**STRATEGIC RESEARCH AND INNOVATION AGENDA FOR THE RENEWABLE HEATING AND COOLING SECTOR**

**Authors/editors page**

THE SRIA IN A NUTSHELL

[To be prepared at the final draft stage]

List of figures + Glossary

AI: Artificial Intelligence

BIM: Building Information Model

CO2: Carbon Dioxide

CAPEX: Capital Expenditure

CHP: Combined Heat and Power

DC: District Cooling

DH: District Heating

DHC: District Heating and Cooling

DHW: Domestic Hot Water

EPBD: Energy Performance of Buildings Directive

ESCO: Energy Services Company

EU: European Union

H&C: Heating and Cooling

HP: Heat Pump

IoT: Internet of Things

LTDH: Low-Temperature District Heating

ML: Machine Learning

OPEX: Operating Expenses

PID: Piping and Instrumentation Diagrams

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

SCADA: Supervisory Control And Data Acquisition

SHIP: Solar Heat for Industrial Processes

SRH: Self-Reported Health

ST: Solar Thermal

SV: Securitisation Vehicle

TES: Thermal Energy Storage

UI: User Interface

UIM: Urban Information Models

4GDH: 4th Generation District Heating

5GDH: 5th Generation District Heating

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1. INTRODUCTION

The heating and cooling sector has a central role to play to successfully face the climate change challenge and achieve the decarbonisation of the energy system.

Each year, almost 50% of the final energy consumed in Europe is used for heat or cold generation either for residential, tertiary or industrial purposes. The vast majority (around 75%) of this energy demand is met by the combustion of fossil fuels such as oil, gas and coal – with notably major environmental impact, including in terms of greenhouse gas emissions and concerns about security of supply – while only 19% is generated from renewable energy[[1]](#footnote-1). Today the social, environmental and economic costs of climate change highlight the urgency of moving towards a new and more sustainable energy scenario.

Amid this situation, the European Technology and Innovation Platform on Renewable Heating and Cooling, 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 sector. As a result, the whole society will benefit from the increasing contribution of renewable heating and cooling towards the European Union’s 2050 targets.

The European Commission (EC) supported the establishment the European Technology Platform on Renewable Heating and Cooling (RHC-Platform) initially in 2008 with the aim to create a common framework within which European industry and research stakeholders can define technological research needs and strategic priorities to increase the use of renewable energy sources (RES) for heating and cooling and to consolidate EU technological leadership.

Since its creation, the RHC-ETIP has produced several documents, whose starting point was the single renewable heating and cooling technology. Common documents were also produced, but mainly as a collection of inputs from specific technologies. As a new approach, Horizontal Working Groups (HWGs) bring together interested experts from different technology panels to work on common horizontal topics, defined on the basis of main challenges to be addressed by the RHC-sector. Due to the structure of the current RHC-ETIP (Figure 1), only actors of the RES H&C sectors are involved in its work.

The RHC-Platform takes a holistic view of research and innovation priorities related to renewable heating and cooling technologies, providing strategic insight into market opportunities and needs, sharing information with almost 900, representing all renewable energy technologies for heating and cooling from industry, research, and the public sector from all over Europe to work in partnership and deliver on agreed priorities. RHC-ETIP is well established, crucial and highly appreciated forum for bringing the renewable heating & cooling sector together to advise policy-makers and to foster research & innovation.



Figure **Error! No text of specified style in document.**‑1 Structure of the RHC-Platform

The RHC-ETIP has been instrumental in raising the profile of the renewable heating and cooling sector by publishing a set of common documents, which have defined the sector’s strategic research directions, and projects’ ideas to be implemented to increase the share of renewable energy in the heating and cooling sector.

### Main political messages from Vision

*Figure SEQ Figure \\* ARABIC 1: Structure of the RHC-Platform*

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.

### Objective of SRIA

In order to realise the Vision[[2]](#footnote-2), the RHC-Platform has produced the present updated Strategic Research and Innovation Agenda for Renewable Heating and Cooling (RHC-SRIA), a key document which identifies R&I priorities to boost the market uptake of renewable heating and cooling technologies.

The document focuses on market rather than technology to avoid being technology-specific, considering interaction between technologies and the surrounding environment. The approach of this document can be described as focusing on research push rather than market pull.

The RHC-SRIA sets out the likely directions of technological and organisational changes that will need to be converted into specific research activities over the next years, starting from Horizon Europe (2021-2027). Furthermore, it aims to facilitate the coordination of other research programmes in and between member states. As market growth to a great extent depends on major technological advances, the implementation of the RHC-SRIA, along with appropriate market conditions, will be crucial to realising the shift to a renewable energy system in which European citizens can enjoy affordable and sustainable heating and cooling services.

The RHC-SRIA has been prepared by the RHC-Platform’s Horizontal Working Group on SRIA, it was edited and coordinated by the Secretariat of the RHC-Platform and ultimately approved by the Board of the RHC-Platform. Horizontal Working Groups on 100% RE buildings, 100% RE districts, 100% RE cities and 100% RE industries, consisting of numerous experts, provided essential input and insight. This publication was made possible thanks to the support of the European Commission through the Horizon 2020 Research and Innovation Programme (Grant Agreement n. 825998).

### How to read SRIA

This document develops and presents technology and innovation priorities for reaching full decarbonisation of the heating and cooling sector in the EU by 2050. In chapter 2, the document positions the RHC sector within the broader framework of achieving carbon net-zero EU by 2050. Transversal priorities cutting across the horizontal division of R&C sector are outlined in chapter 3. Next, chapters 4 to 7 present technology and innovation priorities of the horizontal working groups, each describing state-of-the-art of the thematic sector, scope of the priorities and the expected outcome/impact. For some priorities, needed cooperation with third countries is described as well. Finally, chapter 8 presents conclusions and synthesises the main takeaways from the agenda.

2. RHC IN THE FUTURE EU ENERGY SYSTEM

The EU aims to have a net-zero greenhouse gas emissions economy by 2050, as envisioned in the European Commission´s 2050 long-term strategy. This objective is also at the heart of the European Green Deal and is in line with the EU’s commitment to global climate action under the [Paris Agreement](https://ec.europa.eu/clima/policies/international/negotiations/paris_en). The decarbonisation of the heating and cooling (HC) sector plays a strategic role in the transition towards a climate-neutral European economy. While renewables have made an important contribution in this area, there is still a long way to go.

To support the decarbonisation of the H&C sector, in February 2016 the Commission unveiled the first **EU strategy on heating and cooling** (COM(2016) 51 final) as part of the Sustainable Energy Security Package. While the strategy did not include any new legislative proposals, it set out a vision for HC consumption in buildings and industry, aimed at maximising the use of renewable energy sources and the use of waste heat.

The ***recast Renewable Energy Directive*** (Directive (EU) 2018/2001), together with the Energy Efficiency Directive and the Energy Performance of Buildings Directive, specified that renewables should cover 32% of total energy consumption by 2030. Some 40% of this is expected to come from the HC sector. The Directive recognises that H&C plays a key role in accelerating the decarbonisation of the energy system. **The challenge is how to reach such ambitious targets!**

A more intensive deployment of Renewable Heating and Cooling is not a chimera. As the following figure (Figure 1-2) highlights, in 2018 about 98 Mtoe were already provided by RHC (biomass, solar, geothermal and heat pumps) and the plan of the COM (as included in the EUCO3232.5 Green Deal scenarios) is to reach 124 Mtoe by 2030 with an annual average increase of about 2.3%. Continuing at the same rate and combined with the reduction in consumption due to efficiency measures in the building sector, with about 155 Mtoe of RHC production, 50% of the heating and cooling sector could be decarbonised by 2040. The same graph includes a second more ambitious scenario to stress that a Full Decarbonised RHC scenario (with a total production of 311 Mtoe) could be envisaged if the implementation of new additional RES HC technologies (based on green gases and electrification) is accelerated and added to the system. Figure 1-3 shows what could be a future share amongst the different HC sources in view of its deployment potential and technical limits.

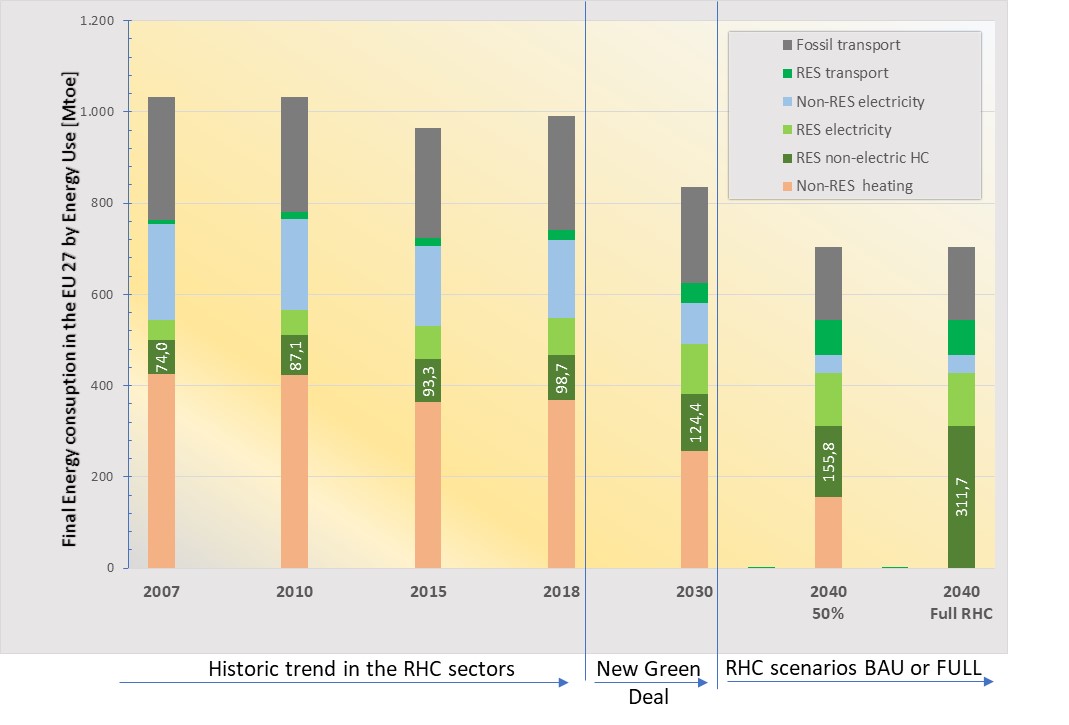


Figure 1‑ Final energy consumption in the EU27 by energy use

Thanks to technological developments which has happened along the last two decades, renewable HC (RHC) technologies are well positioned against the environmental and energetic targets set by the European Commission. RHC covers all applications and temperature ranges required by the heating and cooling sector: space heating and cooling and domestic hot water preparation in buildings and cities, as well as industrial process heat and refrigeration.

Strenghts of RHC technologies can be summarised in seven topics:

1. **Local** – the RHC industry is mainly based in the EU. This is a pre-condition to ensure that changes the energy sector will reflect positively on the European economy
2. **Affordable** – non-electric RHC is generated locally and therefore does not require high public infrastructure investments
3. **Economical** – many RHC technologies show competitive LCCs even against cheap fossil fuel alternatives. In a future scenario in which environmental externalities associated to fossil fuels are increasingly brought to the surface, RHC will increase its competitiveness and attractiveness for stakeholders and investors. Moreover other economic factos such as the reduction of imports and energetic dependencies are other strong arguments for the increased deployment of RHC
4. **Scalable** – RHC technolgies have a high level of scalability, covering almost any size of end-users‘ needs
5. **Available –** market readiness level of RHC technologies is generally high. This is a pre-condition for a high deployment potential within the next 10 years
6. **Cross-cutting** – RHC industry is cross-cutting, covering multiple technologies, which can be used in almost all scenarios and geographical locations
7. **Ecological** – RHC technologies have considerable potential for emissions reduction due to very high efficiencies if compared to most RES electricity technologies (COP up to 5-6 for heat pumps, efficiencies up to 60-70% for solar thermal and up to 90% for solid biomass boilers). This is key to achieve the EU's greenhouse gas emission reduction goal and meet its commitment under the climate agreement reached at the COP21 climate conference in Paris

A solid state of the art and crucial strenghts make RHC technologies ready for deployment if the required support is given to foster research, development and innovation in this sector. To this end, the Renewable Heating and Cooling Technology Platform went through a thorough review of Research & Innovation priorities, previously identified in the 2013 SRIA document. This important process reflected the technological and policy changes implemented in the past years and led to a clear vision about R&I support needed by the sector.

