computer science will be essential. A new position of energy manager will emerge in cities, whose role will be central to drive the RHC transition; this role will combine both energy planning and public policy skills.

A shift is also needed in terms of business logic, moving from large production plants and distribution networks to decentralised, efficient production and distribution of H&C. For DHC providers and policy makers this implies a better understanding of the new demand and needs of the customers, who will increasingly be prosumers.

The public sector should pave the way

The deployment of 100% RHC in EU can be most effectively overseen by public authorities, if they take over the pioneering role of first movers by considerably investing in public buildings and H&C network renovations.

Involving industries in the RHC transition

One of the biggest challenges in the decarbonisation of the industrial sector will be to engage businesses that are not energy-related. For higher temperature needs (e.g. in the cement or steel industry), viable solutions will be renewable electricity and green gas, even though direct heat solutions are proven and efficient in the market. This however is currently not a priority for non-energy related businesses such as companies in the food and beverage, or textile industries. Manufacturing represents a high share of the energy consumption in EU but for most businesses, taking concrete measures and securing investments to switch to renewables is a low priority.

To enable a behavioural change in this context, the benefits of a clean energy transition (other than cost savings and contribution to climate protection) must be highlighted (e.g. increase in productivity, better working conditions, improved corporate image, and of course long-term financial returns). These are direct benefits, unlike the indirect benefit of contributing to the overall sustainability goals, which often is not the primary goal, metric, or business driver in for-profit organisations.

[4] Final report on the analysis of the heating and cooling consumers -Contract number PP-2041/2014 - VITO / EnergyVille /Fraunhofer ISE - 1 March 2019

ANNEX I – TECHNOLOGY STATE-OF-THE-ART

i. Solar thermal

What is solar thermal?

Solar thermal (ST) systems function by collecting solar radiation and converting it into heat using a collector absorber. That heat is then exchanged with a heat transfer medium, which can be in air, water (liquid and steam), a mixture of water and glycol, or oil (for higher temperature applications). Depending on the system design, the thermal energy of the heated medium is transferred, through a heat exchanger to a storage tank and used to supply heat (e.g. in buildings, for swimming pools, domestic hot water (DHW), space heating, industrial processes, or district heating (DH) systems). ST technologies are highly flexible, scalable, and easily integrated with both fuel-based and electricity-based heating solutions. Furthermore, ST systems have very low operating and maintenance costs, use components that are almost 100% recyclable or reusable, and present no health risks or hazards.

State-of-the-art of solar thermal technologies

Current key applications of ST technologies are:

- domestic hot water preparation for single- and multi-family houses with typical solar fractions (i.e. the share of heat demand covered by solar energy) between 40 – 90%;
- space heating for single and multi-family houses with typical solar fractions between 15 – 40%;
- space heating for non-residential buildings;
- DH, with solar fractions going up to 50%, depending on the type of storage;
- low, medium, and high temperature heat for industrial process applications;
- other applications, such as ST for swimming pools and solar cooling applications.

Solar heat technology is extremely scalable, ranging from decentralised domestic solar water heaters with a 2-kWth capacity, to large scale plants in the MW capacity range. The most common applications today range between 40-70°C for domestic hot water and space heating, including residential and commercial buildings. Solar-assisted DH systems can go above 100 MWth and are commercially available today, and particularly developed in Central and Northern Europe. Concentrated solar thermal (CST) technologies offer great potential for energy generation and large-scale industrial solar heat for industrial processes (SHIP) GW-size systems have already been built. Large-scale ST systems can produce heat at a cost of around 20 to 30 EUR/MWh. In comparison, the full cost of generating heat via gas boilers ranges between 28-35 EUR/MWh (Solar Heat Worldwide, 2019). Solar heat costs are highly predictable and virtually fixed for the whole lifetime of the solar plant; therefore, ST represents a risk mitigation against fuel price fluctuations. Solar active houses are buildings that use predominately solar energy for DHW preparation and space heating. With typical solar fractions in the range of 70% to 80%, solar sctive houses is by far the most cost-effective technological solution to provide the predominate share of the building's thermal energy demand on a large-scale basis by renewables.

There are also well-known applications of SHIP in almost all industrial sectors with an appropriate heating demand (including space heating, cleaning processes, and drying), and in particular in the food and drink sectors (e.g. breweries, dairy, etc), as well as in the mining, automotive, rubber, and textile sectors. These ST systems show great potential and are well suited for generating heat up to 150°C with good return on investment (ROI), but there is still a need for promoting further demonstration projects and feasibility studies.

ST provides clear benefits for local economies. With 90% of products available in the internal market being of EU origin, this solution allows the production of clean local energy, creating new businesses, new jobs, and job-reconversion. Furthermore, ST is an exporting sector, with annual net exports surpassing at times 1 billion Euros.

