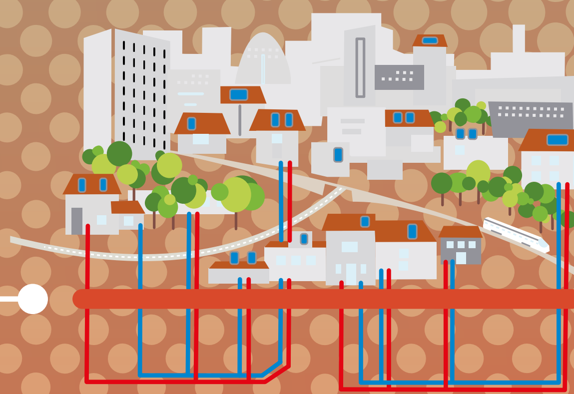
Renewable
Heating & Cooling
European Technology and Innovation Platform

STRATEGIC RESEARCH AND INNOVATION AGENDA FOR CLIMATE-NEUTRAL HEATING AND COOLING IN EUROPE



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THE SRIA IN A NUTSHELL

"Renewable heating & cooling... a closer, simpler and cheaper way to reach full decarbonisation of European buildings, districts, cities and industries".

Javier F. Urchueguía - Chair of the RHC-ETIP

Europe will not achieve climate neutrality by 2050 without a strong contribution of the RHC sectors.

Today the social, environmental and economic costs of climate change make the mission of embracing new and more sustainable sources of energy urgent. RHC technologies are mature, commercial, and market ready, today. They will be continuously developed for increasing their performance and competitiveness if the required support is given to foster research, development and innovation. RHC technologies cover all applications and temperature ranges required by H&C: space heating and cooling, domestic hot water for buildings and cities, for the agriculture and the tertiary sectors, as well as industrial process heat and refrigeration.

Most of our energy still comes from fossil fuels, but this is about to change!

The provision of **100% renewable** energy-based heating and cooling (100%RHC) in buildings, districts, cities, and industrial processes in Europe is **achievable even by 2040**.

Today´s decarbonisation strategy tends to emphasise electrification. However, a dramatic increase in electric H&C and electric mobility would require costly upgrades to distribution networks. While for mobility, this may be unavoidable, **a fully carbon-neutral H&C sector is possible with currently available thermal RHC technologies**. Today, H&C is thermally driven and it should remain this way in the future.

This **Strategic Research and Innovation Agenda** responds to the need for an **update of the priorities** identified in 2013 and the need to **push RHC technologies** to centre stage in order to achieve carbon-neutrality by 2050 at the latest. It presents the main R&I priorities to overcome current and imminent societal, technological and industrial challenges facing RHC.

Raising the public-private expenditure for RHC research to the average annual level **close to EUR 2 billion is crucial to achieve RHC's full potential**. To this end, support is required at the EU level through different funding instruments, which should dedicate to RHC R&D the attention and resources the sector deserves.

By investing in the ambitious RHC priorities presented in this document, the EU H&C sectors can achieve decarbonisation within the next 20 years.

List of figures + Glossary

- **AI**: Artificial Intelligence
- **BIM**: Building Information Model
- **BEM**: Building Energy Modelling
- **CO_2**: Carbon Dioxide
- **COP**: Coefficient of Performance
- **CAPEX**: Capital Expenditure
- **CHP**: Combined Heat and Power
- **CHPC/CCHP**: Combined Heat, Power and Colling
- **CST**: Concentrated Solar Thermal/Heat
- **CSP**: Concentrated Solar Power
- **DC**: District Cooling
- **DES**: Digital Energy System
- **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
- **EV**: Electric Vehicles
- **GWP**: Global Warming Potential
- **H&C**: Heating and Cooling
- **HP**: Heat Pump
- **HT**: High-Temperature
- **HVAC**: heating, ventilation and air conditioning
- **IEEE:** Institute of Electrical and Electronics Engineers
- **IoT**: Internet of Things
- **ISO:** International Organization for Standardization
- **LCA**: Life Cycle Analysis
- **LCC**: Life Cycle Cost
- **LT**: Low-temperature
- **LTDH**: Low-Temperature District Heating
- **MES**: Multi-Energy Systems
- **ML**: Machine Learning
- **NECP**: National Energy and Climate Plans
- **OPEX**: Operating Expenses
- **ORC**: Organic Rankine Cycle
- **OS:** Open Source
- **OSM:** OpenStreetMap
- **P2H**: Power-to-Heat
- **PM**: Particulate Matter
- **PID**: Piping and Instrumentation Diagrams
- **PV:** Photovoltaic
- **PVT:** Photovoltaic thermal
- **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
- **SOFC**: Solid Oxide Fuel Cell
- **SRH**: Self-Reported Health
- **ST**: Solar Thermal (same as Solar Heating and Cooling)
- **SV**: Securitisation Vehicle
- **TES**: Thermal Energy Storage
- **UI**: User Interface
- **UIM**: Urban Information Models
- **UTES:** Underground Thermal Energy Storage
- **4GDH**: 4th Generation District Heating
- **5GDH**: 5th Generation District Heating

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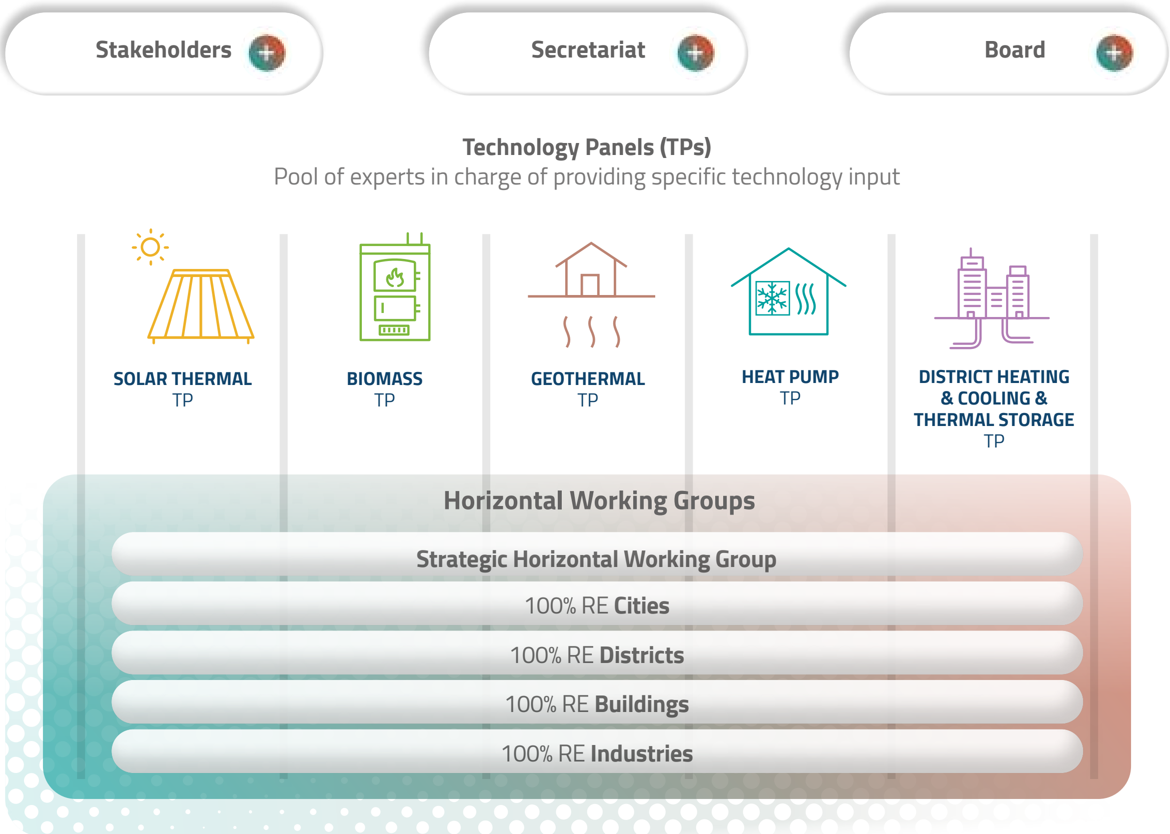
1. INTRODUCTION

The heating and cooling sectors have 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 heating, cooling or refrigeration 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 – which do considerable environmental damage, including in terms of greenhouse gas emissions and air pollution – while only 19% is generated from renewable energy. Today the social, environmental and economic costs of climate change make the mission of embracing more sustainable sources of energy urgent. Recognising this situation, the European Technology and Innovation Platform on Renewable Heating and Cooling (RHC-ETIP), aims at playing a decisive role in protecting Europe's leading position in renewable heating and cooling technology. We want society to benefit from an increased contribution of renewable heating and cooling, which will help to reach the vital goal of a carbon-neutral world by mid-century.