**The energy sector is currently still driven by fossil-fuel technologies, but is about to undergo a complete revolution.**

**Today´s decarbonisation strategy tends to put electrification as the main tool to achieve the EU´s decarbonisation goals. However, this discussion neglects the fact that a dramatic increase in electric H&C and electric mobility would raise very crucial issues with the distribution of electricity requiring great economic (public) investments with enormous impacts at social level. While in the mobility sector alternatives to electricity are not mature, a fully renewable H&C sector is possible with currently available thermal RES H/C technologies. H&C is thermally driven today and should be thermally driven in the future.**

**By investing in the RHC priorites presented in this document, the EU H&C sector can achieve decarbonisation within the next 20 years.**

**R&D budget needed for the RHC sector**

While revising R&I priorities, RHC ETIP quantified the budget needed to reach decarbonisation targets.

[This part is being prepared]

The following figure shows two scenarios for decarbonising the heating and cooling sector by 2040. The full RHC scenario is ambitious, but for sure feasible with proper support measures on member states and EU level. It is also important to underline thatachieving 50% or 100% RHC depends not solely on the funding for R&D, but also on electricity taxation and on fossil fuels subsidies.

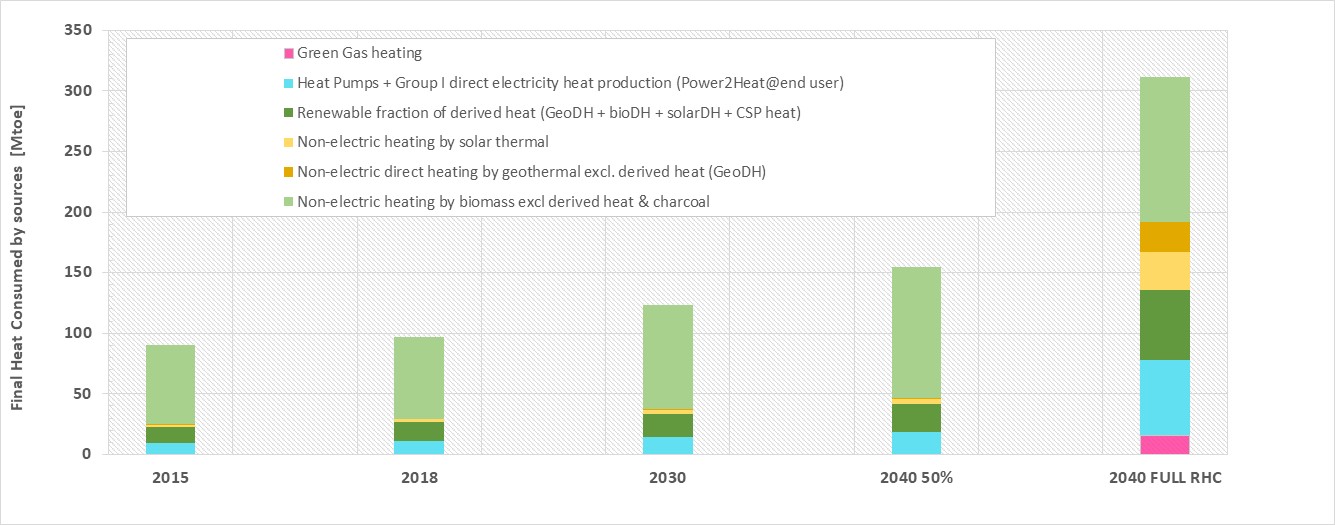


Figure 1‑3 Heat production by sources and uses

As set out in the ***Clean energy for all Europeans*** package, innovation is one of the keys to fostering the development of RHC. While the core investments need to come from the private sector, the EU also plays a decisive role.

It is important to highlight that investments in R&I RHC should be considered separately from investments focused on electricity. While sector coupling may act as an enabler to connect these two areas (plus transport), they should be addressed separately and in a more targeted manner. New funding programmes, such as Horizon Europe, should take a more balanced approach covering both research (lower TRLs) and practical demonstrations (higher TRLs) and should promote solutions incorporating multiple RHC technologies. Such approach will create suitable conditions for RHC technologies to improve qualitatively (i.e. wider range of mature technologies to better suit different needs and boundary conditions across Europe and across all sectors); and quantitatively (i.e. higher efficiencies, lower inestment costs).

RHC technologies are intrinsecally local. If well exploited, they do not need to be transported via public infrastrcures (i.e. electricity grid, hydrogen networks, biogas networks). These infrastructures will therefore be expected to satisfy the H/C demand of end users which cannot, for technical or economic reasons, exploit locally available RHC sources. Consequently, lower upgrading investments will be needed.

Given the dramatic imporvement of data connectivity over the last years, RHC will be part of the digitalised energy infrastructure: every RHC system will be online and will be operated not only according to the end-user’s needs, but also to the needs of the extended energy system. The electric grid will benefit from RHC systems and from their thermal storages to exploit Demand-Response advantages.



*Figure SEQ Figure \\* ARABIC 2 - Heating supply from renewable energy sources in EU*

*Figure SEQ Figure \\* ARABIC 3 - Heating potential by renewable energy source in EU*

3. TRANSVERSAL TOPICS

3.1 HEAT AND COLD STORAGE TECHNOLOGIES

Thermal energy storage (TES) will be a key enabler for the deployment of RHC, in cities, districts, 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 storages, 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) and dispatchable RES-e (CSP, Bio-energy, Geothermal, etc.). As a result, improved reliability, security of supply, and higher efficiency can be reached.

Current challenge of increasing the share of renewable energy use and the efficiency of processes in industry could be overcome via integrating thermal energy storages in the process. Next to that, thermal energy storage technologies can couple different parts of the process chain, moving thermal flows from one part to the other and reducing the amount of process waste heat. Challenges in the introduction are finding the thermal energy storage technology with suited temperature and power levels and integrating this technology in the industrial process.

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 consumption 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 RES.

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| **SCOPE** Develop and demonstrate energy storage solutions for heating, cooling and DHW production integrated with RES both in active and passive ways. Solutions must be easy to install in new (and in retrofitting of existing) buildings, must be modular, plug and play or being part of the heating, cooling and DHW equipment using RES, as components. In systems based on heat pumps, storage solutions should clearly demonstrate the contribution to increase the energy efficiency of these systems. Energy storage solutions should preferably operate for the three modes heating, cooling and DHW production and it must be easy to remove any of the modes, in the case of applications where one of them is not necessary or is of little relevance. The proposals must demonstrate that the storage solutions, namely the materials used, through a life cycle analysis, are sustainable, while they fulfil all the legal and standard requirements to be used in buildings. The solutions are expected to ensure some of the following positive impacts:   * increase in the energy efficiency of buildings * increase in the share of RES and the use of residual heat in CHP systems * contribute to the flexibility of the electricity networks * cost-effective and easier acceptance of the owners and end-users   The solutions should highlight the time of the storage cycles, for references cases of building categories and for the European climate zones. Whenever relevant, proposals must simultaneously present short term and long-term cycles solutions, including seasonal energy storage, covering a significant part of the energy demand of the building. They must also identify the categories of buildings and the climatic conditions where the solution has relevant impacts. Business plans should be developed considering not only the installation of the energy storage solution but as well the integration with all energy systems of the building.  If there is a lack of standards related to the solution, all relevant standards must be identified and proposed to allow confidence throughout the solution chain, from design, production andmanufacturing, installation, operation and maintenance. Proposals should also clearly identify gaps in the training of technicians and propose training solutions, where possible integrated or in addition to existing courses, such as RES technicians.  On **industries** level, thermal energy storage technologies that have charging and discharging temperatures in the cold (lower than 20 °C), lower (up to 135 °C), middle (135 °C to 250 °C) and higher temperature level (above 250 °C). The upper limit of 135 °C for the lower class enables the inclusion of slightly over-pressurised water storages as alternative for low pressure steam vessels. Depending on the industry process, the requirements on the thermal storage technology are given by the power, by transportation possibility, by storage duration or by compactness. Depending on the industry process, the requirements on the thermal storage technology are given by the power, by transportation possibility, by storage duration or by compactness. Therefore, the full range of technologies needs to be developed further; from sensible storage (molten salts, molten metals) to phase change (paraffines, salt hydrates, polymers, salts, metals) to sorption and hydration (zeolites, salt hydrates) to chemical reactions (metal oxides/hydroxides, chemical looping, other processes). |
| **RESULTS**  * Increase in the value of energy storage densities, relative to the state of the art * Reduced thermal losses during storage, especially for long-term solutions, in relation to the state of the art * Fast enough response solutions facilitating integration with the building's demands, with the availability of RES and with the interaction with the electricity networks * Use of safe, sustainable and environmentally friendly materials * Increased share of RES, comparing with the reference solution without thermal storage, depending on the European climate zones and the renewable sources or sources to be used * Present flexibility in storage cycles (daily, weekly, monthly or seasonal) optimizing its use * Modular solutions, plug and play, kits approach integrated in the heating and cooling systems or installed in their equipment * Thermal storage solutions integrated in active and passive ways, namely, integrated with the thermal envelope of buildings, in passive house solutions * Integration in CHP systems, to increase the energy utilization factor * Development of specific algorithms for storage solutions for integration in modelling software and monitoring tools to design and control energy systems and services in 100% RE Buildings * Be cost-effective and have reduced payback times (or other economic parameters) * Developments programmed in all phases of technology readiness for a number of applications in industry (covering the temperature levels mentioned above) with development progress measured according to a set of KPIs for each application and development teams consisting of organisations covering as much of the value chain as possible (especially the industry of application) * High temperature heat storage up to 1000°C developed at TRL 4-6 |
| **COOPERATION WITH THIRD COUNTRIES** As industrial processes are employed similarly on a global scale, the effectiveness of the development program and the effect of the development will increase through international collaboration. |

3.2 POLICY AND SOCIAL INNOVATION

A very strong political will to change the heating sector towards 100% renewables is needed to achieve 100% RHC in EU by 2050. Technologies are mature, commercially available, and market competitive already, and they will be continuously improved. However, without drastic political support, the vision of 100% RHC in EU by 2050 will hardly become a reality. Courageous, clear and effective policy instruments are needed to stepwise phase out any fossil H&C systems well in advance of 2050 as these provide stable framework conditions and will also create risk sharing schemes between investors, utilities, and public administration, thus increasing attractiveness to private investors.

Inefficient incentives, policies and legislation in the RHC sector, whether on buildings, district, or city levels, continue to hinder progress towards the 100% RHC. In some EU member states, there are still fossil fuel subsidies on replacement of old systems with efficient fossil fuel boilers, which are disrupting the achievement of level playing field in the heating and cooling sector.

To illustrate, with no dedicated policy for district energy, the development of the projects are based on local (municipal) tenders or private initiative but without a common vision that allows and protects the district developers at the same time than protect users about price stability and competitiveness. Identifying, testing and deploying the technologies and systems that will allow participation of consumers and energy communities to the whole energy system is also required. Wherever possible, energy should be produced and consumed locally in order to add value at local levels.[[3]](#footnote-3) That means that citizens want and should play a more active role in the local energy market acting not just as a prosumer, but also taking a participation in the shares of the energy system and then benefiting from their results (e.g. “heat as a service” concept).