Within the heating and cooling sectors, ST has some key specific strengths, as it:

- is based on a standardised design process offering fixed energy costs over the system lifetime (more than 20 years);
- is easily integrated with other renewable energy sources for heating and electrical solutions, or with conventional fossil fuel-based systems, which makes it a positive factor for building renovation;
- always leads to a direct reduction of primary energy consumption;
- is an infinite source of energy which does not produce CO_2 thus making it a no regret option;
- creates local jobs along the value chain (distribution, planning, installation and maintenance);
- is a scalable solution, applicable at different temperature levels and for very different purposes;
- has no exposure to the volatility of prices and doesn't cause an increase of electricity demand;
- allows forreal self-consumption and energy independence.

Potential of solar thermal technology

Renewable heating solutions are expected to take a prominent role to achieve a 2050 decarbonised EU. This could not be reached without ST, which is expected to cover at least 50% of the final energy demand for heating and cooling in Europe with an average collector area of 8 m^2 per European citizen. The market in Europe is showing positive trends, as 2018 indicated strong growth rates in some of the largest markets, which is expected to continue (Solar Heat Worldwide, 2019).

Nowadays, the potential for renewable based DH is underestimated and its implementation is limited to areas with natural gas networks. Solar-based DH is an innovative and promising solution which can be more cost-effective than gas-based DH. Integration of solar thermal with other low temperature heat sources will also prove beneficial as ST is an effective solution for peak shaving in summer and contributes significantly to winter heat demand, especially if coupled with seasonal thermal storage.

Another positive trend is related to the adoption of SHIP, which shows already good results especially in the aforementioned sectors[5]. Furthermore, large scale SHIP systems need project financing and bankability assessment tools, which implies among other issues, standardisation, system validation, and risk assessment procedures.

Among the mega trends influencing the potential of ST technology, digitalisation will play a key role. It will allow a further integration between different technologies and devices but will represent a challenge especially for the small-medium enterprises that influence the ST sector. The internet of things (IoT), industrial digitisation (industry 4.0), domotics, and overall the integration among power and thermal appliances are expected to have a deep impact in making grid and off-grid ST solutions smarter.

Like every other renewable heating and cooling technology, ST is facing the hurdle of competing with natural gas, which is an extremely cheap fuel and is readily available all over Europe. Therefore, a Europe-wide carbon tax is a necessary step to protect the environment and induce meaningful investments towards ST and renewables. Additionally, as ST solutions used in Europe are mostly manufactured in Europe, additional advantages will be unlock such as job creation for local economies and the enhancement of European industrial competitiveness at global level. Finally, a clear streamlined legislation at EU level for facilitating and incentivising the use of available surfaces (rooftops, industrial and commercial buildings, industrial ground surface, reclaimed areas, etc.) for ST installations would accelerate the deployment of ST solutions, thus valuing it's high energy efficiency potential in the context of higher energy density requirements in urban areas.

ii. Biomass

What is biomass?

Biomass is plant- or animal-based material used for energy production, heat production, or in various industrial processes such as raw material for a range of products. Biomass contains stored energy from the sun, which is absorbed by plants through the process of photosynthesis. As a storable energy carrier, biomass can significantly contribute to increasing the share of renewable energy consumption and reducing CO_2 emission from fossil fuels. Biomass is not only an energy carrier, but it's also used as food, feed, chemicals, and for biomaterials. In a bio-based economy, these different uses are linked to each other and if managed well, complementary and sustainable.

Biomass can be collected from many sources and converted into many forms of energy. Current sources of biomass include:

- Forest products (e.g. firewood);
- By-products of the wood industry (e.g. bark, saw dust, shavings or black liquor);
- Energy crops (e.g. rapeseed, cereals or corn for biofuels; short rotation coppices, energy grass);
- Agricultural by-products (e.g. straw, manure, fruit wood, pruning residues);
- Biomass from waste streams (e.g. municipal waste, animal by-products);
- Aquatic biomass (e.g. microalgae).

Biomass is converted into energy through combustion. Direct combustion is the most common biomass conversion technology. However, the main advantage of pure or converted biomass is its storability in liquid, gaseous or solid forms, that allows for a high degree of flexibility. In fact, there are several thermal (gasification, pyrolysis, torrefaction), biological (anaerobic digestion, fermentation), mechanical, or chemical processes, through which biomass is first converted into other solid, gaseous, or liquid forms to obtain biogases or biofuels with far greater energy density and calorific value on a mass basis than the original feedstock. Storability will be essential in a fully renewable energy-mix as a baseline to grant security of supply.

State-of-the-art of biomass technology

Bioenergy is currently covering 10.5% of the gross final energy consumption in EU28, representing 59% of all renewable energy consumption (EC, 2019), and the largest share of this energy, about 75%, is used for heat. The remaining share contributes to the power and transport sectors.

Biomass covered around 87% of the total renewable heating and cooling (H&C) demand in Europe in 2016, corresponding to 17% of the total EU H&C demand (EUROSTAT, 2017). 50% of the bioheat in EU is directly used for the residential sector, 26% for industrial processes, 16% is derived heat (heat only and combined heat and power (CHP) plants), and the remaining 8% is used in services and other residual sectors. The development of new technologies will enable the production of secure and sustainable biomass supplies, clean and effective conversion processes, high-quality fuels, and optimally integrated solutions for households, services, industry, and district heating and cooling (DHC).