The European Commission (EC) has supported RHC-ETIP since 2008. The Platform is a forum where European industry and research stakeholders can define technological research needs and set strategic priorities to increase the use of renewable energy sources for heating and cooling. RHC-ETIP adopted new approach to produce this SRIA: Horizontal Working Groups (HWGs) were created to bring together interested experts from different technologies directly related to heating and cooling from renewables (Figure 1) to think synergistically about how to tackle some high-level challenges.

FIGURE 1 - STRUCTURE OF THE RHC-PLATFORM



The RHC-ETIP takes a holistic view of research and innovation priorities related to renewable heating and cooling technologies, providing strategic insight into market opportunities and needs. It reaches almost 900 stakeholders from industry, research organisations, and the public sector from all over Europe, and represents trusted and competent advisor to policy-makers. The RHC-ETIP has been instrumental in raising the profile of the renewable heating and cooling sectors through its recommendations for research priorities and project ideas.

The RHC-ETIP Strategic Research and Innovation Agenda (SRIA) was prepared by the RHC-ETIP's Horizontal Working Group on SRIA, edited by the Secretariat of the RHC-ETIP and approved for publication by the RHC-ETIP Board. We are grateful to the members of the Horizontal Working Groups on 100% RE buildings, 100% RE districts, 100% RE cities and 100% RE industries, consisting of numerous experts, who provided their valuable 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).

MAIN POLITICAL MESSAGES FROM VISION

100% renewable energy-based heating and cooling (100% RHC) in Europe is possible by 2050 if coordinated steps are taken at European, national, and local levels to reduce fossil fuel use to zero by that date. The long lifespan of (collective) heating and cooling (H&C) systems means action must be taken by public authorities in the next decade. Solar thermal, geothermal, aquathermal, bioenergy, district H&C, and ambient and excess heat recovery – complemented with renewable electricity – are to be the backbone of a radically new, user-oriented, carbon-neutral, efficient, reliable, and flexible energy system. Such a system will harvest locally available RES, providing considerable employment and recirculating money in neighbourhoods. RHC technologies are affordable for all.

Switching from the EU's over 400 billion cubic meters of fossil fuel imports to employment creation will bring many benefits. The provision of 100% RHC in cities, districts, buildings, and industrial processes will be characterised by larger RES-based District Heating and Cooling (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 easily installable and manageable hybrid systems.

OBJECTIVE OF SRIA

This updated RHC-SRIA is a key document which identifies R&I priorities to boost the market uptake of renewable heating and cooling technologies and thereby realises the Platform's 2050 Vision[1].

The document identifies R&I priorities to boost the market uptake of renewable heating and cooling technologies needed at buildings, industry, cities and districts level, by focusing on deployment environments (i.e. market-pull) rather than technologies individually (i.e. technology-push). This means its priorities are wide-ranging and consider the interaction between technologies and the surrounding environment.

The RHC-SRIA translates expected imminent technological and organisational changes into specific research activities for the Horizon Europe 2021-2027 EU Research and Innovation Framework Programme. Furthermore, it aims to facilitate the coordination of other research programmes in and between EU member states and with the industry. As market growth to a great extent depends on major technological advances, accompanying the RHC-SRIA with appropriate market conditions will be crucial to realising the shift to an energy system in which European consumers can enjoy affordable and sustainable heating and cooling services.

1 The European Technology and Innovation Platform on Renewable Heating and Cooling (RHC-ETIP), 2019. https://www.rhc-platform.org/content/uploads/2019/10/RHC-VISION-2050-WEB.pdf

DIFFERENCE WITH RESPECT TO PREVIOUS RHC-SRIA

The first Strategic Research and Innovation Agenda for Renewable Heating & Cooling sector published in 2013[2] provided stakeholders with a structured and comprehensive view of the strategic research priorities to enable an increasing share of H&C to be supplied by RES.

The 2013 RHC-SRIA guided the RHC community towards achieving the EU energy targets by 2020 and exceeding them in the years to follow. Expanding the market for biomass, geothermal and solar thermal applications, achieving significant breakthroughs through targeted, collaborative research and development activities in RHC technologies played an important role in the timeframe considered then, and in that considered by this RHC-SRIA.

Since 2013, new RHC-related European policies have been launched including the EU Strategy on heating and cooling. These represent important references for the future of the RHC-ETIP and prompted the need for an update of our recommendations. With this update, RHC-ETIP seeks to ensure good alignment of the research and innovation agenda with these policies and specify in which areas and through which key activities the platform can contribute best in order to achieve its goals and strategies.

While the previous RHC-SRIA addressed research and innovation area by technology type, the current SRIA focuses instead on deployment environments: buildings, districts, cities and industries level and takes account of the interactions between technologies within them. The different approach makes direct comparison of the two documents not possible.