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| **SCOPE** Examining the effects of hard legislation for increasing RE (e.g. EPBD, bans, etc.) is needed. In addition, comprehensive studies are needed to better understand:   * European incentive programs and their results * Consumer behaviour, especially regarding large purchases * Role of RE in energy poverty situations * Possibilities for retraining workers from the fossil work roles into RE * Which energy-as-a-service suppliers exists and what challenges they face   Solutions involving fossil free DHC supply, which are socially and ecologically acceptable need to be found. Therefore, planning of national & local district energy plans as well as combining and implementing spatial planning and heat planning by municipalities is essential. Knowledge transfer and networking between cities is another identified need with a lot of best practice examples available, e.g. climate protection laws. Furthermore, it is needed to address stakeholders in specific target groups to combine all relevant knowledge on a regional level as well as provide capacity building and training for local politicians, decision makers, consultancies and advisers about the benefits of sustainable district energy solutions. Defining measures to support local decision making for renewables instead of fossils needs to be also supported.  **Social innovation**: including open innovation & lead user innovation; co-creation of end user engagement strategies, participatory public service delivery; participatory knowledge creation; consumer preferences & motivational patterns and demographic segmentation; Avoid negative social impacts; Participation of communities in the ownership of the grids  **Local energy markets for heating & cooling**: development, test-implementation and optimisation of local heating & cooling markets considering private and commercial consumers, producers and prosumers and the interface to electricity markets as well as local storage units  **Coupling of the thermal and electrical grid** and inclusion of EV, energy storage (both thermal and electrical) and residual energy for local activity (industries, agriculture,...) that can provide not just the local energy but also allows to play a role in the electricity market balancing |
| **RESULTS** Finding and understanding:   * Key success factors for cost efficient subsidy systems with minimal market disturbance * If pure legislation is an effective way for increasing RE uptake * Consumer behaviour enabling effective marketing, information campaigns and sales tools for people in the RE sales chain * Solutions for large scale RE implementation in energy poverty affected housing * If energy-as-a-service works in practise and showcase good examples * Mapping and matching future unemployment within fossil fuels with a demand for competence in RE * Political pathways describing precise policy measures on local and regional level to improve regulatory frameworks for DHC * Introduction of the improved planning methods in the established planning processes of cities and regions * The sustained awareness created in public and policy which will lead to investments in the transformation of the DHC sector contributing to 100 % fossil free supply * The market-uptake project SDHp2m (Horizon 2020- 691624) targeted for a 5-year period on 1,740 Mio Euro cumulative investment made by European stakeholders in RES to trigger 7,100 GWh/year RES heat and cold production * Energy communities demonstrating that involving citizens directly translates into high rates of energy savings and catalysing new projects for energy system decarbonisation and sustainability; at the same time, they return profits for the community that can be reinvested into new decarbonisation projects * Initialisation of heat prosumers (pilot demonstration) * Development of energy communities centred around heating and cooling * Funding/market models for local participation in heating and cooling |
| **COOPERATION WITH THIRD COUNTRIES** All topics are relevant for non-EU countries and, as such, any cooperation is encouraged |

3.3 DIGITALISATION, OPERATION AND SYSTEM FLEXIBILITY

Simply put, digitalisation is about enhanced communication, resource optimisation, and energy flexibility. It is not a goal per se, but a very interesting mean to get a more renewable and efficient energy system while also saving costs. Digitalisation and improved operation need to be applied to different levels, i.e. production, distribution, consumption, design and planning levels.

Research and innovation on digitalisation, as on all other RHC-relevant technologies, is needed for large scale adoption of RHC applications. Technology advancements in digitalisation 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 regards 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. In the future, digital energy systems will enable district energy systems to fully optimise their plant and network operation while empowering the end consumer. DES will be able to use the connected infrastructures as efficiently as possible, time their production according to forecasted demand and supply, enhancing the usage of renewables and lowering the heat losses.

The impact of digitalisation will be especially strong for industries, with industrial energy management systems for manufacturing 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 volatile renewable and conventional energy sources. The development of a methodology and software tool to optimise the operation and design of industrial energy management systems will be especially important in the future.

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| **SCOPE** **Generation of Digital Twins and Autonomy**: Digital twins are a means to combine system models for different purposes and combine them with intelligence to create value, essentially answering posed contextual questions. The generation of these digital twins or an ecosystem of digital twins requires access to information sources like BIM; UIM (CityGML); PID; SCADA system; etc. for the modelling, which needs to be automated. This includes mapping of demand and supply as well as future heat sources. The autonomy of the digital twins, when combined with the purpose-oriented intelligence, will enable monitoring, optimisation and control on a large scale. The generation of the digital twins that will be used is fundamentally depending on the existence of the information that is sketched out.  **Digital twins & optimization**: Assessment, monitoring and optimization of the thermal and hydraulic behaviour of DHC networks and their components, including tools for optimization of supply and controllable loads and co-simulation approaches including the electricity network. Exploitation of system flexibility in terms of design, operation and control facilitates increased efficiency and sector coupling. To enable such schemes there is a need for tools to explore the available flexibility, both in space and time, and on which time-scale (planning, design, operation, control) it is available. Digitally connected laboratories to test solutions and make resources available in a pan-European way.  It is also needed to develop data platforms for monitoring and optimised operation of sustainable energy systems in cities as well as innovative planning tools for integrated energy systems in cities. Developing general valid techniques and applications for industrial use, including the suitable environment (overarching platforms, standardised interfaces and software, suitable sensors, etc.) and measures to accelerate the adaption rates including preparation of regulatory and legal aspects to find business models for collaborative use of platforms; set up of suitable security systems; etc.  Realising an open source SCADA system for individual buildings is also required. In terms of modelling, software and monitoring tools for new and future buildings & for retrofitting of old and historical buildings, it is not easy to model an old building due to lack of drawings and detailed information (e.g. thermal properties of the layers of the walls of the buildings). Therefore, the following actions will be needed:   * Development of open source tool which allows an easy and fast creation of a BIM model (Building Information Model) and which is able to assess its energy performance and suggest building and HVAC retrofit based on BEM (Building Energy Modelling) * Development of open source tool for BIM (Building Information Modelling) to BEM (Building Energy Modelling) * Prove to the end-user that the upgrade to 100% RE buildings are feasible and reliable in specific cases * Prove to the end-user that 100% RE buildings are feasible, reliable and cost-effective * Integration of RES systems in the building thermal envelope, considering the building aesthetic appearance and its architecture form in the most cost-effective way * Use of ecological materials to control energy consumption, promote circular economy and offer extra comfort to the end-user   **Controller-in-the-loop-testing**: Experimental demonstration of advanced control schemes and policies for DHC systems in controller-in-the-loop environments to test and evaluate the control actions upon relevant equipment (e.g. heat and cold generation units, storage, etc.) in close to real-life conditions before actual deployment.  **IoT, AI & cloud services**: Development and testing of advanced control schemes using IoT (internet of things), AI (artificial intelligence) that are potentially deployed as cloud based services in order to allow decentralised/distributed units and individual components to be operated in an optimum way. These would also include developing:   * Control the Heating Ventilation and Air-Conditioning (HVAC) system as a function of the data available (e.g. as a function of the number of persons and their locations in a building) * Effective control of multi generation systems for heating and cooling * Fully automated building energy systems, utilising an ensemble of sensors and control possibilities to optimise the energy system and the contribution from the individual energy technologies to enable smart use of the increasing number of data available (e.g. mobile phone, wearable sensors) * Realise a controller which can communicate with the devices of any manufacturer   **Short term forecasting**: Development of algorithm for short term forecasting of heating (and cooling) demand as well as electricity demand & prices, using innovative approaches, enabling a better estimation of uncertainties. Similarly, development of Model Predictive Control algorithm for effective control of non-programmable RE sources (e.g. implementing Artificial Intelligence based algorithm).  **Sector coupling and flexibility**: Integration of power-to-heat (p2h) technologies (especially HPs) and combined heat and power (CHP) plants and optimization of their revenues on different electricity markets and supporting the electricity grid (e.g. reducing curtailment)  **Interfaces between different control layers**: Interconnection of control systems of different components, including customers to better manage generation and storage systems as well as the network. |
| **RESULTS** The expected results are:  On **buildings** level:   * Controller for multi generation systems driven by renewable energy sources * Building envelope component integrating RES systems * Software tool for the modelling of old and historical buildings and for their retrofit into 100% RE Buildings * Large scale monitoring program of 100% RE Buildings from the retrofit of old buildings * Realization of retrofit of buildings to 100% RE buildings * Realization and performance monitoring of 100% RE new buildings   On **districts** level:   * Increased ratio of operational digital platforms that integrate consumer side with, production and distribution facilities enabling data aggregation, data sharing, and creation/operation of city-level digital twins * Digital twin enabled control, optimisation and monitoring solutions integrating system flexibility and even reaching beyond substations. Thereby enabling fully integrated and autonomous predictive production and distribution control in life operation, proven to reduce losses (in highly efficient grids reducing losses by at least 2% from 7% to 5%, according to a case study in (OPTi H2020 project, Deliverable D6.3, [www.opti2020.eu](http://www.opti2020.eu)). Digital twins also enable auditing of building energy consumption profile which can reduce energy with up to 10% by exploiting comfort zones (see D6.3 OPTi) * Digital twins also enable model-based engineering solutions for complete toolchain from design through validation to commissioning and decommissioning of control, optimization and monitoring systems reducing the engineering effort by a factor of 5 in building energy automation[[4]](#footnote-4) * Demand-side smart controllers can optimise production and ideally distribute the produced heat: reducing peak heat (over a heating season 12.75% on average), freeing up capacity with cell balancing (up to 42%), interacting with electricity grid in systems with HPs ([STORM project](http://www.storm-dhc.eu)) * Pan-European digitalised lab   On **cities** level:   * Data platforms for monitoring and optimised operation of sustainable energy systems in cities * Innovative planning tools for integrated energy systems   On **industries** level:   * A collaboration platform for industrial actors where e.g. data for ML or computer models are available for general issues (no process details, emphasize data security) * Models, techniques and applications are developed for flexible adaption of industrial processes to react to fluctuating and volatile generation are available (digital twin, optimization, digital value and supply chains) * Quantitative assessment of the impact AI and IT have on energy consumption of energy, resources, GHG emissions * Security standards defined and implemented * Measure list of how to successfully implement such applications and techniques (key word: acceptance of staff) * Sector specific characteristics and therefore “requirements” / ”validity ranges” |
| **COOPERATION WITH THIRD COUNTRIES** For **industries**, cooperation with Canada on digitalisation and related technologies for efficiency increase and reduction of GHG emissions in industry. |

3.4 INNOVATIVE FINANCING SCHEMES AND NEW BUSINESS MODELS

Extending the ability to generate revenue and access financing at lower opportunity costs will support the efforts to undertake sustainable energy programmes and infrastructure projects in RHC. 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, one of the main barriers for new developments across all levels is lack of funding and financing options. For example, for districts, financing of the infrastructures (mainly pipes) as they have a higher service life than contract periods, is especially challenging. Accordingly, new solutions based on the ownership of infrastructures must be analysed. Another relevant challenge is the general lack of private investments in DH because of its inherent high risk and length of ROI. The challenge is mainly present on the supply and distribution side. On the demand side the main issue concerns the search for a more comprehensive approach in terms of contracting and financing, in particular in relation with sector integration and increase of the overall energy efficiency in buildings. For industries, one of the big barriers is financing industry projects in the short-term period for the return of the investment (4 years) as these issues are not considered core business. For carbon footprint reduction, contracts between 7-10 years are expected. Those time restrictions make the feasibility of the projects difficult. Therefore, new financing schemes for short and mid-term contracts and business models for a quick deployment of green energy supply are required.