[5] During last years the largest industrial process heat plant in Europe grew from 2 MW up to 12 MW.

The wide variety of biomass products can enable and facilitate the multiple uses of biomass in a bio-based economy. For heating purposes, biomass conversion technologies are manifold, depending on the biomass type, the system size, its value chain, and its final use. Typical biomass fuels for heating are logwood, pellets, and woodchips. Stoves are used for heating individual rooms and partly adjacent rooms, with typical capacities of a few kW. Boilers with capacities of a few tens of kW up to the MW scale are used for central heating systems and hot water supply for individual houses, large buildings, industries, or DHC. Biogas and biofuels can be burned directly in a boiler for heat or in a CHP system for cogeneration, while upgraded biogas (biomethane) can be injected into the natural gas grid. However, biogas for plant oil use is still at a much lower level than solid biomass. Biogas is mainly used in industrial processes, and the biogas industry is constantly striving towards higher fuel quality and more efficient, low emission equipment, just as in the CHP and transport sectors.

Technologies for providing biomass-based heat to households, companies, and industries are available, reliable and efficient. Bioenergy can provide low-temperature heat, steam, and high temperature heat suitable for industrial processes. Thus, it is one of the most convenient solutions for decarbonising industrial sectors, where not many options are available. Small-scale heating systems fired with logwood, chips, or pellets are easy to use, have low operating costs, and are replacing heating oil in many European regions. Biomass district heating (DH) is of growing importance in several EU countries (Scandinavian countries, Austria, Lithuania and others), where demand for heat by the residential and service sectors is high. Additionally, fossil fuel-based DH could be retrofitted to utilise biomass fuels.

When supplying a DH system or industry, biomass is often used not only to provide heat, but also for power generation in CHP, allowing for better use of the primary energy (efficiency rates up to 85-90%). Even though 58% of the bioelectricity produced in the EU28 came from CHP plants in 2016, only around 20% of the biomass was used in CHP plants showing that there is large potential to increase the use of biomass in CHP. Medium to large CHP plants can be based on steam cycle or Organic Rankine Cycle turbines. Small CHP systems based on piston engines or recuperated gas turbines can be used for DH, large buildings, or small industrial sites. Looking more closely at technological development, household-scale CHP (so-called “micro-CHP”) is still at market infancy but has the potential to increase the share of bioelectricity. As a controllable energy source, biomass in CHP can also be used to compensate fluctuations of other renewable sources and thus help to promote the use of renewable energy in different sectors.

Potential of biomass technology

The future development of biomass depends to a large extent on policies at EU and national levels. The potential of bioenergy technologies to further penetrate the heating market depends on:

- the existence of a supportive and stable legislative framework for bioenergy;
- the development of well-established biomass value chains, from supply to equipment installations and maintenance, as well as effective marketing and communication;
- the creation of a level playing field in the heating and cooling sectors, eliminating subsidies for fossil fuel-based energy;
- secured supply of high-quality biomass fuels that meet sustainability standards;
- adaptation of biomass technologies to market needs and reduction of investment cost (CAPEX);
- support of intermediaries in the heating sector (installers, chimneysweepers, planners);
- innovation in biomass technologies (including those for harvesting and processing the biomass);
- intelligent system integration including hybrid- and multi-hybrid systems that reduce complexities of planning, installation, and operation by way of digitalisation and artificial intelligence that meets demands for negative GWG-emissions.

Developing a long-term research and development strategy to support the bioenergy industry is, therefore, key to keep improving the performance of the biomass technologies that allows fast decarbonisation of all sectors.

Existing studies have calculated the domestically available potential for energy generation from biomass in Europe to be between 169 and 737 Mtoe (7 - 30 EJ) a year from 2050 onwards (with the middle range being 406 Mtoe), taking sustainability issues into account (Faaij, 2018). Hence, there is still a large margin for development of bioenergy compared to the projections in the EU energy roadmap (see Table 1). It is very difficult to give reliable estimates for the end-use division in 2030 and 2050. Indeed, this will depend on many parameters linked for example to political choices, the market growth, or the feedstocks development evolution and their physical characteristics. However, it is very likely that heat will remain the main sector for bioenergy use.

TABLE 1: BIOENERGY EVOLUTION FROM 2000 TO 2050 (IN MTOE)

	2000	2016	2020*	2030**	2050**
Total primary energy consumption	60.5	134.5	167	245	322
Total final energy consumption	55.4	115.9	139	192	252
	Made up of:				
Bioheat (biomass for heat and derived heat) [6]	51.8	86.6	90.0	/	
Bioelectricity	2.9	15.5	19.8		
Biofuels for transport	0.7	13.8	29.1		

* From the NREAPs; ** From A Clean Planet for all scenario 1.5TECH, EU Strategy - 2018.

iii. Geothermal

What is geothermal?

Geothermal energy is, by definition, the energy stored as heat beneath the earth's surface, and has all the characteristics to play a crucial role in the future energy mix, providing flexible, affordable, and carbon-free energy while enhancing the competitiveness of European industries.