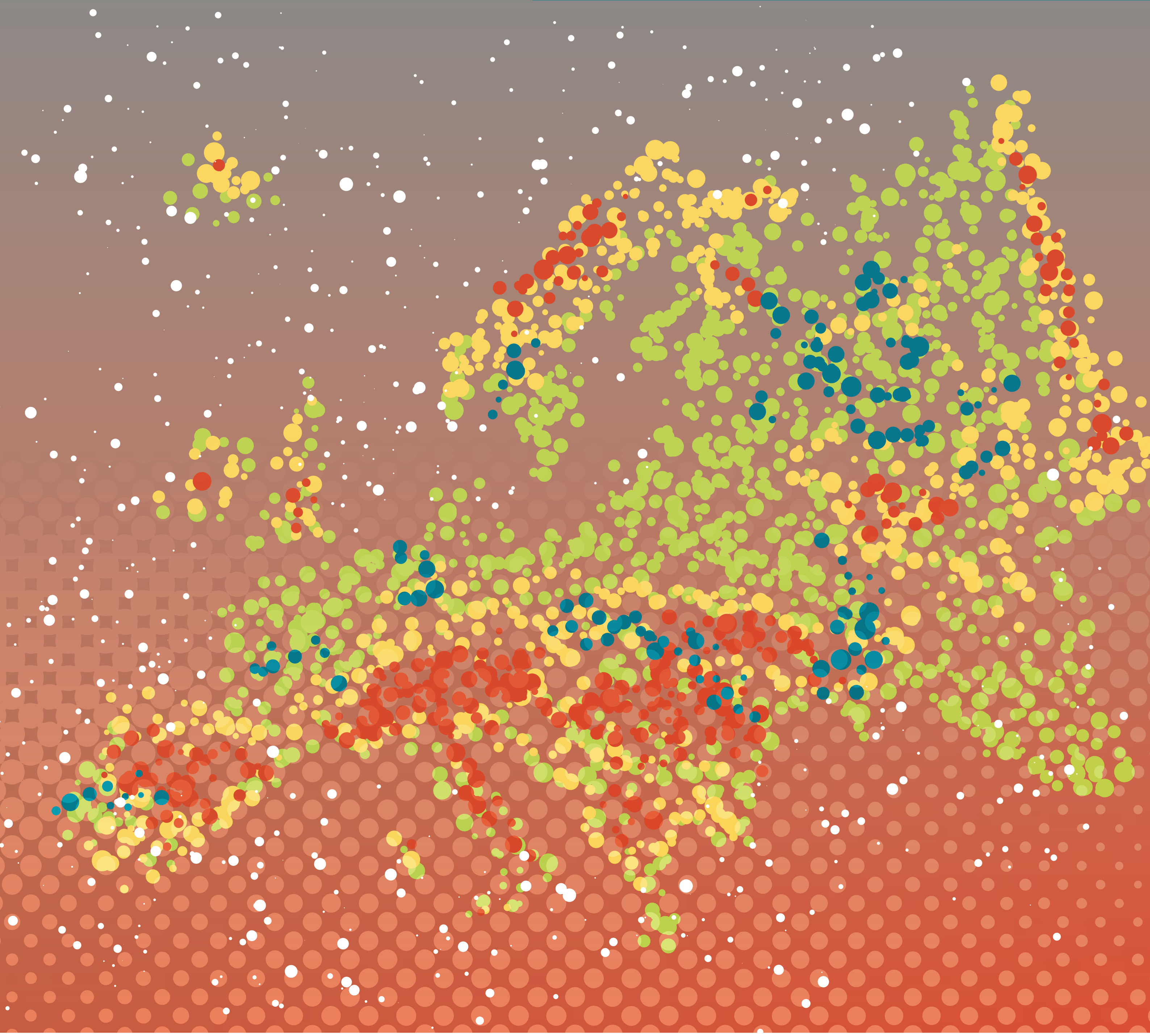
HOW TO READ SRIA

This document develops and presents technology and innovation priorities for reaching 100% RHC in the EU by 2050. **Chapter 2** positions the RHC sectors within the broader challenge of achieving carbon net-zero EU by 2050. Transversal priorities cutting across the horizontal division of H&C sectors 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 deployment environment, scope of the priorities and the expected outcome/impact. **Priorities from the previous SRIA are flagged** to allow similarities and areas requiring continuous R&I effort to be spotted. Moreover, for some priorities, any **cooperation needed with third countries** is described as well. **Chapter 8** offers concluding remarks and summary. Finally, **Annex I** shows R&I targets for the 4 horizontal working groups, while **Annex II** presents data and assumptions behind calculations for the graphs presented in Chapter 2.

2 The European Technology and Innovation Platform on Renewable Heating and Cooling (RHC-ETIP), 2013. https://www.rhc-platform.org/content/uploads/2020/06/gp_eudor_WEB_LDNA26009ENC_002-1.pdf.en_-1.pdf

2.

RHC IN THE FUTURE EU ENERGY SYSTEM



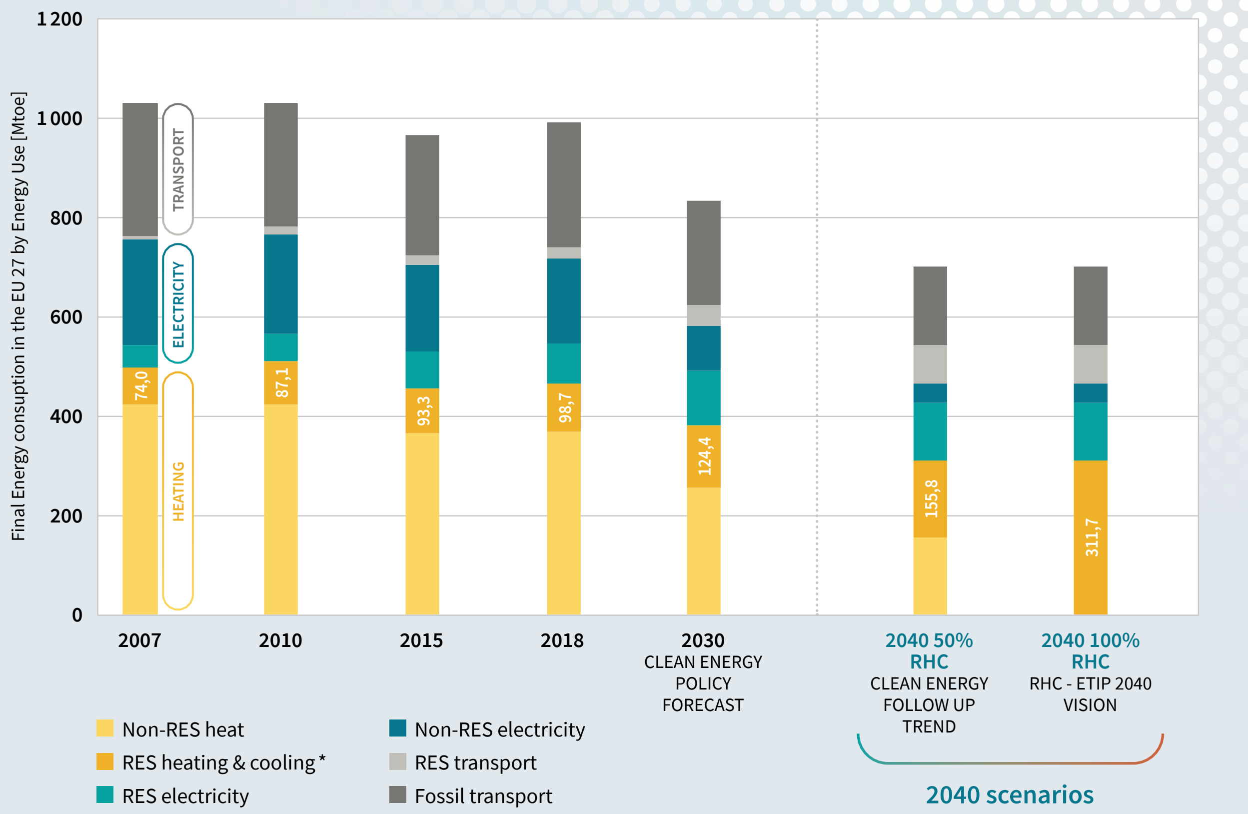
The EU aims to have a net-zero greenhouse gas emissions economy by 2050, as envisioned in the European Commission´s 2050 long-term strategy[3], to meet the EU's commitment under the Paris Agreement. While renewables have made an important contribution in this area, there is still a long way to go.

To push the decarbonisation of the H&C sectors, in February 2016 the Commission unveiled the first **EU strategy on heating and cooling**[4]. While the strategy itself did not include any new legislative proposals, it set out a vision for H&C from renewables 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**[5], together with the Energy Efficiency Directive[6] and the Energy Performance of Buildings Directive[7], specified that renewables should cover minimum 32% of total energy consumption by 2030. Some 40% of this is expected to come from the H&C sectors. The Directive recognises that H&C plays a key role in accelerating the decarbonisation of the energy system. On 17 September 2020, the EC pledged[8] to present new legislation by June 2021 setting a new renewables target of 38.5% by that date. **The challenge is how to reach these ambitious targets!**

More intensive deployment of RHC is possible. As Figure 2 shows, already in 2018 about 98 Mtoe were provided by RHC (biomass, solar, geothermal and ambient heat with heat pumps). The plan of the EC, under the 32% overall target for RES was to reach 124 Mtoe by 2030 with an annual average increase of about 2.3%. Combined with a reduction in consumption due to efficiency measures in the building sector, this moderate rate will decarbonise 50% of H&C by 2040 and produce 155 Mtoe annually. Figure 2 also contains a 100% RHC scenario (with a total production of 311 Mtoe), achievable if the implementation of new innovative RHC technologies is accelerated. Figure 3 shows what could be the future share between different H&C sources considering their deployment potential.