Another focus is the development of innovative, simplified business models and opportunities for final users related to flexibility and efficiency as well as for utilities related to the development of an economic model for the viable long-term decarbonisation of DHC networks.

* PPPs, energy supply as a service: e.g. heat supply contracts for public buildings: new equipment purchased as part of service package (risk management)
* Innovative ideas on CAPEX: promote new business and market models for projects requiring high up-front investment with long pay-back time and to reduce the pressure for high profit margins on the short term

For industries, these new business models need to be developed on top of common models like the P1-P4 approach (fix pay for the investment, the maintenance and a variable pay based on the real consumption) or the performance based energy as a service (EaaS) paying an agreed price based on consumption.

Lastly, in terms of heat pricing, in most cases tariffs do not take into account energy mix and network stability. There is then need for developing new pricing schemes that reward and encourage positive user behaviour (e.g. participation in demand response, consumption patterns to support network stability and higher renewable / lower emission heat production). These schemes should take into account current contractual constraints, simplicity of deployment and compatibility with available infrastructure.

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| An exploration to new opportunities must be conducted on:  **Alternative financing schemes:** Validation of alternative financing schemes and products to leverage more private funds in infrastructure financing. Open the opportunity to citizens to participate in the investment of the RHC projects through 'citizens funding', for instance with crowdfunding, through specialised companies to assess potential investors who may supply with finance. Lower rates can be expected. Additionally, the establishment of crowdfunding tools should give potential investors the possibility to compare and assess the quality of industrial projects and further decide on the project to invest. Alternatively, the potential of further new participatory sources of funding such as: cooperatives, equity crowdfunding, peer-to-peer lending, etc. needs to be explored.  **Energy as a service**: An energy service company (ESCO) allows companies to carry out energy services without the need for clients to invest their own capital  **Development of Blockchains** as possible providers for e.g. energy trading in industry and RHC sector as such. Exploring innovative activities for investors and institutional financers. The investor demand for green bonds is growing rapidly. Financing tools like Securitisation Vehicle (SV) will purchase the receivables and convert them to securities. These green bonds and tranches can be offered to investors on the capital markets. Furthermore, development of methodologies, taking into account positive externalities and sustainability aspects in appraisal of projects bankability is also important.  **Leasing or contracting**: An analysis to this option for RHC sector can be explored also in terms of different models (e.g. AssetCo, OptCo). As an example in industry, solar thermal contracting is an interesting way to finance medium size solar thermal projects : a third part company is investing on the system, managing the sourcing, design and installation as well as collecting the public incentive for its own and then is selling thermal energy for a fixed term and at a fixed (or indexed) price. O&M is as well managed by the third part developer. Development of standardised contracting and/or legal frameworks taking into account different sources of financing is similarly important.  **Green and public funds**: Today there are a lot of investment funds interested in green projects. Mapping any existing green financing systems to find out what entities are involved in such systems is needed. Low rates to incentivize the adoption of carbon reduction measures retaining the ownership of the installations (e.g. pooling to provide industrial heat to industrial compounds, Industrial steam and cooling networks). Further public insurances and development of de-risking platforms/frameworks reduce the counterparty's risks in realising green projects (investments)  **Bartering**: Commercial agreements between companies to develop the project without money exchange |
| **RESULTS** The expected results are:   * Showcasing successful green financing systems to gain interest among investors * Full dataset of options of ownership and the impact on energy price and contract length * Investment pathways for local communities wanting to invest in their local heat infrastructure: creating a new heat network, expansion, decarbonisation of supply * Efficient contractual forms and business models[[5]](#footnote-5) * Pilot Credit Facility to improve bankability[[6]](#footnote-6) * New schemes that will help in a greater deployment of investments to green energy for industry * New business models that open more flexible options at lower risk to deploy the green energy supply for industries |
| **COOPERATION WITH THIRD COUNTRIES** All topics are relevant for non-EU countries and, as such, any cooperation is encouraged. |

3.5 CIRCULARITY

The integration of circularity into RES H&C production indicates that all its components and products need to be optimised, re-used, repaired, redistributed, refurbished, and/or remanufactured. It means that the value of these components and products shall be maintained and optimised for as long as possible. Circularity is the cornerstone of a sustainable future, where renewable sources have a crucial role to play. A concrete example would be the extraction of lithium and other minerals from geothermal brine for the batteries industry. The transition from linear to circular business models shall be based on a more comprehensive approach. 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) and residential buildings, 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, and including multi-purpose uses of geothermal heat 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). With the increasing market share of biobased products, the concepts of circular economy are highly relevant to the biobased sector. Specifically, biorefineries that will in the future focus more heavily on resource-based products (chemical building blocks, biobased chemicals and materials) and less on energy production will face the challenge to render themselves energy efficient and sustainably supplied with RES energy. Bioenergy has the potential to eliminate municipal, 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. Residues from biogas plants and ashes from bioenergy plants can be utilised for different purposes, contributing to circularity and value creation.

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| **SCOPE** Develop new concepts and valorisation pathways to tackle the above-mentioned challenges. Identify the different value chains within different energy sectors, including products, by-products made of raw resources but also waste streams (circularity, avoiding depositing and creating value) considering the energetic-/ and exergetic point of view. |
| **RESULTS** In order to deliver a successful circular economy plan for RHC, the following priorities should be achieved:   * Adopt a dedicated set of legislative measures that will regulate the applicability and use of recycled/secondary materials/waste in RHC installations * Adopt standardisation procedures and quality branding for components (such as geothermal pipes, pumps etc). This measure is essential to improve the confidence of consumers and legal authorities in sustainability of RHC products. * Continuously monitor the use of raw materials, especially the critical materials in terms of their availability. This should be implemented by using digital applications that will identify, classify and quantify the data regarding raw materials. * Support research and innovation projects that will develop new technologies for waste and water management * Provide support funding to projects that will deliver innovative products, components and systems, that will use sustainable materials * Ensure support for new business models that will implement the principle of circularity in their operations in line with the proposed set of measures in the EU Circular Economy Action Plan, which are aiming to encourage industries to produce more sustainable products * A guideline for biorefineries on energy vector production along the processing chain, with identification of key enabling technologies and possible technology adoptions needed for energy vector production * Holistic concepts for material (waste) valorisation and impact on energy vector production, energy efficiency and RES energy supply (within/outside biorefinery) * Significant increase of RE by linking them to production processes, exergy-optimised demand and supply systems and by this offer a big hub, by and for hybrid concepts * Enabling the link to energy vectors as Nitrogen (N2), Methane (CH4), ammonium (NH4), Hydrogen (H2) (extract from waste, using low-exergy RE competing energy intensive industry/supply) * Guidelines for enhanced circularity and value creation for all residual streams from bioenergy plants |
| **COOPERATION WITH THIRD COUNTRIES** In terms of industrial cooperation with third countries, cooperation with UK, Africa, Switzerland and Brazil would be especially advantageous. |

3.6 HEALTH

According to recent studies, air pollution is the main risk factor contributing to premature death worldwide.[[7]](#footnote-7) The health and well-being of citizens, including their labour performance, is significantly impacted. In Europe, the cost from air pollution is estimated at 1.5 trillion Euro per year according to the World Health Organisation (WHO), concluding that it must be addressed with top political priority.[[8]](#footnote-8) The heating industry should be vary of the current scrutiny around emissions from diesel combustion in cars as emissions from fossil fuels combustion in H&C applications may well be treated in the same way. Replacing combustion-based heating systems with e.g. heat pumps would be a suitable means to address the issue of air pollution.[[9]](#footnote-9)

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| **SCOPE** Not only the comfort of citizens and energy users would be positively impacted from innovative developments in RHC (via improved thermal control, which in turn supports well-being), but also the health of the user (both psychological and physical) as per: reduced direct emissions to ambient air, and also emissions to indoor air and of emissions directly or indirectly affecting health (with many chemicals encountered in indoor air known or suspected to cause sensory irritation or stimulation. These, in turn, may give rise to a sense of discomfort and other symptoms commonly reported in so‐called “sick” buildings. Complex mixtures of organic chemicals in indoor air also have the potential to invoke subtle effects on the central and peripheral nervous system, leading to changes in behaviour and performance[[10]](#footnote-10); reduced energy poverty (lower monthly and yearly expenditures for heating), as literature shows that across the majority of 32 countries in Europe, the energy poor population is statistically more likely to report poor health and emotional well-being than the non-energy poor population, with a higher incidence of bad and very bad self-reported health (SRH) status, poor emotional well-being, and likely depression (the relationship between SRH and energy poverty with mental health and energy poverty)[[11]](#footnote-11); Improved heating systems with respect to operation, automation, control and design, which supports well-being and improves health (device, UI and control ergonomics); current passive consumers may become less dependent on energy price fluctuations and even become “prosumers” (an aspect that enhances grid flexibility (decreasing the potential health implications of power outages) and alleviates energy poverty (generates income that can be spent on quality of life and health services); the health and comfort of EU citizens would benefit from innovative developments in RHC in many ways (devices with sensors to monitor user comfort and health (e.g. smart meters or H&C tailored to a users’ health condition); innovation in the H&C sector can potentially be used and deployed in other sectors (e.g. as mentioned before, H&C in the process of patient recovery); a better environment, sustainable for future generations, which means a continued healthier life earlier in life, preventing potential afflictions exemplified above); circularity, design and the materials used in the H&C devices (as per the use of materials that do not badly affect the health of the value chain that brings and installs the devices for the user, the user him/herself during operation and the environment and other users when being recycled and repurposed). |
| **RESULTS** Through achieving a decarbonised building stock and H&C sector by 2050 and simultaneously reducing emissions that directly or indirectly affect health, air pollution from heating and cooling would be reduced by more than 90%, largely eliminating related health problems. Moreover, an emphasis on the importance of therapeutic temperature modulation as used for reversing injury and inflammation and launching the healing process[[12]](#footnote-12), underlines the importance of heating and cooling in patient care. |
| **Cooperation with third countries** Horizon 2020 projects such as [ENABLE.EU](http://www.enable-eu.com) (involving partners from the Ukraine) or [MOBISTYLE](https://www.mobistyle-project.eu/en/mobistyle), shed light on user behaviour and analyse it through the lens of perceived health benefits to the energy user. More information available in the MOBISTYLE D3.1. ‘MOtivating end-users Behavioral change by combined ICT based modular Information on energy use, indoor environment, health and lifeSTYLE’ accessible [HERE](https://www.mobistyle-project.eu/en/mobistyle/dissemination/PublishingImages/public-deliverables/MOBISTYLE_D3.1.pdf). |

4. RESEARCH AND INNOVATION PRIORITIES FOR BUILDINGS

**State of the Art**

This section briefly summarises the current situation for RE HC technologies and systems for old, including historical/special, and new individual buildings, while the following five sections summarise key research and innovation needs within five key areas to arrive at 100% RE HC in these buildings in 2050.