Geothermal heating and cooling (H&C) can supply energy at different temperatures (low or high temperature), loads (it can be base load and flexible), demands (from less than 10 kWth to a tenth of a MWth), and with no geographical restriction:

- On the one hand, geothermal heat pumps can use the temperature at shallow depth without any geographical restriction.
- On the other hand, higher temperatures are available at greater depth everywhere, which constitutes a resource for buildings, services, and industry process heat.
- The ground can also be used for heat and cold storage with underground thermal energy storage (UTES) (in aquifer thermal energy storage (ATES) or in borehole thermal energy storage (BTES))

State of the art of geothermal technologies

Currently, geothermal energy sources provide about 31 GWth for H&C in Europe. In particular, geothermal energy can be used for the H&C of domestic how water (DHW) for individual buildings, including both small (5-30 kW, mainly residential), medium (30-500 kW, mainly commercial), and large stock typologies (> 500 kW), as well as for district heating (DH). The range of users comprises residential houses, offices, shops, health care facilities, schools, university campuses, museums, as well as commercial, institutional, and historic buildings. Geothermal H&C also supplies heat to greenhouses, aquaculture, agricultural and industrial processes, etc., and to numerous spas and swimming pools. New and innovative applications of geothermal energy have been developed, and some of those have already been demonstrated, such as geo-cooling, melting snow or ice, and sea water desalination.

Existing housing infrastructure represents an overwhelming share of the low temperature energy demand that can be logically supplied by geothermal heat pumps and geothermal DH systems. Geothermal DH will be increasingly targeted at existing buildings and old inner cities rather than new housing developments. Current benchmark studies indicate that geothermal energy and small thermal grids are probably the most effective option for individual buildings, both in terms of carbon footprint and economics.

Potential of geothermal technology

The key challenge for the widespread use of geothermal heat in the coming decades will be the ability to reliably design, engineer, and control both geothermal DH and ground source heat pump installations, in order to be able to use the year-round potential of geothermal energy for sustainable H&C supply. The further development of heat from cogeneration geothermal systems, such as combined heat and power (CHP) plants with low temperature installations and new generation of geothermal systems (like enhanced geothermal systems), will also play a crucial role.

Geothermal heat pumps will likely become firmly established in the markets of all EU countries, and a continuous growth is expected everywhere. They will be classically integrated in energy systems for buildings and combined with other renewable systems, in particular in H&C networks. Multi-functional networks (buildings and industrial processes) will be developed, too. Geothermal energy storage (UTES: BTES and ATES) will be built-up for seasonal storage, with specific applications for residual heat from industry and storage of solar energy (high temperature storage). For low temperature heat pump supported applications, natural heat and cold from the air, or surface water will be stored underground and used for combined H&C. These systems will become an important provider of H&C for individual houses, industry and services, but also within district H&C systems. Moreover, geothermal H&C will be further developed, most notably for agri-food applications (heating greenhouses, etc.). Finally, new applications for pre-heating in high-temperature industrial processes will begin to be installed.

The EGS, a real breakthrough technology, will experience a strong development in Europe, producing a large amount of electricity and combined heating/cooling through cogeneration installations. These installations will allow the development of new DH systems for urban areas.

Thanks to the continued technological development, in 2050 Geothermal H&C systems are expected to be available and economically viable everywhere in Europe, for both individual buildings and geothermal H&C from enhanced and combined systems for urban areas, industries, and services. To fully realise the potential of geothermal energy in supporting decarbonised H&C, however, strong technology-specific regulatory measures will also be required, especially in DH and energy intensive areas.

[6] According to Eurostat methodology, the final energy consumption of biomass equals the energy content of biomass used for heat, except when heat is sold (this is the case of CHP and district heating). This sold heat is called derived heat.

iv. Heat pump

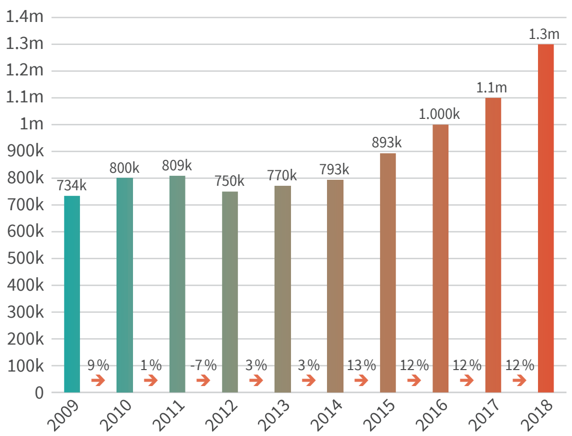
Basic principle of heat pump technologies

The function of heat pump (HP) technologies is based on the refrigeration cycle, a technological concept known for more than 160 years. It is deployed to provide heating, cooling and hot water for residential, commercial and industrial applications using renewable energy or waste heat. Any HP installation can provide heating and cooling (H&C) in parallel. Depending on which service is used predominantly, the device is called a HP, an air-conditioning unit, or a cooling/refrigeration machine. Numerous thermodynamic principles exist and are used to provide H&C. Consequently, the term HP does not refer to a single solution but rather to an array of technologies that can be used. This was enough reason for the International Energy Agency (IEA) to rename its knowledge centre to "technology collaboration program on heat pumping technologies (IEA HPT TCP)".