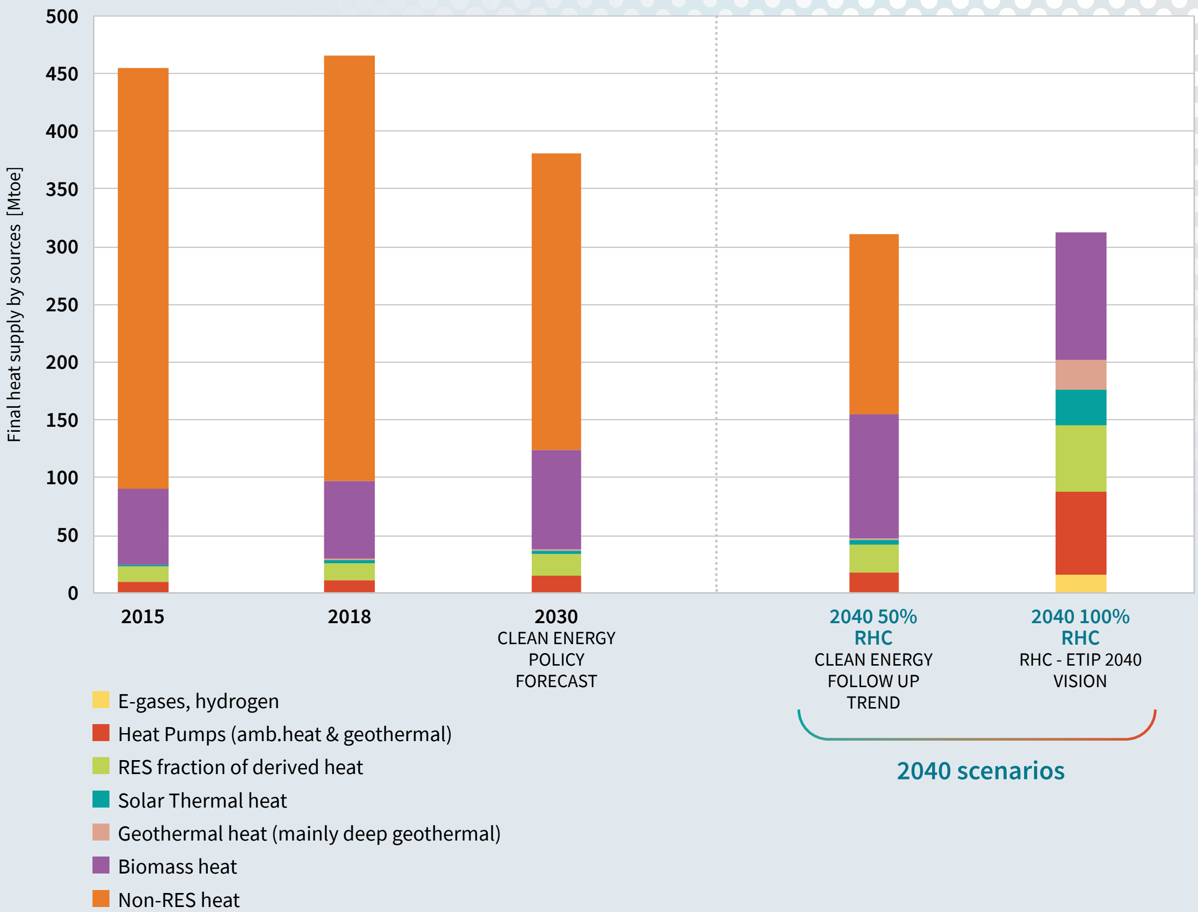
FIGURE 2 - FINAL ENERGY CONSUMPTION IN THE EU 27 BY ENERGY USE AND ORIGIN (RES AND NON-RES)[9]



* This includes RES non-electric H&C+ derived heat (incl. heat from cogeneration) + heat pumps

The following figure shows two scenarios for decarbonising the heating and cooling sectors by 2040. The full RHC scenario is ambitious, but feasible with proper support measures at member state- and EU-level, particularly if electricity taxation and fossil fuels subsidies are tackled alongside the provision of support for R&D.

FIGURE 3 - HEAT PRODUCTION BY SOURCES AND USES [10, 11]



3 See European Union, Council of the European Union, 2020.
4 European Commission, 2016
5 Council Directive 2018/2001, 2018
6 Council Directive 2018/2002, 2018.
7 Council Directive 2018/844, 2018
8 European Commission, 2020, Stepping up Europe's 2030 climate ambition.
9 See Annex II
10 See Annex II
11 RES fraction of derived heat refers to heat by cogeneration from renewable electricity production (e.g. bioenergy electricity plant that cogenerates heat for a DHC network)

RHC technologies cover all applications and temperature ranges required by H&C: space heating and cooling, domestic hot water for buildings and cities, for the agriculture and the tertiary sectors, as well as industrial process heat and refrigeration.

The main assets of RHC technologies are the following:

1. **Local** – the RHC sources and value chain is mainly based in the EU. This ensures that changes within the energy sector will affect the European economy positively
2. **Affordable** – RHC is generated locally and therefore does not require high energy distribution system costs and does not have externalities
3. **Cost-effective** – many RHC technologies show competitive lifecycle costs (LCC) even against cheap fossil fuel alternatives. In a future where environmental externalities associated with fossil fuels are increasingly internalised, RHC will increase its competitiveness and attractiveness for citizens and investors. Moreover, other macroeconomic or geopolitical factors such as the reduction of imports or of energy dependency are other strong arguments for the increased deployment of RHC
4. **Scalable** – RHC technologies are scalable, making small or large projects economic
5. **Available** – market readiness of most RHC technologies is high. This is a pre-condition for a high deployment within the next 10 years
6. **Cross-cutting** – The RHC industry is cross-cutting, meaning combinations of its technologies make them flexible especially when installed in combination
7. **Ecological** – RHC technologies have considerable potential for emissions reduction due to very high efficiencies if compared to most RES electricity technologies. 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 strengths 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 and Innovation 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.

R&D BUDGET NEEDED FOR THE RHC SECTORS

In preparing R&I priorities, RHC-ETIP quantified the private and public budget needed to reach decarbonisation targets.

Public and private funding is crucial for accelerating the decarbonisation of the heating and cooling sector. RHC-ETIP estimates that EUR 400 billion is the total investments required at the European level to substitute 50% of nowadays about 200 Mtoe yearly heating and cooling demand within the next 20 years. The related European R&D expenditure in the 2021-2027 period should therefore amount to **EUR 14 billion**, out of which approximately 2/4 would correspond to industry and 1/4 to EU related research, taking into account the trends in the share of R&D efforts between the different national, European and industrial stakeholders. This amounts to approximately EUR 3.5 billion investment by the European Commission in the next 7 years[12].

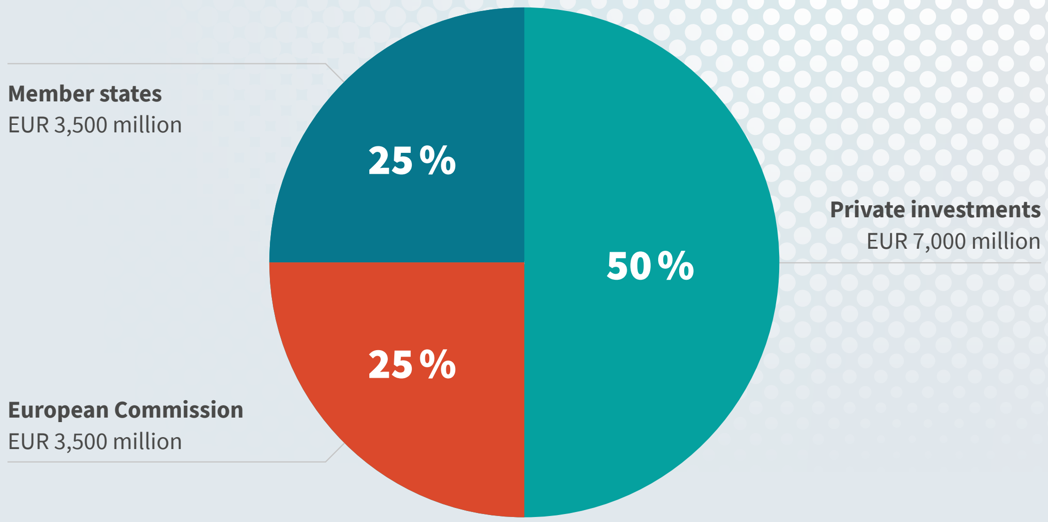
Figure 4 illustrates the RHC-ETIP's proposal for the resources expected to be committed respectively by the European industry (50%), European Commission (25%) and Member States (25%). **Over the period 2021 - 2027, on average EUR 2,000 million should be allocated annually to RHC research and innovation activities in the EU.**

Most of our energy still comes from fossil fuels, but this is about to change!