Bioenergy technologies and systems for heating of buildings have a long history, having been the dominant RE heat source through combustion, for heating and cooking, through the centuries. However, today the contribution to heating of buildings from other RE sources (active solar, geothermal, ambient, RE electric) is rapidly increasing. Increased focus on emissions and energetic performance has resulted in much improved biomass heating technologies in the recent decades, including down to wood burning stoves. Combined heat and power (CHP) production from biomass through a number of technologies has been developed also at small- to micro-scale, suitable for installation in domestic to larger individual buildings not connected to a district heating network or gas grid. Current R&D efforts are mainly focused on further technology optimisation, emission reduction, increased energetic (thermal, or thermal-electric) performance, reduced costs, optimum integration or hybridisation with other RE sources and technologies and energy storage solutions on a building level, stable and adaptive heat delivery and improved user interaction and satisfaction. Biomass, in its various basic or upgraded forms, has as a storable and all-year heat source available in a large amount, a significant role to play to cover parts of the future heating and cooling needs in individual buildings, and to relieve the electricity grid in peak heating need periods. However, the relative contribution of biomass to RE HC will decrease in the future as the other RE sources are implemented to a higher degree, while the limited biomass resources are needed to cover also other energy (e.g. transport fuels) and materials (e.g. reductants, chemicals) needs. Biomass is also the only RE source resulting in direct emissions during energy production, and these emissions must be minimised. However, all RE HC technologies contribute to some degree to emissions from a cradle to grave value chain perspective.

Harvesting direct solar energy for heating of individual buildings has a very long history too, as part of the building architecture. Solar energy is today also extensively harvested in solar collectors for hot water heating and in photovoltaic (PV) cells for electricity generation. Combining PV with solar thermal in PVT collectors is today attracting increasing interest, as well as solar heat driven cooling solutions.

Geothermal energy can be extracted directly from hot springs or deep wells in many places, but the biggest potential lies in extracting lower temperature geothermal energy from shallow ground or water in combination with a heat pump (HP), especially for individual buildings. Extracting heat from ambient air has experienced a big increase, but a large fraction is air to air HP, with modest heat extraction performance compared to electricity input, but this performance is continuously enhanced.

RE electricity production from wind and PV has increased tremendously in the last decade and is considered to maybe be the key player in our future overall RE HC system, including individual buildings, through HP. However, its intermittent nature demands backup solutions, i.e. storage solutions or on-demand electricity generation from non-intermittent RE sources (biomass and hydropower). Thus, electricity storage and power to fuels solutions receive increasing attention today, and from the other side of the grid electricity generation in individual buildings through PV and biomass CHP, and their grid connectivity and interplay.

In the end, replacing all fossil energy sources with RE is the ultimate goal, which should be combined with effective energy efficiency measures in buildings to limit the HC need. New buildings are built according to building standards where this is done by default. The main challenge is to provide cost-effective and easy/fast to install retrofitting solutions for old buildings, both regarding energy efficiency measures and HC solutions, a topic attracting much attention today. Finally, education, training and certification is key to optimum installation and operation of energy systems, and this is a field with still a large potential for improvements.

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| TOPIC 1: RE HC TECHNOLOGIES AND SYSTEMS FOR COST-EFFECTIVE RETROFITTING OF OLD BUILDINGS |
| **Scope** Carbon neutrality of buildings by 2050, driven first and foremost by energy efficiency for heating and cooling, can be achieved by increasing the annual renovation rate to more than 2% by 2030. This process needs to be backed by developments in systems and technologies. Firstly, developing affordable, compact, highly efficient, easy to install, and intelligent renovation kits for replacement of traditional fossil oil- and gas-fired heaters, allowing ease of control, operation and maintenance. Features like air condition capacity or hybrid combinations with e.g. clean and efficient wood burning stoves is an option and beneficial for downsizing the new heating equipment, allowing cost reduction. Renovation kits should include innovative storage concepts. Secondly, pushing developments for achieving the economic breakeven point for serial renovation of buildings earlier, through efficient prefabrication of elements and advanced HVAC capabilities. Thirdly, empowering heat pump technologies regarding (a) capability for simultaneous heating & cooling, (b) higher efficiency, (c) use of refrigerants with low GWP, (d) as part of a renovation kit, (e) adaption to dynamic electricity tariffs and (f) hybrid combinations with CHP and micro-CHP systems. Fourthly, optimising the system architecture for combination with new RE-sources allowing tri-generation of low temperature heat, cold and electricity, while considering the multi-level cost of electricity, heat and cold and the overall renovation cost, rather than just cost for the refurbishment of the HC equipment. Coupling with new intelligent storage concepts is essential. Lastly, exploring and demonstrating new RES, which can act as heat source for more efficient sole-based heat pumps. The RE heat source should be (a) more efficient, e.g. higher source temperature and extraction power, (b) environmental-friendly, (c) ahead of today’s earth collector and boreholes regarding approval, cost and installation time and (d) should allow free cooling instead of operation of a chiller. |
| **Results** Due to serial renovation of buildings, the renovation time is reduced from months to days or a few weeks. Due to highly automated production of e.g. façade elements and HVAC-modules the renovation cost is no longer an issue. Available technologies, especially easy to install renovation kits for serial renovation of buildings. Highly efficient HP systems with new refrigerants with low GWP for heating and cooling. Optimised system architectures for combination with new hybrid RE sources for tri-generation of electricity, heat and cold and availability of geothermal sources for co-generation of heat and cold for single buildings, and districts. |
| **Cooperation with third countries**  1. REN21: Activities fostering RE worldwide (e.g. global reports) 2. Countries with programs for serial renovation (e.g. Germany: [dena](https://www.dena.de/themen-projekte/projekte/gebaeude/serielles-sanieren-von-mehrfamilienhaeusern/)) |

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| TOPIC 2: RE HC TECHNOLOGIES AND SYSTEMS FOR COST-EFFECTIVE RETROFITTING OF HISTORICAL AND SPECIAL BUILDINGS |
| **Scope** Another priority is the mapping of the historic buildings (one fourth of major cities’ building stock[[13]](#footnote-13)) and characterisation of their energy needs for HC in order to find possible classifications that allows to develop plug & play solutions for integration of RES is needed. Special care should be addressed to these buildings to guarantee comfort conditions to users without impairing their aesthetic value. Another needed activity is the development of solutions for integration of RE systems in historic and special buildings that do not compromise the value of the building, in terms of aesthetics and lifetime, especially when some of the components of the RE HC systems need to use the building façade to capture the energy.  Evaluate available spaces and possibilities for energy storage systems, as well as possible energy efficiency measures in order to reduce energy demand of the buildings. Identify the stakeholders of the buildings and their information, and ensure their involvement and cooperation in the retrofitting process. Development and application of easy to use methods that allow evaluation of aesthetical impact of solutions with integration of RE in the façade in order that it can be accepted by stakeholders.  Based on the existing European standard EN 16883:2017 Conservation of cultural heritage — Guidelines for improving the energy performance of historic buildings, further develop its application in order to include also the integration of RE for HC. |
| **Results** The expected results are reduced energy demand of the buildings due to energy efficiency measures, raised percentage of integration of RE for HC in historic and special buildings, and raised acceptance by stakeholders to the integration of RE for HC in historic buildings. |
| **Cooperation with third countries** Cooperation with third countries with important historical building stock would be especially advantageous. |

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| TOPIC 3: RE SOURCES, FUELS, TECHNOLOGIES AND SYSTEMS FOR NEW BUILDINGS AND THEIR INTEGRATION AND EXTERNAL CONNECTIVITY |
| **Scope** Provide a wide range of sustainable RE HC technologies and combinations for energy-efficient buildings, i.e. buildings built according to modern building standards, by:   * Further development of integration of RE systems (solar thermal and PV or PVT) in the building envelope (Façade), and new system architectures for utilisation of the intrinsic advantage of PVT collectors for tri-generation of electricity, heat and cold * New solutions for HP and their integration with RES and the building thermal envelope * Development of compact, affordable and easy to install HC kits, e.g. (HP + TS + control software) for efficient harvesting of LT heat from LT RE heat sources * Integration with geothermal heat sources like e.g. thermally activated Energy Sheet Piles * Development of new biomass fuels (solid, liquid, gas) for existing or new technologies * Development of new biomass heating technologies adapted to the needs of new buildings * Optimised integration with grid RE electricity, from and to the grid * Considering alternative electricity production and storage solutions (e.g. fuel cells, vehicle-to-grid) and smart grid integration for demand response, peak shaving and increased share of RE own-use * RE CHP and CHPC integration, and heat and cold storage integration * Increase of building automation through BMS (monitoring sensors, controls, actuators) and decision-making tools for optimum use of buildings/systems in terms of energy efficiency |
| **Results** Provision of RE HC technologies and systems that are well suited for inclusion in cost-effective RE systems for new buildings. Expected key results:   * 100% RE coverage of HC in new individual buildings * Complete independence of fossil fuels' use in the buildings when they are built, and from external gas supply (i.e. only electricity grid connection) * 100% RE coverage solutions adapted to local possibilities and regulations * Maximised solar contribution to heat, electricity and cold needs * Maximised ambient (effective HP) and geothermal contribution to additional heat needs * Biomass based heating as a natural option providing energy security through storable fuels and peak shaving capability (e.g. wood burning stoves) * RE CHP and CHPC as a natural solution, including biomass based * Heat and cold storage as a natural part of the HC system, increasing system efficiency and providing energy security, and electricity storage as well, in close interplay with the electricity grid, to and from the grid * High efficiency, cost-effective and sustainable RE systems |
| **Cooperation with third countries** Cooperation with third countries on technology development, to maximise the research and development output. |

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| TOPIC 4: CHP TECHNOLOGIES AND SYSTEMS AND THEIR INTEGRATION IN OLD/HISTORICAL AND FUTURE BUILDINGS AND EXTERNAL CONNECTIVITY |
| **Scope** The development and demonstration of CHP and CHPC technologies will ensure secure, reliable and efficient power, heat & cold supply for historical and new buildings. These technologies provide full integration with other RE technologies, they can use storable RES (biomass, biogas, underground storage, renewable hydrogen etc.) to produce on-demand electricity and storable heat and cold, while reducing GHG emissions and increasing the primary energy savings, through:   * Reduction of manufacturing and maintenance costs * Development of fuel flexible systems with low/zero emissions * Development of higher efficiency systems through new configurations, more efficient components and use of new materials * Power factor correction; grid code compliance; connection with energy storage; off grid capability; integration with stochastic PV generation * Adaption of the power/heat ratio to different types of buildings and needs * Flexible power/heat ratio for the overall system adapted to variations throughout the day / year |
| **Results** CHP/CHPC technologies and systems that are well suited for cost-effective inclusion in RE packages for different types and sizes of buildings, by:   * Compensating for fluctuating RE sources * Minimising transmission and distribution losses * Reduced load and congestions on the electricity transmission grid * Power/heat ratio adapted to the building demand, and through the day/year * Reliable and easy to use, monitor and control CHP/CHPC technologies and systems * Close integration with other RE technologies and storage solutions * Short amortization times * Reduction of maintenance costs of micro CHP/CHPC in residential and commercial buildings * Increased primary energy savings compared to separate generation of electricity, heat and cold * Reduced GHG emissions compared to conventional generation of electricity, heat and cold |
| **Cooperation with third countries** Cooperation with third countries on technology development, to maximise the research and development output. |

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| TOPIC 5: ENERGY SYSTEMS, EDUCATION, TRAINING AND CERTIFICATION FOR DIFFERENT BUILDING CATEGORIES |
| **Scope** In order to enhance competitiveness and technical skills of fossil technologies installers, as well as create solid background to installers for optimum RE technology selection related to buildings’ needs, several activities are needed:   * Developing an EU information strategy aimed at informing the installers, architects, end users, manufacturers, suppliers etc. of the benefits of working with RE technology * Finding out what the key success factors are for training systems to make them attractive to installers (online, modular approach etc.) * Identifying where the need for training is and which competences are missing * Developing a platform for spreading training material and best practises to be used by training providers in different markets * Enabling markets to actively participate in development of training information * Finding out if, and in what way, certification may be an enabler for increasing interest of RE between installers and consumers * Identifying existing schemes and how to use them in a comprehensive approach |
| **Results**  * EU information strategy (posters, commercials, social media strategy) * Online platform with up-to-date training material and tools, e-learning tools for students * Certification system for RE installers (if it is deemed an enabler) |
| **Cooperation with third countries** Non-EU countries may cooperate on the development of the results. They may also use the results as part of their work on spreading the use of RE. |

5. RESEARCH AND INNOVATION PRIORITIES FOR DISTRICTS

**State of the Art**

Though not a new technology, District Heating and Cooling (DHC) has been widely acknowledged as the future for urban heating and cooling, as concerns of sustainability and [greenhouse gas](https://www.sciencedirect.com/topics/engineering/greenhouse-gas) emissions are pushing to revamp the heating and cooling sector, with the characteristics of modern DH, evolving to cater for distributed [renewable technologies](https://www.sciencedirect.com/topics/engineering/renewable-technology) with the aim of making the entire system carbon free and sustainable[[14]](#footnote-14). With EU funded projects (among many others), such as FLEXYNETS (Fifth generation, Low temperature, high EXergY district heating and cooling NETworkS)[[15]](#footnote-15); STORM (Self-organising Thermal Operational Resource Management)[[16]](#footnote-16) or REWARDHeat (Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks)[[17]](#footnote-17), a lot of research, practical experience (via pilot sites), modelling (of technology and financials via business models) and dissemination to all relevant stakeholders is being conducted.