State of the art of heat pump technology

The potential of HPs in heating and hot water provision is increasingly recognised in Europe and worldwide. Figure 4 shows a double-digit growth in unit sales for the last four years in Europe and industry experts expect this trend to continue and potentially accelerate.

FIGURE 4: EUROPEAN HEAT PUMP MARKET DEVELOPMENT
2009 - 2018 INSTALLED HEAT PUMPS: 11.8 MILLION



With the increase in deployment, HP technology is now becoming a keystone to the energy mix, decarbonising H&C in residential and commercial buildings as well as in industry. But HP technologies are also the preferred choice when it comes to improving energy efficiency in white goods – dish washers, washing machines, tumble dryers, and even electric cars rely on this technology. With most of the energy generated extracted renewably from the environment (air, water and ground), HPs can also use:

- excess energy from industrial processes,
- infrastructure installations (sewers, subway, underground parking),
- reused exhaust air from buildings and industrial processes.

Time differences between energy production and use can be bridged by integrating thermal storage into the HP system design (e.g. when cooling is required, the waste heat from the cooling process can be used for hot water production), as well as easily by combining it with other renewable energy systems (e.g. solar photovoltaics).

HPs can operate at outdoor temperatures ranging from -25° Celsius (C) to 25°C. They typically cover a temperature lift of about 50-70 Kelvin (K) per operating stage, depending on the refrigerant used and the system design. Larger temperature gaps can be overcome with a multi-stage design combining two or more compressors, potentially with different refrigerants, that lift the temperature in multiple steps from source temperature to useful temperature levels. In this case, the heat provided by the first HP unit is the energy source for the second refrigeration process, and so on.

Compression cycle (electrically driven) HPs transform thermal renewable energy at low temperature levels to heat at higher temperature levels. This system consists of a heat source, the HP unit (with pumps, heat exchangers, valves and a compressor) and a distribution system for heating/cooling the building, device or industrial process. A transfer fluid transports the heat from a low-temperature source to a higher temperature sink. The compressor is typically run by electricity, but also engine-driven compressors are available in the market. The auxiliary energy needed to run the compressor and the pumps can be minimised by reducing the temperature gap between the heat source and the heat sink, as well as by optimising the components. Therefore low-temperature heat distribution systems play a major role in allowing HPs to work efficiently. The same system provides both H&C. Making use of both services results in highest efficiencies and gives an additional economic advantage as only one hardware investment is needed.

Thermally driven HPs (sorption chiller) are based on the thermal sorption cycle (equivalent to the compressor). Therefore, thermal energy is needed to drive the cycle and electricity is needed only for auxiliary components like pumps to circulate the working fluid. Thermally driven HPs are mainly used for cooling purposes in combination with waste heat or heat produced by renewable sources. Sorption chillers can be used for air conditioning of buildings with driving temperatures between 70°C and 100°C, or for refrigeration purposes, where driving temperatures of over 100°C are needed to reach temperatures below 0°C in the chiller. They can be realised in single, double, or triple effect, leading to enhanced coefficient of performances and achieving driving temperatures up to 250°C. A wide range of renewable energy sources and technology combinations can reach a wide range of possible driving temperatures.

Industrial HPs are most often bespoke systems designed to cater to specific needs. Depending on the system design and refrigerant used, a temperature difference of about 70K is covered with a maximum useful heat of around 150 - 170°C. Most applications are for providing heating at 30 - 55°C and hot water at 55°C to 65°. The latter can be increased by deploying HPs that efficiently provide hot water at 90°C. Research is now aiming at the 200° - 250°C temperature range. This will have to be tackled with new system designs.

Innovation and research in the HP sector are focused on improving components, products, and systems, while on a conceptual/experimental stage, promising development is being conducted into new fields (e.g. magneto-caloric HPs).

Potential of heat pump technology

One unit of electricity can provide between three and five units of heat (in very specific designs even six to seven units are possible). At the same time, such a system provides an additional two to four units of cooling, making overall H&C efficiencies of between five to eight possible.

In more practical terms, exchanging a fossil boiler with a HP saves about 50% of primary energy, while exchanging a direct electric heating system with a HP frees 2/3 to 3/4 of final/primary energy used; in other words, the energy needed to heat one building with fossil fuel-based energy is sufficient to heat two buildings with HP systems. If a direct electric system is replaced, savings are big enough to heat 3-4 buildings with HP technology.

The savings potential is even bigger from a systems perspective: if the fossil fuel-based energy saved by replacing boilers with HPs is converted to electricity in efficient cogeneration plants, not only can the electricity generated be used to heat 2-3 houses with HP technology, but the waste heat can be fed into district heating (DH) and made therefore additionally useful. Thus, a wide deployment of HPs will lead to a reduction of energy demand for heating while having only a small impact towards the maximum load on the electricity grid.