Today´s decarbonisation strategy tends to emphasise electrification. However, a dramatic increase in electric H&C and electric mobility would require costly upgrades to distribution networks. While for mobility, this may be unavoidable, a fully carbon-neutral H&C sector is possible with currently available thermal RHC technologies. Today, H&C is thermally driven and it should remain this way in the future.

By investing in the bold RHC priorities presented in this document, the EU H&C sectors can achieve decarbonisation within the next 20 years.

FIGURE 4 - ESTIMATION OF TOTAL RESOURCES REQUIRED BETWEEN 2021 AND 2027, IN MILLION EURO AND IN % TO ACHIEVE RHC-ETIP GOALS



As set out in the **Clean energy for all Europeans** package[13], 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. The analysis of Horizon 2020 projects showed that **about EUR 850 million** has been spent on heating and cooling technologies related R&D between 2014 and 2020. This indicates that a substantial increase in public R&D dedicated to RHC is needed, stimulating private investments, with potentially vast benefits. Still greater investments would be needed if decarbonisation is pursued through fuel switching from coal to gas or substantially greater electrification.

It is important to highlight that investments in **R&I RHC should be considered separately from investments focused on electricity**. While smart 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 an approach will create suitable conditions for RHC technologies to improve qualitatively (i.e. wider range of mature technologies to better suit different needs wherever they occur in Europe); and quantitatively (i.e. higher efficiencies, lower investment costs).

RES are intrinsically local. If well exploited, they do not need to be transported via huge public infrastructures (i.e. electricity grid, hydrogen networks, methane 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 RES. Consequently, investments to upgrade these infrastructures may be deferred or avoided entirely. Given the dramatic improvement 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 their thermal storages to match supply and demand in electricity.

12 This value has been estimated based on Eurostat economic statistics. Gross domestic expenditure on R&D in Europe is approximately 2% of GDP, while the overall investment level in the EU is 20% of GDP. Each Euro spent for R&D therefore mobilises EUR 10 of investments. Given the need for EUR 400 billion within the next 20 years, EUR 140 billion will be required in the period 2021-2027. Those will be leveraged with 14 billion investments in R&D of which at least 25% could come from the EU R&D budget (i.e. Horizon Europe, Innovation Fund, and others), which amounts to EUR 3.5 billion.

13 European Commission, 2016, Clean Energy for All Europeans.

RENEWABLE COOLING

Cooling is worldwide the fastest-growing end-use in buildings, as its energy demand more than tripled between 1990 and 2016 to around 2,000 terawatt hours (TWh) of electricity [14]. While much higher-efficiency air conditioners (AC) are currently available, most people purchase new ACs that are two to three times less efficient. Growing cooling demand is impacting power generation and distribution capacity, especially during peak demand periods and extreme heat events [15].

The EU can support R&D efforts to foster innovative and renewable AC technologies, including those that use refrigerants with low global-warming potential or that do not use refrigerants at all. There are different R&D pathways to reach a more climate friendly cooling & refrigeration sector considering the potential of RHC. Efficient heat pumps driven by ground source geothermal heat provide superior seasonal performance ratios and are considered by Internaitonal Energy Agency among highest performing HVAC solutions, providing solutions for mixed climate condition, where there is a balance between heating and cooling demand, making use of the capacity of the underground to store and reutilise heat. Thermally driven sorption chillers for solar thermal cooling render systems with natural refrigerants at electrical efficiencies far above conventional AC systems (by a factor of 5). Thus, solar cooling can reduce electricity consumption associated with cooling equipment as well as related carbon emissions significantly by 80% [16]. The stress on the electricity grid can be minimised when solar radiation and cooling loads are coincident or by means of integration of storage technologies. The sorption chillers for (solar) thermal cooling use natural refrigerants only, thus supporting the F-gas phase out whereas PV driven compression technologies in self consumption mode also permit to dramatically reduce electricity consumption from the grid as well as associated carbon emissions. Moreover, sorption chillers can also use other available heat such as geothermal or bio-based heat considering the resource availability.

Incentives and support for market-based measures can also create economy-of-scale benefits to reduce upfront costs of energy-efficient products. If the technologies are reversible, such benefits can be extended to the heating sector.

14 IEA, 2018.
15 IEA, 2020.
16 Köll and Neyer, 2018.

3.

TRANSVERSAL TOPICS

3.1 TECHNOLOGIES OF HEAT AND COLD STORAGE AND DISTRIBUTION

Thermal energy storage (TES) will be a key enabler for the deployment of RHC in cities, districts, industries, and buildings, at small or large scale. The use of high-capacity underground storage shared by several heat or cold generation systems, instead of a high number of small decentralised storages, may be cheaper. Additionally, the combination of TES and predictive control algorithms will help to increase the share of renewables and at the same time stabilise the electricity 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.

Energy savings can be made by storing waste process heat until it can be used in the same process or a different process. The challenge is to find or create a thermal energy store and heat distribution technology suited to the temperature and quantity of heat transfer fluid.

An integrated approach implies better exploitation of TES. The cost-effectiveness of all types of TES, including combined storage, long-term and seasonal solutions, should be identified and unlocked for heat and cold. TES and DHC tuned to supply heat at the right temperatures 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[17].

17 See Lund et al., 2012
18 **Priority identified in the RHC ETIP SRIA 2013 (RHC.1)**

SCOPE

Develop and demonstrate energy storage and distribution 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 retrofitted buildings, must be modular, plug-and-play or integrated in heating/cooling system and DHW equipment. In systems based on heat pumps, storage solutions should clearly demonstrate the contribution to increase the energy efficiency of these systems. Energy solutions should preferably operate for the three modes: heating, cooling and DHW production, but 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 these solutions, including in the materials used are sustainable. The solutions are expected to ensure some of the following positive impacts:

- increase in the energy efficiency of buildings or industries
- increase in the share of RES and the use of residual heat (e.g. in CHP systems)
- contribute to the flexibility of the electricity networks
- cost-effective
- satisfied owners and end-users

On the residential level, the solutions should be designed for certain durations of charge and discharge according to the kind of building and the climate in which it is located. Whenever relevant, proposals must present short and long cycles, and take into account seasonal variations.

If there is a lack of standards[18] related to the solution as a whole, the customer's confidence in the solution will need to be earned by demonstrating adherence to standards applicable to the solution's components or installation individually. 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 for RES technicians.

For **industry**, thermal energy storage technologies 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 allows water to be stored in slightly over-pressurised water storages rather than low-pressure steam vessels. Depending on the industrial process, the requirements on the thermal storage technology are given by the output, the transportability of the heat, the store's dissipation rate or its compactness. Therefore, the full range of technologies needs to be developed further; from sensible storage (molten salts, molten metals) to phase change stores (paraffins, salt hydrates, polymers, salts, metals) to sorption and hydration (zeolites, salt hydrates) to chemical reactions (metal oxides/hydroxides, chemical looping, other processes) and to underground thermal. Also, innovative hybrid storage solutions using different storage materials increase the applicability.