As such, the state of the art revolves around applying new technology (e.g. AI), optimising existing technology, optimising the transport of energy, adapting to local renewable resources (including high- and low-temperature solar thermal, biomass, wind, PV, geothermal and waste heat) and financial conditions (e.g. developing business models and financial schemes to enable large public and private investments to be mobilised by focusing on the green dimension of investments and developing appropriate business models, the REWARDHeat project aims to encourage a shift in thinking where heat is viewed as a service rather than a commodity), efficiently planning and deploying the networks using the latest modelling/data gathering (sensors)/testing tools, optimally integrating renewable energy/heat/cold generation/storage and the use of reversible heat pumps.

With current DHC networks, effectively integrating multiple low-grade urban energy sources (where they are available along the network), while operating at low temperature and providing heating and cooling, in some cases also from the same pipelines. The networks are benefiting from prefabrication, standardisation, circularity and modularity in an effort to streamline design and installation. And, using a centralised digital management system of the DHC network as to use multiple, unpredictable heat sources and more complex elements (e.g. waste heat), while combining them with complex and highly efficient heat pumps[[18]](#footnote-18). This centralised system, being highly adaptable, while applying dynamic modelling, machine learning (e.g. using pattern recognising algorithms) and instant data analysis coming from a diverse set of sensors and measurements (e.g. indoor temperature sensor data which also monitors external weather conditions and heating system constraints). With renewed investment, assuring higher penetration of smart DHC networks on the heating and cooling market and contributing to the European recovery plan.

As such, due to current population and economic (after the recovery post CV19) growth driving energy demand in hot/humid climatic regions, compounded by climate change and its effect on cooling loads, DHC networks will gain increasing importance over the coming decades[[19]](#footnote-19), with the topics discussed below, needing a concerted Research, Development and Innovation approach.

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| TOPIC 1: EFFICIENCY AND TEMPERATURE REDUCTION  Identifying measures, technologies and strategies to lower network temperature in order to decrease heat losses while widening the range of renewable heating and waste heat source integration. |
| **Scope** Energy efficiency is one of the key measures to tackle the decarbonisation goal also in the H&C sector, enabling to reduce energy consumption, while more efficient networks with lower temperatures allow tapping into renewables and waste heat sources. In addition, system-level approaches (i.e. heat networks) are generally more efficient in dense districts than individual solutions, simultaneously boosting local renewable resources.    Systems as well as component design should be adapted to the conditions for LTDH systems, with modelling representing an important tool to assess the impact of control strategies and measures on consumer decrease in heat demand, while checking proper integration of renewables (especially in a distributed form). Models, however, will have to evolve over time and, hence, will not be a one-stop-shop and as such, some areas will need to be designed, developed and optimised. These areas include:  **Low temperature networks**: Develop, test, implement and standardise innovative and flexible concepts for low and ultra-low (Anergy) heating and cooling networks that can be tailored to the local situation and exploit locally available and renewable or residual heat and cold sources best, considering prosumers and storages. Pathworks to reach LT in existing DHC networks; reduced costs for network (such as none/lower insulation for pipe requirements), but more flow volume (ultra-low-temp networks). Low temperature DH should be referred to as lower than the current status quo in a given country and it depends on the different countries - using only one definition for all Europe would not be helpful as the status is very different from country to country.  **Innovative substations**: Develop and optimise concepts for new substations in order to increase the flexibility and reduce the temperature levels in DH networks, including bi-directional supply and integration of heat pumps, solar thermal booster stations, electric boilers and storages as well as a superordinate controlling and monitoring system. Cost reduction for consumer; problem rather how to finance transition  **Return temperatures**: Develop and implement measures for reducing the return temperatures of existing DH networks in a cost-effective and sustainable manner, including the development of new hardware and software to reduce the return temperatures in the in-house installation. Additionally, create business models to support these optimisations (e.g. bonus heat tariff); Ownership model of substation, customer ownership - e.g. heat as a service (cf. Northern European model); Setup "caretaker" experts for in-house installations to lower the return temperature faster.  Issues related to the inefficiency of buildings have to be considered along with the potential to gradually reduce the supply temperatures in branches of networks with refurbished and energy efficient buildings. The synergies between low temperature district heating and the energy refurbishment of buildings must be explored and exploited. While also addressing health concerns in LTDH networks with domestic hot water systems (DHW), latest research developments on legionella (ultra-filtration or instant heat-up in local substations should be deployed and tested at a large scale, e.g. encompassing multiple apartment buildings with regular testing). Today’s legal requirements in DHW systems can be seen to unnecessarily aggravate possible system efficiency in the district heating business, that comes with lower supply temperatures. (cf. Legionella study by CoolDH) |
| **Results**  * Heat losses can be reduced down to 15% and even reaching 10% in case of 4GDH-5GDH. (cf. IEA DHC Toward 4th Generation District Heating, 2014) * Wide-scale rollout of LTDH systems in Europe can significantly boost the integration of renewables and low temperature waste heat covering a significant portion of heat demand * Unconventional urban excess heat sources alone could cover more than 10 % of the EU’s total energy demand for heat and hot water (ReUseHeat D1.4 on Accessible Urban Waste Heat) * Options/models for the gradual reduction in supply temperatures in existing DH networks and/or options for refurbished buildings to connect to return pipes |
| **Cooperation with third countries** Innovations, pilot projects and deployment of LTDH technologies and networks in the EU can be applied to third countries, with the companies that design and build them locally, acting as experts and consultants in their deployment abroad. |

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| TOPIC 2: ENERGY SYSTEM INTEGRATION  Smart sector integration refers to the interaction between different sectors (buildings, services, transport and industry) and energy carriers (electricity, heat, gas) including storage, leading to energy system optimisation. |
| **Scope** Sector integration offers significant opportunities for supporting the development of renewables and decarbonisation of the energy system. By increasing the synergies between electricity, gas and heat/cooling networks, multi-energy carrier integration can support RES development, preventing curtailment of variable renewable sources (variable RES should be used as locally as possible) in the electricity system.  Given the crucial role of heating and cooling in sector integration, the fact that power-to-gas is not yet commercially available and that system integration can speed up the decarbonisation of the European energy system, while delivering energy efficiency gains, DHC networks facilitate the integration and storage of intermittent renewable electricity and gas and provide a link between a wide range of local sources of heat or cold and the buildings in which they are needed, particularly in cities. Though, capacity building and mutual exchange (given that thermal and electricity stakeholders (e.g. utilities) have limited knowledge of each other’s domains) is needed to increase knowledge and facilitate cooperation.  In addition, an integrated approach together with public stakeholders is needed, such as to successfully set up territorial goals, and integrated planning not only for available energy sources, but also considering nature protection and recreational areas, as well as maximising synergies with utilities/data sharing/building retrofitting.  Address market and regulatory barriers to energy system integration. The regulatory framework plays a key role in sector integration and the way that multi-energy systems can support the development of RES. Regulatory barriers (such as grid tariff structure or incompatible incentive schemes) can prevent the provision of flexibility to the electricity systems and hinder the development of certain technologies. Electricity used in power to heat applications is considered and taxed as end-used electricity. Setup of local energy communities for heat for higher flexibility should be considered.  Mainstream the concept of sector integration and its potential to facilitate the development of RES into policy, infrastructure planning and financing. There should be a level playing field for all flexibility solutions.  Developing market conditions for flexibility services for example adjusting tax rates and connection charges as well as the markets themselves (market access for ancillary services).  Integration of RES often requires available land that is located close to the district. This land use is in competition to urban development, nature protection or equal. Integral planning paves the way to synergies when the urbanity can take advantage of RES energy production in areas that improve the health of inhabitants and biodiversity.  Flexibility provision from sector coupling solutions relies on the availability of data of production systems, demand and distribution networks and on standardised data sharing between relevant stakeholders.  Suitable monitoring of the energy production and distribution assets are as well required to be able to quantify dynamically the flexibility that can be offered by multi-energy systems, either with their direct participation to energy markets or via aggregation. (cf. MAGNITUDE project). |
| **Results**  * Options to integrate heat pumps for DHC (DC) to be powered by “green electricity” and through thermal storage * System solutions and control strategies to increase the interaction between the building, service, industry and transport sectors, to maximise renewable energy uptake, minimise unwanted peaks in power demand and CO2 emissions. * Enable DHC operators participation in the power markets. * Nationally regulated district heating pricing, as unlike for gas and electricity, prices seem to be set for every heat network given local conditions but they might have to be approved by local or regional authorities in some countries. The price level for district heating and the share of fixed and variable fees in the total price will strongly depend on the heat production technologies (Magnitude). * Increase synergies between heat networks and the electricity system requiring to take into account all the specificities of both systems at the local scale. Indeed, heat networks are inherently local systems and rather different situations can be met from one area to the other (Magnitude). * Regulation fostering a high share of RES/waste or heat recovery in district heating sector might have an adverse effect on the exploitation of multi-energy-based flexibility, Through the provision of flexibility to the electricity system, the MES could exceed or on the contrary come below certain thresholds that allow to benefit from support mechanisms, reduction of fees, derogation, etc (Magnitude) * Heat storage is not only capable of shaving heat peak loads, but, in combination with P2H technologies, also to shave electrical peaks. Furthermore, the increase of energy efficiency is an additional solution, which can be achieved either by internal heat recovery or by identifying additional heat demand, e.g. new clients for the district heating networks. (Magnitude) * Electric boilers and heat pumps associated with a DH system can provide demand side flexibility with the coupling of power and heat, especially when associated with storage. They can facilitate the integration of large shares of renewable electricity (Magnitude) |
| **Cooperation with third countries** System integration can be a helpful, efficiency increasing model for countries outside the EU. Furthermore, installation of DHC networks on models already developed should offer the needed alternative for countries looking to transition and streamline their energy demand and generation. |