The clear opportunity to deploy HPs more effectively lies in harnessing better sources of heat from ground, or solar, feeding into better managed buildings systems (at lower temperatures) and harnessing electricity at more suitable periods of higher availability and hence lower cost.

To summarise, HP technology:

- is mature and reliable;
- can be easily integrated with other systems;
- can use a diverse set of (renewable) resources;
- comes in many shapes and sizes (capacities covering few Kilowatts to several Megawatts, catering to household appliances as well as to industrial appliances and DH systems);
- works with a wide range of temperatures and atmospheric conditions;
- can be used in energy storage and grid management;
- has complementary advantages (dehumidification, air quality improvement); and
- delivers heating that will have minimal local emissions of CO_2 or NOx.

v. Thermal energy storage

What is thermal energy storage?

Thermal energy storage (TES) is a technology that stocks thermal energy by transferring heat or cold to a storage medium so that the stored energy can be used at a later time for heating and cooling (H&C) applications and power generation. Therefore, TES solutions are used to correct the mismatch between heat supply and demand, thus allowing for optimal utilisation of a combination of different renewable energy (RE) sources over a day or even a year. The storage medium is responsible for temporarily separating energy production and energy consumption, for heating, cooling and domestic hot water (DHW). Therefore, TES technologies can contribute to increase the share of RE and at the same time enhance energy efficiency for heating, cooling and DHW production. Through sector coupling, TES can also contribute to balancing the power grid.

State-of-the-art of thermal energy storage technology

TES technologies can be divided in Sensible Heat Storage (SHS) technologies, Latent Heat Storage (LHS) technologies, thermo-chemical heat storage (TCS), and Underground Thermal Energy Storage (UTES). SHS is the simplest method based on storing thermal energy by heating or cooling a liquid or solid storage medium (e.g., water, sand, molten salts, or rocks), with water being the cheapest option. The most popular heat storage medium is water, which has several residential, district H&C, and industrial applications. Underground storage of sensible heat in both liquid and solid media is also used for typically large-scale applications. SHS has two main advantages: it is inexpensive and poses no risks associated with the use of toxic materials. However, SHS based on water cannot be used efficiently for cooling and the energy storage density (amount of energy per unit of volume or mass) is relatively small.

LHS can solve both these problems: it can be used for different storage temperature levels, including for cooling (by using materials such as such as paraffins and hydrated salts), and depending on the storage medium used, it is possible to find solutions with higher energy storage density than SHS. LHS is based on Phase Change Materials (PCM), a storage medium releasing or absorbing energy with a change in physical state (mainly solid/liquid). The energy storage density increases and hence the volume needed is reduced, in the case of LHS. The heat is mainly stored in the phase-change process (at an almost constant temperature) and it is directly connected to the latent heat of the substance. The use of an LHS system using PCMs is an effective way of storing thermal energy and has the advantages of high-energy storage density.

Thermo-chemical heat storage (TCS) is based on reversible exothermic and endothermic chemical reactions. This technology has a theoretical storage density of up to ten times higher than water-based heat storage systems. Furthermore, TCS allows for quasi-loss-free storage as the energy is stored as chemicals and not as heat, which leads to heat losses. As TCS is a relatively new technology, substantial efforts are still required in order to develop appropriate market ready products for various types of applications.

Underground storage can offer levelling of seasonal unbalances in supply and demand. UTES can also be used in medium temperature range, making use of available surplus heat.

TES enables the increased use of renewable and waste heat sources in energy systems and increases the flexibility of these energy systems on all scales and in multiple application fields. The main developments in TES technology can be subdivided into large, sensible TES, and in compact TES technologies (CTES).

Potential of thermal energy storage technology

Aspects for further development or improvement of large-scale TES technologies are:

- liner materials for high temperatures that have a (very) long lifetime and acceptable costs;
- construction techniques for large volumes, deep pit or tank storage, in different geological settings;
- thermal insulation materials and techniques to cost-effectively lower the heat loss and improve storage performance;
- floating or self-carrying lid constructions to enable the use of the storage top area;
- optimised system integration and hydraulics and controls to optimise system performance.

Important for cold storage are the development of phase change materials (PCMs) with working temperatures between 5 and 15 degrees C, the integration of cold storage in cooling systems and the optimisation of these systems. For PCM, there are several solutions of paraffins and hydrated salts that cover this temperature range. The most traditional solutions have been based on tanks filled with water and PCMs inside small containers with different shapes (plates, balls, cylinders). More recent developments include tanks with heat exchangers where the PCM is immersed in the exchanger and transport fluid (water) passes through the interior of the tubes. The main objectives are to reduce the volume of tanks and increase the rate of energy transfer. Some recent investigation has been done to increase the thermal conductivity of paraffins using nanoparticles (nano enhanced, NPCM); this solution can be useful mainly for cooling systems where the delta T in the heat exchangers are more limited.

Several CTES technologies have reached a technology readiness level between 5 and 6. Further improvement towards cost-effectiveness of such systems is dependent on the parallel development of novel materials, improved components, and further development and demonstration of systems based on the present generation of CTES materials.