DESIRED RESULTS

- Increased energy storage densities in thermal solids and fluids
- Reduced thermal losses during storage and distribution, especially for long-term solutions
- Solutions that respond faster enough for the heat storage to contribute to balancing the electricity grid or the building's changing surpluses or shortages of energy
- Use of safe, sustainable and environmentally friendly materials
- Achieving greater use of RES, compared to no thermal storage
- Adaptable storage cycles (daily, weekly, monthly or seasonal), if adaptability is required to optimise the storage's contribution to the system
- Easy-to-install TES, including through kits or through the heating system being "TES-ready"
- Thermal storage solutions integrated with the thermal envelope of buildings, in passive houses
- Residual heat 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
- Cost reduction
- High temperature thermal energy storage up to 1000°C developed at TRL 4-6
- Thermal energy storage and grid balancing through phase-change materials and slurries for industrial cooling or air conditioning of buildings

COOPERATION WITH THIRD COUNTRIES

Desired because industrial sites that could use RHC are found across the world.

3.2
POLICY AND SOCIAL INNOVATION

A big political effort is needed to achieve 100% RHC in EU by 2050. RHC technologies are mature, commercially available, and market competitive already, and they will be continuously improved. However, without effective political support, the vision of 100% RHC in EU by 2050 will not become a reality. Courageous, clear and effective policy instruments are needed to phase out fossil H&C systems before 2040. Stable framework conditions are needed to increase their attractiveness for private investors, and so are risk sharing schemes between investors, utilities, and public administration.

Inefficient incentives, policies and legislation in the RHC sectors, whether at the level of buildings, districts, or cities, continue to hinder progress towards the 100% RHC. In some EU member states, there are still fossil fuel subsidies for replacing old fossil fuel systems with more-efficient ones. Such measure put RES-based technologies at a disadvantage.

District energy requires coherent policies often from several levels of government that offer price stability to the end-consumer, to the operator of the DHC network for the source and availability of its heat and for the civil works related to construction. Identifying, testing and deploying the technologies and systems that will encourage the emergence of prosumers or prosumer communities is required [19]. These individuals or entities could buy shares in their system, potentially giving them a financial return as well as cheaper energy.

SCOPE

Studies are needed to better understand:

- Legislation for increasing RE (e.g. EPBD, bans, etc.)
- European incentive programs and their results
- Consumer behaviour, especially regarding large purchases related to heating
- The role of RE in alleviating energy poverty
- The scope to retrain workers from fossil fuels for RE
- Which energy-as-a-service suppliers exist 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.

DESIRED 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 [20]
- 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 renewable heating and cooling
- Funding/market models for local participation in renewable 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 stor-

19 Heat prosumers: to fully integrate consumers also in the heating market as prosumers - similar to the electricity sector, technical, legal and financial issues still have to be addressed

20 See the market-uptake project SDHp2m (https://www.solar-district-heating.eu/) targeted for a 5-year period on EUR 1,740 million cumulative investment made by European stakeholders in RES to trigger 7,100 GWh/year RES-powered heating and cooling

age) 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, schedule 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.

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 & optimisation: Assessment, monitoring and optimisation of the thermal and hydraulic behaviour of DHC networks and their components, including tools for optimisation 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 need 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. Development of a holistic optimisation approach, based on (near-) real production data, historical data, and predicted data about the existing energy management system, both for the process demand and supply levels. Industry would then be supported with reliable solutions in terms of fluctuating, volatile, and renewable energy supply that is well designed for efficient process technologies. The methodology of the digital twin will be developed and validated for single-use cases and more importantly implemented in the manufacturing industry (e.g. the printed circuit board industry). Also, 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 adoption 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 and which is able to assess its energy performance and suggest building and HVAC retrofit based on BEM
- Development of open source tool for BIM to BEM
- Prove to the end-user that the upgrade to 100% RE buildings are in specific cases feasible and reliable
- 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 architectural 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
- Heat transfer modelling and optimisation of energy-intensive low-temperature processes and systems

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. heating and cooling 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:

- Control the 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
- Digitalisation of cooling, low-temperature energy storage and cold chain
- 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 P2H technologies (especially HPs) and combined heat and power (CHP) plants and optimisation 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.

DESIRED 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
- Realisation of retrofit of buildings to 100% RE buildings
- Realisation 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 real-life operation, proven to reduce losses (in highly efficient grids reducing losses by at least 2% from 7% to 5%[21]). Digital twins also enable

21 According to a case study in Saurav, 2018.

auditing of building energy consumption profile which can reduce energy with up to 10% by exploiting comfort zones [22]

- **Digital twins also enable model-based engineering solutions for complete toolchain from design through validation to commissioning and decommissioning of control, optimisation and monitoring systems reducing the engineering effort by a factor of 5 in building energy automation** [23, 24]
- 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 [25]
- 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, emphasise data security)
- Models, techniques and applications are developed for flexible adaption of industrial processes to react to fluctuating and volatile generation (digital twin, optimisation, 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 especially 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 higher investment and lower 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 renewable 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 a 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.

SCOPE

An exploration of new opportunities must be conducted on:

Alternative financing schemes: Validation of alternative financing schemes and products to attract more private funds for infrastructure. Perhaps using brokers, open the opportunity to citizens to participate in the investment of the RHC projects through 'citizens funding', for instance with crowdfunding. 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 projects to invest. Alternatively, the potential of further new participatory sources of funding such as cooperatives, and 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

Use of blockchain to record peer-to-peer energy exchanges.

Securitisation: The investor demand for **green bonds** is growing rapidly, aided by a taxonomy for sustainable finance set at EU level[26]. 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, that take account of positive externalities and sustainability aspects in appraisal of projects bankability is also important.

Leasing or contracting: An analysis of this option for RHC sectors can be explored also in terms of different models (e.g. AssetCo, OptCo). As an example in

22 See Saurav, 2018.
23 **Priority partially identified in the RHC ETIP SRIA 2013 (CCT.3 & CCT.10)**
24 See Delsing, 2017
25 “STORM” Project. Self-organising Thermal Operational Resource Management, 2019
26 Council of the European Union,2020.

industry, solar thermal contracting is an interesting way to finance medium size solar thermal projects : a third party company buys the system, managing the sourcing, design and installation as well as collecting and keeping any grant, then sells thermal energy for a fixed term and at a fixed (or indexed) price. The third party companies are also responsible for O&M. Developing standardised contracting and/or legal frameworks taking into account different sources of financing is important.

Green and public funds: Many investment funds are interested in green projects. Mapping existing green financing systems to find out which entities are involved where is needed. Low capital costs to incentivise 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). Publicly subsidised risk sharing arrangements must be developed.

Bartering: Commercial agreements between companies to develop the project without money exchange

Blending finance is another potentially valuable instrument. Among the components of the blended finance might be "convertible grants" (grants converted to equity or debt in the case of investment sector), zero-interest loans, or convertible loans (convertible to equity). The resource risk (i.e. uncertainty in the size of the available resource), long lead times for project development and high capital intensity of projects are significant barriers to financing energy projects, which these instruments, and traditional ones, can mitigate.

DESIRED 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 [27]
- Pilot Credit Facility to improve bankability [28]
- 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 renewable energy supply for industries

COOPERATION WITH THIRD COUNTRIES

Cooperation with non-EU countries is desirable.