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| TOPIC 3: DECARBONISATION – SCENARIO EVALUATIONS AND DECARBONISATION STRATEGIES  Identifying and implementing future sustainable technology scenarios to decarbonise the heating and cooling sector. |
| **Scope** To achieve and goal and vision of decarbonising heating and cooling systems in Europe by 2050, the decarbonisation of district heating systems by 100% by 2050 with maximum integration of locally available renewable sources (including waste heat) is vital.  As such, two areas need to be modelled and improved upon: regulations governing the system and the system itself.  A way to test new regulations and market models (allowing dynamic tariffs in a specific territory and DHC operator) and the interconnection of electricity and heating markets, would be achieved by regulatory sandboxes, that can assist in:   * Mapping of cooling demand with specific focus on tertiary buildings * Mapping of RES/waste heat/natural cooling sources * Development of technology scenarios considering the impact on electricity market/grid, peaks, of the increasing cooling demand covered by individual systems vs. DC systems * Mapping of "matching" cooling and heating demand in order to make use of the waste heat from cooling to as large extent as possible, i.e. make use of both the cold and the warm side of the heat pump/refrigeration cycle.   Moreover, the development of technological scenarios to reach targets comparing them in terms of costs and environmental impacts, (LCA) and an analysis of the roadmap to reach these targets (including financial framework), would add upon the regulatory sandbox tests and allow the drafting of Heat (and cold) supply strategies. These being utilised in the development of technology scenarios for DHC networks with a focus on maximising the share of local renewable and emission free energy resources (RES) like: Solar thermal, Geothermal, Heat from heat pumps using renewable electricity on a monthly basis, industrial and urban waste heat as well as waste heat from cooling, biomass from local sources (while maintaining air quality// health). By maximising the use of waste heat sources and promoting heat cascading, the circularity principle is also adhered to.  While, technical and digital (e.g. control strategies) system integration of all heat sources in combination with large-scale multifunctional heat storages, being an important aspect to consider. The aim of these systems is a high supply security and user comfort, while maintaining their cost competitiveness.  **Evaluation in pilot realisations**:   * + Pilot cases and implementation of 100 % emission free heat supply in real districts and evaluation by monitoring   + Continued and regular **risk assessment** for scenarios over time |
| **Results**  * 100% decarbonised system - impact on health * Waste heat utilisation as circularity principle * Technological pathways describing precise decarbonised systems, which are economically feasible and have a high supply security and user comfort. * Best practice cases as role models for other stakeholders. * Identify synergies regions in which demand and renewable/waste heat sources coexists * Assess the suitability of RES DH&C in comparison to individual solution in terms of multiple factors such as:   + Primary energy savings   + €/tCO2 reduction   + Air quality impact (PM10 and similar) |
| **Cooperation with third countries** Decarbonisation scenarios for cooling could benefit from cooperation with warmer countries outside of Europe. Modelling and data collected from pilot sites and simulations can inform tertiary countries and provide a baseline for comparison and improvement. |

6. RESEARCH AND INNOVATION PRIORITIES FOR CITIES

**State of the Art**

[This part is being prepared]

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| TOPIC 1: TOOLS AND GUIDELINES FOR THE DEVELOPMENT OF TRANSFORMATION STRATEGIES AND ROADMAPS TO ACHIEVE DECARBONISED ENERGY SYSTEMS OF CITIES |
| **Challenge to be tackled** The conversion of local energy systems and especially of our urban heat and cold supply systems requires a high speed of transformation to achieve the European decarbonisation goals by 2030 and 2050. The rapid changeover to smart and highly efficient infrastructures and buildings as well as to renewable energy sources will only be successful, if at least high-density areas of ​​cities are supplied by district heating and cooling systems. They show a high flexibility and adaptability and allow the integration of low-exergy sources in an efficient manner. Planning and implementation of DHC systems on urban scale enable a fast transformation due to the limited numbers of stakeholders involved if it is supported by (inter-) national policies. Separate strategies must be developed for those parts of cities which, because of their low density, cannot be supplied by DHC. Millions of apartment and building owners in Europe must be convinced in a few years to invest in efficiency measures and switch to renewables. Only standardised solutions enable this development.  Each city in Europe needs its own strategy for the decarbonisation of their energy system, adapted to their local conditions. But today we are lacking methods and tools for the development of localised strategies and roadmaps. Knowledge and capacities are missing for energy planning in cities, as well as to develop strategies for the implementation of sustainable, resilient and robust energy systems. |
| **Scope** **R&I action is needed to develop methodologies and related tools which help cities to develop transformation strategies and related roadmap to decarbonize their energy systems e.g. by 2030 or 2040.**  The transformation strategy should aim for an integrated approach and therefore must include all energy domains (heating, cooling, electricity, mobility). However, it should especially highlight the heating and cooling sector since heating infrastructure solutions are competing (central or decentralised, electricity or gas-based heating solutions etc.) and basic infrastructure decisions must be taken in an early phase. Furthermore, the high number of stakeholders involved in the heating sector requires a higher effort in motivating them to contribute to the roadmap and its implementation.  The technological solutions, which, amongst others, must be evaluated in the strategy development are: cost-effective heating and cooling systems based on non-electric and electric renewable energy sources with the goal of a high share of self-supply; advanced, flexible district heating systems combined with short and long-term stores, which allow the use of low-temperature renewable and waste heat potentials and coupling with the electricity sector; low-temperature district heating in combination with partly local cooling solutions, which also uses unconventional waste heat potentials (e.g. waste heat from data centres) and could make use of the building mass to store heat; decentralised heating and cooling systems based on local non-electric and electric heating systems using renewable energy sources, taking into account the related infrastructure, which is necessary to operate them. Technology solutions for all energy domains must be assessed and compared including the benefits of coupling the sectors. Due to the high relevance of the fluctuations of demand and supply in the future energy system, its temporal dynamic and especially the seasonal mismatch and the possibilities to compensate it by large thermal or gas stores must be evaluated.  Beside the different technologies also the local and regional available sources on renewable energy and waste heat must be evaluated the expected improvements in regard to efficiency costs for technologies should be taken into account. Furthermore, the economic, regulatory, and sociological aspects like investor and user acceptance should be taken into account.  Methodologies should be developed, how such a strategy development process in a city can be implemented successfully, this includes the structure and governance of the process, the steps and milestones, the stakeholders to be involved as well as the experts and the input, which is needed from them. Fully digitalised planning tools to calculate the optimised decarbonised energy system for a specific city, using modern optimisation algorithms and taking into account open data sources to provide localised basic data, covering the full complexity of the multi-domain energy system and its dynamic, should be developed and made available for use by the local actors. Further decision support systems should be provided. |
| **Results** Methodologies, guidelines and tools for the development of strategies and roadmaps to decarbonise the energy system of a city, which can be used by European cities to plan and implement the transformation of their energy systems will be provided. This will help the cities to identify the possible and the most cost-effective pathways for their energy system transformation and will therefore contribute to the acceleration of the decarbonisation of the European energy system. |

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| TOPIC 2: TECHNOLOGIES FOR INTEGRATED SYSTEM SOLUTIONS OF DECARBONISED ENERGY SYSTEMS OF CITIES |
| **Challenge to be tackled** Our future, fully decarbonised energy systems will consist of flexible prosumers with low energy demand, they will be smart and efficient and will be supplied by a mix of 100% renewable energy sources and waste energy. Energy systems will be structured to a high extend decentral on city level with a maximised share of self-supply. Due to a growing number of energy sources and technologies integrated in the energy systems, their complexity will grow and therefore the need for an integrated design and a connected and smart operation. Since the design of heating and cooling systems depends a lot on local conditions design optimisation is needed within the heating and cooling domain as well as between the heating, cooling, electricity and mobility domains.  Therefore the challenges are to provide technologies which enable a much higher level of integration of different technologies and solutions of an optimised multi-domain energy system within a city and to assure, that all components and sub-systems can be integrated in complex energy systems easily. |
| **Scope** **R&I actions are needed to increase the modularity as well as the physical and digital connectivity of all energy components and sub-systems needed for decarbonised energy systems of cities in the field of generation, distribution, conversion, storage and consumption of heat, cold, and electricity from renewable energy sources and waste energy.**  This includes the development of standards and recommendations for interfaces and component and system designs on the physical level as well as the development of solutions to improve the digital connectivity of components and systems from different producers and domains. The development of a scheme to measure and evaluate the level of modularity of energy components and systems would help the producers as well as the planners and investors to implement integrated systems.  **R&I actions are further needed to develop platform solutions for integrated energy systems, e.g. for district energy systems with a multi-source DHC system coupled with local renewable electricity generation, which enable the integration of components from different producers, but guarantee a high system efficiency by optimised design and operation.**  Platform solutions must focus on the physical as well as on the digital layer of the system. They should be developed and demonstrated in living labs for different types of systems and sub-systems from the heating and cooling domain as well as coupled with the electricity domain. General recommendations should be derived from living lab experiences and guidelines for platform solutions should be derived. The need of the development of a regulatory framework to enable the establishment of platforms should be evaluated. |
| **Results** Increased share of integrated energy system solutions will result from these actions with an increased system efficiency of the energy systems and an increased share of self-supply with renewable and waste energy sources. This will reduce energy costs and, at the same time, improve the resilience of the energy system.  The provision of study and demonstration results, recommendations and eventually a regulation on platform solutions will improve the accessibility of component and system producers to the markets of energy systems, will ease the integration of innovations in the energy system and will avoid lock-in effects by closed systems provided by a few system providers. Finally, the transformation of the energy system will be accelerated and the economy stimulated. |
| **Cooperation with third countries** In regard to digital connectivity, international standards (IEEE, ISO) should be taken into account and further developed together with third countries. |

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| TOPIC 3: Tools and guidelines for the planning of decarbonised energy systems for cities |
| **Challenge to be tackled** Decarbonised energy systems of cities will be characterised by a high level of integration of many sources and components, a strong interaction of sources, components and domains and a smart operation of the energy system. To identify the optimised sustainable energy system for a city, the planning processes and tools must represent the high integration of the energy system, the interaction of all components and domains and the high dynamic in demand and supply.  Such integrated planning tools for energy system optimisation of cities are urgently needed, but they are not yet available for use by local energy experts or city administration. Only pilot tools are available for the use in research institutes, which provide only parts of the functionalities.  The challenges in the development of such tools are:   * Lack of standardised definitions, data and methodologies for energy planning in cities * Lack of consideration of non-technical aspects in energy studies at the municipal scale * Insufficient open source data and models due to proprietary developments and one-off case study applications * Incomplete consideration of technical details that are important to 100% RE integration, e.g. heat temperature levels and storage dynamics * Inadequate model validation based on empirical data and real-world contexts |
| **Scope** **R&I actions are needed to develop planning tools which allow the identification of the optimised design for decarbonised energy systems for cities. The energy system planning tools should be based on existing tools, but allow an integrated multi-domain optimisation and should reflect the complexity and dynamic of the decarbonised energy system. It should be usable by local energy experts and should use modern digitalisation methods, e.g. making use of open data pools and using artificial intelligence methods for optimisation.**  The planning tool development should include but is not limited to:   * Quantitative/measurable definitions of 100% RE Cities, Positive Energy Districts, which can be measured/verified with indicators * Measures aiming at increasing the availability of open source models and data for municipal-level energy planning, as well as their usability * Improved methods and models (or couplings) to include temperature levels and storage dynamics in RE heating/cooling systems * Methods and models which are enhanced with respect to non-technical aspects, e.g. public acceptance, transition dynamics, stakeholder interactions * Harmonisation of assumptions, data and methods for municipal energy analysis etc. R&I measures should aim to exploit existing OS data such as OSM, digital maps etc. * Extensive model comparison/harmonisation and validation exercises with real-world data   **R&I actions are needed to develop guidelines for energy planning in cities, taking into account the energy system optimisation by using the energy planning tool (see R&I action above) as well as the other dimensions of the planning process (organization and governance of the planning process, stakeholder participation, duration, work packages and milestones, experts input needed, dimensions to be considered like definition of targets, financing and business models of actions, user acceptance, etc.).** |
| **Results** New planning tools and guidelines, which are usable by local actors will allow decision makers in cities to take decisions on the energy system transformation on a reliable and sound basis. This will increase the acceptance of the target energy system proposed and will allow to develop a well based transformation strategy and roadmap. In general, an adequate planning tool is a key factor for a sound planning and implementation of transformation roadmaps to achieve decarbonised energy systems in cities and will therefore improve the quality and the efficiency of the planning and implementation process and therefore help to accelerate the decarbonisation of the European energy system. |
| **Cooperation with third countries** In principle cooperation with all eligible non-EU countries is possible. Priority should be given to a representative selection of different “types” of countries in terms of urbanization rate, income level, climate etc. |

7. RESEARCH AND INNOVATION PRIORITIES FOR INDUSTRIES

The European process industries are collectively at the forefront in the sustainable energy transition. They produce materials which directly contribute to the quality of life of all citizens. They are an integral part of most of the value chains of the European economy. Their strong local presence ensures the European independence and leadership in the production of essential materials and goods.