Regarding materials, novel material classes, like mesoporous materials or composite materials, need to be further developed; moreover, testing methods need to be developed and assessed and the materials should be integrated in the reactor components. Cost reduction is an important target for the storage materials development. As for the components, new reactor principles need to be developed and improved, and existing heat exchanger designs need to be optimised for the storage materials.

At system level, the components need to be controlled in an optimal way, with novel sensor technologies to determine the state of charge and control strategies that take the typical characteristics of thermochemical processes into account. Furthermore, current generation CTES systems need further development towards demonstration, in order to tune the systems to the practical application situations and to find the optimal market introduction schemes for the next generation of CTES systems.

For medium and high temperature TES application in industry and for sector coupling, developments are needed for novel PCM and titanium composite materials, for reactor technology and for system integration.

vi. District heating and cooling

What is District heating and cooling?

District heating and cooling (DHC), which is also referred to as district energy or heat networks, delivers sustainable heating and cooling (H&C), connecting local resources to local needs. DHC is a proven solution for delivering heating, hot water and cooling services through a network of insulated pipes, from a central point of generation to the end user. DHC networks are suited to feed in locally available, renewable and low-carbon energy sources; solar thermal and geothermal heat, waste heat from industry and commercial buildings, heat from combined heat and power plants. The ability to integrate diverse energy sources means customers are not dependent upon a single source of supply.

DHC networks are inherently diverse and variable in terms of size and load; while employing similar operating principles, each network is designed according to specific local circumstances and adapts to continuous innovation. A growing number of cities worldwide are adopting modern DHC solutions, as they are the best way to bring sustainable H&C to dense urban environments.

The refurbishment, construction, and expansion of DHC networks (combining district heating (DH) and district cooling (DC), integrating and balancing a large share of renewable power, serving as thermal storage) are prerequisites for smart energy systems of the future. The constant evolution of DHC mirrors that of the broader energy transition. More efficiency, more renewables, and more flexibility lead to a better energy system.

State-of-the-art of district heating and cooling technology

Currently, approximately 60 million EU citizens are served by DH, with an additional 140 million living in cities with at least one DH system. According to reports by the EU and the International Energy Agency (IEA), DH currently meets around 11-12% of the EU's heat demand via 6,000 DHC networks. It should be noted that the share of DH varies significantly from one region to another e.g. DH is by far the most common heating solution in the traditionally cold-winter countries in North/Eastern Europe (Nordic and Baltic regions, Poland, etc.) whereas it has historically played a very minor role in Southern Europe as well as some Western European countries (e.g. Netherlands, United Kingdom).

Some European countries have achieved very high shares of renewables in their DH supply (more than 40%, in at least eight countries), helping to boost overall renewable energy penetration in the region's heat demand.

Today, the 4th generation DH (4GDH) is emerging as a new system to replace the existing 3rd generation DH system. 4GDH is also named as low-temperature DH (LTDH). The benefits are both in heat distribution and heat generation. In the heat distribution, it reduces the network heat loss, improves quality match between heat supply and heat demand, and reduces thermal stress and risk of scalding. In the heat generation, lower network supply and return temperature helps improve combined heat and power plant power to heat ratio and recover waste heat through flue gas condensation, achieves higher coefficient of performance values (efficiencies) for heat pumps, and enlarges the utilisation of low-temperature waste heat and renewable energy.

What is the potential of district heating and cooling technology?

According to the Heat Roadmap Europe data, if the urbanisation trend continues and appropriate investments are in place, almost half of Europe's heat demand could be met by DH by 2050. The DHC sector is following and covering the global trends toward urbanisation: 72% of the European population (EU28) lives in urban areas - defined as cities, towns and suburbs:41% live cities and 31% in towns and suburbs. It is in urban areas that the demand for H&C demand assumes the highest density. At the same time a huge amount of low-grade waste heat is diffused within the urban landscape and could be captured as used a source for DHC systems.

DC is still a young and maturing sector, with a limited number of DC systems currently operating in Europe. However, the growth rates reported show a strong upward trend which is expected to increase exponentially given the vast untapped potential of the sector, including in national heating markets which have traditionally been dominated by the use of individual oil or gas boilers.

DH has already proven its ability to integrate more renewables, especially geothermal, biomass, biodegradable waste, and solar energy. Renewable electricity powered large heat pumps are also increasingly being connected to DH networks in Europe. Furthermore, DH is starting to utilise the massive untapped potential of excess heat from industrial and commercial activities, which could meet most of Europe's heat demand and bring immense efficiency gains. Finally, with a rapidly increasing amount of variable renewable electricity, DH offers an effective energy storage solution to absorb excess renewable electricity and help balance the grid, making it a key enabling technology not only for the decarbonisation of H&C but also for the wider energy system.