27 See Winn and Lygnerud, 2019
28 See Bonvicini, 2019
29 **Priority identified in the RHC ETIP SRIA 2013 (CCT.14)**
30 **Priority identified in the RHC ETIP SRIA 2013 (ST.9)**

3.5 CIRCULARITY

"Circularity" in the context of RES H&C production means as many components and products need to be designed for re-use, repair, and recycling. Circularity is the cornerstone of a sustainable future and goes beyond materials. It includes efficient use of low-temperature or excess (waste) heat from industrial processes and commercial buildings (e.g. data centres and other urban infrastructure, such as sewage processing plants, that are currently in large part dissipated in the atmosphere or water) and residential buildings. This heat may be upgraded or supplemented with other RES for space heating and cooling, for example with heat pumps. **The new underground thermal energy storage and heat pumps[29] (UTES) systems offer the possibility to store industrial excess heat in the ground, near the surface. Direct renewable heat technologies are especially suitable in regions that have a seasonal peak in heating demand, which is usually met by fossil fuels.**

Heat should be cascaded from high-temperature users to low-temperature users. Excess heat can be used both for heating and cooling purposes (e.g. by converting it into cold through adsorption chillers[30]).

To illustrate, circularity is central to the bioenergy. Residues from biogas plants and ashes from bioenergy plants can be utilised for different purposes, contributing to circularity and value creation.

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 and waste streams.

DESIRED RESULTS

To deliver a successful circular economy plan for RHC, the following is necessary:

- 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 a quality label for components (such as geothermal pipes, collectors, pumps, etc). This measure is essential to improve the confidence of consumers and legal authorities in sustainability of RHC products
- Continuously monitor the availability of raw materials relative to their use. This should be implemented by using software to characterise raw materials
- Support research and innovation projects that will develop new technologies for waste and water management
- Deliver innovative products, components and systems, that will use sustainable materials
- Ensure support for new business models aligned with the EU Circular Economy Action Plan, which are aiming to encourage industries to produce more sustainable products
- Write a guideline for biorefineries identifying key enabling technologies including energy intermediates such as Methane (CH_4), ammonia (NH_3), Hydrogen (H_2)
- Holistic concepts for material (waste) valorisation and impact on energy intermediates, energy efficiency and RES supply within and outside the biorefinery
- Create exergy-optimised hybrid concepts
- Develop cryogenic recycling of waste for circular energy technologies
- Prepare guidelines for enhanced circularity and value creation for all residual streams from bioenergy plants

COOPERATION WITH THIRD COUNTRIES

Cooperation with the 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, impacting health, wellbeing and productivity of citizens[31]. The World Health Organisation (WHO) estimates the health cost of air pollution in Europe to be EUR 1.5 trillion per year[32]. The conventional heating industry may soon come under the same level of scrutiny for its emissions as currently applies to emissions from diesel vehicles. Replacing combustion-based heating systems with e.g. geothermal heat pumps would be a suitable means to address air pollution[33].

SCOPE

Innovative developments in RHC have potential to:

- Improve comfort of citizens and energy users, e.g. via improved thermal control, which in turn supports well-being; development of devices with sensors to monitor user comfort and health (e.g. smart meters or H&C tailored to a users' health condition); improved heating systems with respect to operation, automation, control and design, which supports well-being and improves health (e.g. device, UI and control ergonomics)
- Improve health of the user (i.e. both psychological and physical) through reduced direct emissions to ambient air (with many chemicals encountered in indoor air known or suspected to cause sensory irritation or stimulation)[34]
- Reduce energy poverty by reducing monthly and yearly expenditures for heating. It has been proved that across the majority of European countries, 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)[35]
- Decrease dependency of current passive consumers on energy price fluctuations and even changing them into "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)
- Innovation in the H&C sectors can potentially be used and deployed in other sectors (e.g. H&C in the process of patient recovery)

Overall, better environment sustainable for future generations means a continued healthier life earlier in life, preventing potential afflictions exemplified above.

DESIRED RESULTS

Through decarbonising the building stock emissions that directly or indirectly affect health, including air pollution from systems burning fossil fuels, would be reduced by more than 90%.

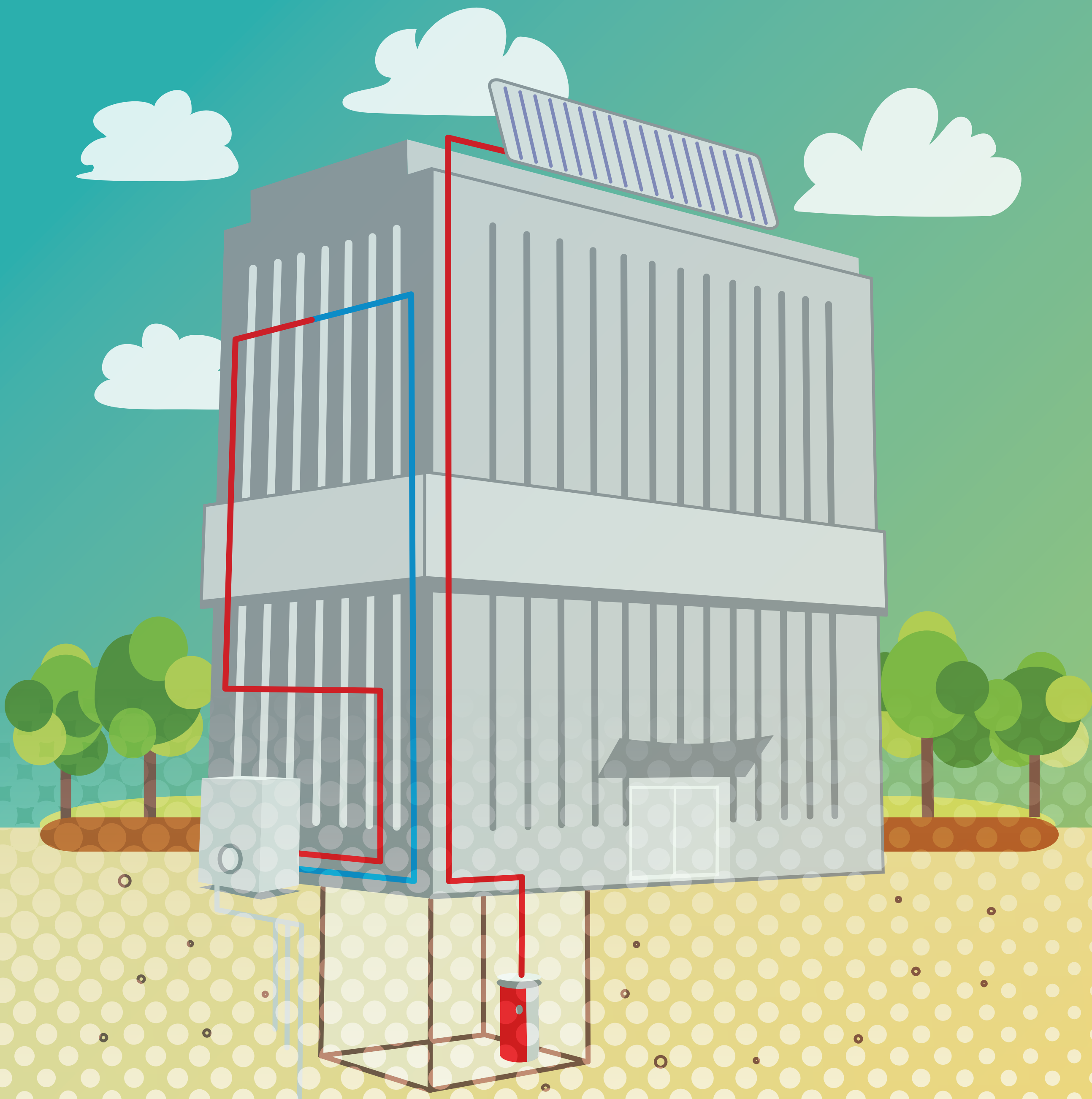
COOPERATION WITH THIRD COUNTRIES

Yes, desired. Horizon 2020 projects such as ENABLE.EU (which includes non-EU partner) or MOBISTYLE shed light on user behaviour and analyse it through the lens of perceived health benefits to the energy user[36].

31 Lelieveld et al., 2020
32 WHO Regional Office for Europe, OECD (2015)
33 Nowak, 2018
34 Berglund et al., 1992
35 Thomson, Snell and Bouzarovski, 2017
36 More information available in Fabi, Barthelmes, Becchio and Corgnati, 2017.