Industrial process heat accounts for about two thirds of the sector energy needs, and around 30% of this heat is consumed between 30°C-400°C. The main energy source for this range is usually combustion of fossil fuels such as natural gas, which leads to large amounts of greenhouse gas emissions. In order to build a low carbon future for the industries, alternative heating sources must be explored, developed and deployed. In this context, solar thermal energy, heat pumps, geothermal and biomass have the potential to be widely used throughout Europe to produce valuable heat as steam, the most utilised heat vector across process industry.

Industrial energy systems for production are mainly designed for single energy supply technologies because with fossil fuels like oil or gas it is easy to reach high supply temperatures. In industry the supply medium is mainly steam, pressurised hot water or thermo oil. There are a few best practice examples worldwide in larger scale which shows the possibility of combination of different renewable energy sources. In order to increase the efficiency in the use of the renewable energy, an optimised interaction of energy supply technologies and the demand of the production processes is needed.

Changing the energy supply for industry requires a redesign of the process technology or, at least, an adaption of the conventional apparatus. New energy systems based on renewable energy are often only to be integrated into low-temperature heat distribution systems (e.g. heat from cogeneration plants, or solar process heat). For example, solar heat for industrial processes (SHIP) is at an early stage of development but is considered to have huge potential for solar thermal applications. Currently, 635 operating solar thermal systems for process heat are reported in operation worldwide. The total gross area of the 301 documented systems which are larger than 50 m² is 905,000 m² gross and the thermal capacity is 441 MWth. Continuous process management, which can be achieved through innovative process technology and which makes the use of renewable energies at low temperature level (<120 °C) possible, would lead to further significant reduction of the energy input and can be defined as a future long-term goal.

For the future, it will be important to support the industry with the development of a methodology and software tools to optimise the operation and design of industrial energy systems. The core of the activities is the development of a holistic optimisation approach, based on (near-) real production data, historical and predictions of the existing system, both the process demand and supply level.

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| TOPIC 1: HYBRIDIZATION OF RENEWABLE ENERGY SYSTEMS  Combination of RES and existing (conventional) technologies towards optimised operational parameters aligned to industrial needs, paving the way towards commercialisation; Development of hybrid solutions to integrate in industry specific energy streams; Innovative applications in the industry (e.g. cement, chemicals, food&beverages, etc.) are contributing to a swift decarbonisation of the heating and cooling sectors. |
| **Scope** The use of RES in industrial processes is rather limited considering that the integration of available technologies is not always adapted to the needs of the industrial process and the existing supply systems. Furthermore, the advantages of utilization of a combination of RES are missing or very little realised and the available RES are not sufficiently used (e.g. organic waste streams). Currently, reliable decentralised renewables for local resource use, territorial resilience and energy poverty abatement are missing. Adaption of existing (conventional) technologies for the combination with RES and optimised use in industrial processes. |
| **Results** Hybrid solutions including adapted and newly developed combinations of RES available for implementation in industrial processes to increase the share of RES significantly and meet the specific needs of industrial processes. Expected key results on a technology level:   * High temperature heat storage * Heat pumps with a supply temperature level higher than 250°C developed to TRL 4-6 * RES based CHP systems providing flexible heat in a temperature range up to 400°C flexible power/heat ratio at a TRL 6-8 * Technologies developed towards feedstock flexibility to make use of organic industrial waste in biomass gasification and biogas processes as well as fuel at TRL 3-5 * High temperature ORC plant developed to TRL 6-8 * High temperature supercritical CO2 plants developed to TRL 5-8 * Solar assisted cooling and refrigeration * Solar thermal process heat above 150°C in combination with other energy supply technologies like heat pump and geothermal technologies * Greenhouse production based on the combination of deep geothermal medium temperature systems with other available bio and solar based RES sources * Combined geo- and solar applications in systems requiring temperature supply in the range of 90 – 180 degrees to accelerate the decarbonisation of sectors such as production of chemicals or ceramic industry * Low temperature chillers * Nexus Energy – Industry – Water: RES for Industrial Water treatment and purification of process water streams * Carbon capture assisted by RES * Highly reliable, flexible and cost effective reversible solid oxide cells for polygeneration (i.e., electricity, heat and synthetic fuels) * Improve reversible fuel cell technology, achieving TRL 6 or even higher |
| **Cooperation with third countries** Current active cooperation between EU and Canadian institutions on reversible fuel cell technology development. |

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| TOPIC 2: INNOVATIVE TECHNOLOGIES FOR OPTIMISED SYSTEM INTEGRATION OF RENEWABLE ENERGIES  Development of new technologies integrating different RES to provide reliable and on demand energy to industrial processes |
| **Scope** Since renewable energy sources are not always available when there is industrial demand (e.g. constant high temperature level or on demand with high flexibility), an interconnection of different sectors (“sector coupling”) is targeted. This on the one hand includes process flexibilization and a deviation from consumption patterns to fit the energy availability. On the other hand the development of technologies, which can use fluctuating renewable energy sources (solar thermal, PV, excess heat) in combination with base load production from geothermal and storable renewable energy sources (biogas, hydrogen, ammonia, HT heat) to supply industrial processes continuously with (high temperature) heat and electricity on demand is fostered. For examples heat integration can come from: (high temperature) solar collectors, deep geothermal, heat pumps and thermal storage. Fluctuating waste streams can be integrated through: low temperature heat; low calorific gases; biogenic materials (organic industrial waste including sewage sludge, municipal waste) by gasification and gas cleaning. |
| **Results** The expected results are the development of new energy supply technologies (TRL 2-4) which are using a combination of RES to provide reliable energy to industrial processes. Expected key results on a technology level are: Integration of solar heat, geothermal, HT heat storage, or HT heat pumps into heat generation or CHP systems in combination with storable RES; Integration of locally generated RES electricity by CHP systems with a high flexibility for the heat/power ratio; Solar assisted cooling in combination with low temperature chillers; Integration of untapped excess heat in combination with heat generation systems of CHP in combination with storable RES. Integrating the production, storage and distribution of green energy vectors (e.g. ammonia, hydrogen, methane) from organic industrial wastes (including sewage sludge); new and retrofitted units that employ CCHP concepts for conversion of these energy vectors; Use of H2 and NH4 as energy vector for stationary fuel cells (SOFC); developing tools and methodologies like machine learning, data driven modelling and digital energy twins. |

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| TOPIC 3: DEVELOPING NEW PROCESS TECHNOLOGY CONCEPTS BEING SUPPLIED BY (LOW-ENERGY) RENEWABLE ENERGY |
| **Scope** Industry is heavily relying on traditional process technologies and reactors which have been not been developed for RES supply. To facilitate the use of RES in industry, new process technologies allowing for cost-effective RES integration are required. The development of innovative technology concepts for production process will involve different sector in a new and energy efficient, low-exergy way. This will address typical unit operations as solid-liquid mixing and transporting, drying, homogenisation, pasteurisation, dissolution processes, adsorption, bio-catalytic reactions, evaporation, L/L separation etc., maximising the product quality and the necessary RE integration. Current industrial processes are in the scope of research, as well as novel biobased pathways. |
| **Results** Novel processing technologies will be available evolving to a TRL 2-6, with radical impact on the RES implementation potential. These novel processing technologies lead to:   * technologies for an exergy-optimised energy supply merging supply and process technology in “one” unit * higher heat transfer coefficients to realise energy supply with minimised heat transfer areas * higher process and resource efficiency in processing and increased energy efficiency (e.g. thermal driven separation technologies) * significant increase of RE potential of specific process technologies requesting a constant and lower energy demand (e.g. by batch-to-continuous approach) smoothening the heat demand profile with positive impacts on the energy supply * concepts addressing thermal (heating, cooling) energy demand as well as electrical demand, overcoming electrification (exergy wastage) and barriers towards low-ex renewable energy and highlight the cost-effective use of these compared to high-ex solutions * Holistic concepts of process technology merging demand and supply by hybrid low-exergy RE systems and storages |

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| TOPIC 4: NEW CONCEPTS FOR AWARENESS DISSEMINATION |
| **Scope** Despite RES are an established reality, RE heating and cooling still needs additional awareness raising. This is especially true in the industrial sector, where most energy-focussed investments are related to electricity consumption & electric motors, CHP, PV, lightning etc. Besides, industrial stakeholders tend to be afraid of switching to new technologies due to the perceived risk of possible malfunctioning. At policy level, there is the need for showing the very good performance of thermal RES compared to other solutions with regard to environmental impact. Citizens should also be aware of the virtuous choices of industries deciding to invest in thermal RES, because this improves environmental performance of goods and services. New awareness-raising concepts focussing on thermal energy should be developed, in order to:   * make industrial owners aware of how much Heating and Cooling contributes to yearly costs * inform about which RES H/C solutions are currently exploitable on the market * provide updates on possible upcoming regulations affecting energy matters in the industrial sector   inform about innovative Business Models and Business to business dissemination through sharing good experiences should also be developed. |
| **Results** Results will consist of information materials/tools (e.g. social exchange platforms for sharing experiences and results) targeting Industry owners, energy managers and industrial facilities planners; Policy makers; Citizens in order to build a community of experts and engineers in process industry in combination with energy use. Outcomes can be: Brochures; Apps. Website aggregating realised systems, including environmental performances. |
| **Cooperation with third countries** Cooperation with third countries is definitely relevant for several reasons:   * Relocation of EU industries in non-EU countries * Climatic conditions (e.g. high irradiation for solar thermal) * Technical and legislative reasons (e.g. biomass is not an option in some EU regions due to limited fuel availability and local regulations)   Third countries to be targeted should be placed in regions with: high solar irradiation and/or large wood areas (and no issues with particle pollution) or moderate climate. |

8. CONCLUSIONS

[To be finalised at the final draft stage] Europe will not achieve its GHG goals without a strong contribution of the RHC sector. Only holistic solutions with a strong contribution of all energy sectors will allow the goals to be achieved. However, despite the increased awareness, RHC industry and markets are still suffering from a lack of dedicated policy initiatives that can accelerate innovation and market deployment in the RHC sector.

This Strategic Research and Innovation Agenda (SRIA) reflects a collective vision for the future of the Renewable Heating & Cooling sector, based on the expertise of key sector players within the RHC-ETIP.

The SRIA builds on the Vision on achieving 100% RHC until 2050 and defines a set of mid-term objectives in order to turn this vision into reality. It gives an overview of the main societal, technological and industrial challenges to be taken up by our sector in the coming decades.

A breakdown of the required EC funding to perform the R&I activities and meet the related targets is proposed accordingly.

This section is being prepared

The SRIA aims to provide guidance and support to the following stakeholders in the coming years:

* The European Commission, in its definition and strategic planning of the HORIZON EUROPE programme for Research and Innovation
* Member States, in their identification of common Research and innovation topics of interest
* Professional RHC companies and industries in their efforts towards integration, joint initiatives and collaborative projects,
* Representatives from companies and industries that are not directly dealing with renewable heating and cooling but are looking into ways of decarbonising their sector
* Representatives from associations in other connected sectors such as: buildings associations, electricity, transport, citizen organisation, environmental NGOs and think tanks
* All stakeholders of the construction sector and the built environment, in their own strategy development towards more competitiveness, sustainability and quality of life for European citizens

ANNEXES

References

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