ANNEX II - COMPARISON OF RENEWABLE HEAT AND COLD SOURCES AND RELATED TECHNOLOGIES

	Solar irradiation	Ambient heat and excess heat/cold	Biomass	Geothermal heat/cold
Available fuels	• Solar direct irradiation • Solar diffused irradiation	• Water (lakes, rivers) • Excess heat and cold	• Wooden (pellets, chips, logs) • Liquid (biogas, bioethanol) • Gasified	• Heat in the rock • Hot fluids and steam in the ground • Heat and cold in ground and groundwater
Availability	• Not constant across Europe: usually: the southern, the higher.	• **Ambient heat:** Not constant across Europe: usually: for heating the southern, the higher. Opposite for cooling. • **Excess heat:** depending on processes from which it is generated	• Basically, possible all over Europe. Import possible but should be limited to neighbouring countries.	• **Low temperature:** abundantly available across Europe. • **Medium to high temperature:** to be found in several, limited areas in EU.
Volatility	Daily and seasonal	• **Ambient heat:** Mainly seasonal • **Excess heat:** can be daily and seasonal	None	None
Intermediate transformations required to generate heating/cooling	Transformation from electromagnetic energy into heat.	• **Ambient heat:** as it cannot be exploited directly due to exergetic issues, it is usually used as source for heat pumps. • **Excess heat:** dependent on the exergetic content, it can be exploited directly or through heat pumps.	• Combustion • Thermal gasification & synthesis • Anaerobic digestion • Fermentation • Torrefaction	• **Low temperature:** usually not exploited directly for heating, but in conjunction with heat pumps: can be used directly for cooling in many cases • **Medium to High temperature:** direct use via heat exchanger possible, cooling via absorption chillers.
Available technologies for fuel exploitation in the EU	• **Flat Plate** (vacuum and no vacuum); • **Evacuated Tubes** (low and high temperature); • **Parabolic Trough** (vacuum and no vacuum); • **Linear Fresnel** (vacuum & not).	Compression, absorption and adsorption heat pumps; Free cooling technologies.	• Boilers • CHP plants • Biogas plants • Bioethanol plants • Gasifier technology • Synthesis technology	• Compression, absorption and adsorption heat pumps; • Free cooling technologies. • Direct heat exchange • Absorption chillers
Typical storage typologies used	• Daily for small systems. • Seasonal for individual and for large systems in DHC sector. • Water, pcm, tcm, underground, steam possible.	• Daily (mainly water) • seasonal for small and large systems (regeneration of underground storage)	• Daily for small systems. • Seasonal for large systems, especially in DHC sector. • Water, PCM, TCM, underground possible.	• Daily for small systems, also buffer storage. • Geothermal/UTES can serve as seasonal storage for large systems, especially in DHC sector. • Water, PCM, TCM, underground possible.
Achievable temperature	Up to 250°C with "conventional technologies". Above 250°C possible.	• With heat pumps 50-60°C • Direct excess heat: up to >100°C; over 200°C with industrial heat pumps	• Up to 540°C (CHP) • Above 1000°C (flame temperatures)	• With heat pumps 30-110°C • Direct cooling ca. 18°C, active cooling ca. 6°C • Direct use up to > 100°C
Typical back-up sources	Any. A back-up source is needed in most cases.	Any. In heat pumps, often electric resistances are used for direct heating when ambient temperature is below given values.	Basically, not needed, but recommended in households in summer to avoid burning wood in the hot season.	Basically, not needed.
Main advantages	100% carbon free, available anywhere (with differences)	Can be used as heat source or heat sink.	Does not have volatility issues.	Can be used as heat source or heat sink with high efficiency.
Main drawbacks	Volatile	Except for excess heat, cannot be used directly, therefore the resulting system may not be 100% renewable.	Competition with nutrition-based agriculture for first generation biofuels (biodiesel, bioethanol)	• **Low temperature:** usually requires additional energy for heat pump, which should be also renewable, if possible. • **Medium and high temperature:** available not everywhere in Europe. • High upfront investments needed, for deep geothermal specific risk profile.

ABBREVIATIONS

ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
CO_2	Carbon Dioxide
CAPEX	Capital Expenditure
CHP	Combined Heat and Power
COP	Coefficient of Performance
CST	Concentrated Solar Thermal
CTES	Compact Thermal Energy Storage
DC	District Cooling
DH	District Heating
DHC	District Heating and Cooling
DHW	Domestic Hot Water
EE	Energy Efficiency
EGS	Enhanced Geothermal System
ESCO	Energy Services Company
ETS	Emissions Trading Scheme
EU	European Union
H&C	Heating and Cooling
HP	Heat Pump
IoT	Internet of Things
LHS	Latent Heat Storage
LTDH	Low-Temperature District Heating
OPEX	Operating Expenses
PCM	Phase Change Materials
RE	Renewable Energy
RES	Renewable Energy Sources
RHC	Renewable Heating and Cooling
RHC-ETIP	European Technology and Innovation Platform on Renewable Heating and Cooling
ROI	Return on Investment
SET Plan	Strategic Energy Technology Plan
SHS	Sensible Heat Storage
SHIP	Solar Heat for Industrial Processes
ST	Solar Thermal
TCS	Termo-chemical Heat Storage
TES	Thermal Energy Storage
UTES	Underground Thermal Energy Storage
4GDH	4th Generation District Heating

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It coordinates the Heat Pump Technology Panel

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