4.

RRESEARCH AND INNOVATION PRIORITIES FOR RHC IN BUILDINGS



STATE OF THE ART

While fossil fuels are the dominant heat source in the world today, contributions to heat supply are certainly also made by bioenergy and increasingly active solar heat, geothermal, ambient, RE electricity. Increased focus on emissions and energy performance has much improved biomass heating technologies in recent decades, including wood-burning stoves. Combined heat and power (CHP) production from biomass 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 fuel is storable from season to season. However, the relative contribution of biomass to RHC will decrease in the future as the other RE sources are implemented to a higher degree, while the biomass resource, which is limited, is used for transport fuels or materials. Biomass is also the only RE source resulting in direct emissions during energy production, and these emissions must be minimised. However, all RHC technologies generate some emissions from a cradle to grave value chain perspective.

Harvesting direct solar energy for the heating of individual buildings has a very long history too, initially through the design and positioning of buildings. Solar energy is today also extensively harvested in solar collectors for thermal uses and in photovoltaic (PV) cells and CSP for electricity generation. Combining PV with solar thermal in PVT collectors [37] is today attracting increasing interest, as well as solar heat driven cooling solutions. Solar thermal is a 'no-regret' option for domestic hot water and space heating without polluting emissions. This reduces greenhouse gas emissions from buildings and improves air quality.

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 surface water, wastewater or drinking water in combination with a heat pump, especially for individual buildings or districts. Extracting heat from ambient air and through air to air HP requires more electricity compared to the heat yielded, but performance is getting better.

Electricity production from wind and PV has increased tremendously in the last decade and is considered to possibly be the key player in our future overall RHC system, including individual buildings. However, its intermittent nature demands backup: demand-response solutions like the activating or switching off of heat pumps; compensation from dispatchable sources of electricity supplying the grid like biomass and hydropower; or from electricity stored in or released from batteries or electrofuels

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 need for active H&C. New buildings are already energy-efficient. The main challenge is to provide cost-effective and easy/fast to install retrofitting solutions for old buildings, both for energy efficiency and H&C, a topic attracting much attention today. Finally, training of installers and certification protocols will ensure systems deliver their full potential.

37 See IEA SHC || Task 60 || Application of PVT Collectors, 2018

TOPIC 1: RE H&C TECHNOLOGIES AND SYSTEMS FOR COST-EFFECTIVE RETROFITTING OF OLD BUILDINGS

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SCOPE

Carbon neutrality of buildings by 2050, driven first and foremost by energy-efficient 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:

1. 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 conditioning capacity or hybrid combinations with e.g. high temperature geothermal heat pumps or clean and efficient wood burning stoves may help to make new heating equipment smaller, allowing cost reduction. Renovation kits should include innovative energy storage.
2. Pushing developments for achieving the economic breakeven point for serial renovation of buildings (i.e. renovating many similar buildings at once) earlier, through efficient prefabrication of elements and advanced HVAC capabilities.
3. 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.
4. 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 H&C equipment. Coupling with new intelligent storage concepts is essential.
5. 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.

DESIRED RESULTS

Renovating many similar buildings in one go (serial renovation) reduces the time needed from months to days or a few weeks. Due to highly automated production of e.g. façade elements and HVAC-modules, components are available at low cost. Systems and technologies developed include:

- Available technologies, especially easy to install renovation kits for serial renovation of buildings
- Highly efficient HP systems with new refrigerants and low GWP for heating and cooling
- Optimised system architectures for combination with new hybrid RE sources for tri-generation of electricity, heat and cold (CCHP) and availability of geothermal sources for co-generation of heat and cold for single buildings, and districts
- Smart, energy-efficient and renewable air-conditioning technologies

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)

TOPIC 2: RE H&C TECHNOLOGIES AND SYSTEMS FOR COST-EFFECTIVE RETROFITTING OF HISTORICAL AND SPECIAL BUILDINGS

SCOPE

Another priority is the mapping of the historic buildings (one quarter of some major cities' building stock [38]) and characterisation of their H&C needs in order to explore the possibility for easy but effective integration of RES. This may be difficult because the look of the building can't be changed. **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 RHC systems need to use the building façade [39] 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 H&C.

DESIRED RESULTS

The expected results are reduced energy demand of the buildings due to energy efficiency measures, raised percentage of integration of RE for H&C in historic and special buildings, and raised acceptance by stakeholders to the integration of RE for H&C in historic buildings.

COOPERATION WITH THIRD COUNTRIES

Cooperation with third countries with important historical building stock would be especially advantageous.

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38 According to IEA SHC || Task 59 || Renovating Historic Buildings Towards Zero Energy, 2017
39 **Priority identified in the RHC ETIP SRIA 2013 (ST.6)**
40 **Priority identified in the RHC ETIP SRIA 2013 (BIO.8)**
41 **Priority partially identified in the RHC ETIP SRIA 2013 (BIO.1)**
42 **Priority partially identified in the RHC ETIP SRIA 2013 (CCT.3 & CCT.10)**
43 **Priority partially identified in the RHC ETIP SRIA 2013 (BIO.2)**

TOPIC 3: RE SOURCES, FUELS, TECHNOLOGIES AND SYSTEMS FOR NEW BUILDINGS AND THEIR INTEGRATION AND EXTERNAL CONNECTIVITY

SCOPE

Provide a wide range of sustainable RHC technologies and combinations of technologies for buildings built according to modern building standards by:

- Further integrating RE systems (solar thermal and PV or PVT) in the building envelope (façade), and new system architectures for using PVT collectors for the generation of electricity, heat and cold
- New solutions for heat pumps and their integration with RES in building thermal envelopes
- Development of compact, affordable and easy to install H&C kits, e.g. heat pump + TS + control software for efficient use of low-temperature heat
- Integration with geothermal heat sources like e.g. thermally activated Energy Sheet Piles
- Development of new **biomass**[40] fuels (solid, liquid, gas) for existing or new technologies
- Development of new **biomass heating technologies**[41] adapted to the needs of new buildings
- Optimised integration with the price signals on electricity market
- 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-consumption
- RE CHP and CHPC integration, and heat and cold storage integration

- Increase of building **automation**[42] through BMS (monitoring sensors, controls, actuators) and decision-making tools for optimum use of buildings/ systems in terms of energy efficiency

DESIRED RESULTS

Provision of RHC technologies and systems that are well suited for inclusion in cost-effective RE systems for new buildings. Expected key results:

- 100% RE coverage of H&C in new individual buildings
- Complete independence from fossil fuel 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 aerothermal and geothermal contribution to additional heat and cold needs
- **Biomass based heating**[43] as an option for energy security through storable fuels and peak shaving capability (e.g. wood-burning stoves)
- RE CHP and CHPC as a natural solution, including biomass
- High-temperature geothermal heat pumps that are suitable for refurbishing old buildings without the need to replace existing high temperature distribution systems
- Heat and cold storage on daily and seasonal basis to increase system efficiency and providing energy security, and electricity storage grid-balancing services
- High efficiency, cost-effective and sustainable RE systems

COOPERATION WITH THIRD COUNTRIES

Cooperation with third countries on technology development is desirable, to maximise the research and development output.

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 old/historical and new buildings. These technologies may be fully integrated 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. They need:

- Reduction of manufacturing and maintenance costs
- Fuel-flexible systems with low/zero emissions
- Higher efficiency through new configurations, more efficient components and the 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

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DESIRED 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
- Reducing load and congestion on the electricity transmission grid
- Adapting power/heat ratio to the building demand, and through the day/year
- Reliable and easy to use, monitor and control CHP/CHPC technologies and systems
- Close integrating with other RE technologies and storage solutions
- Short amortization times
- **Reduced maintenance costs of micro CHP/CHPC in residential and commercial buildings** [44]
- 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 result of research and development exploitation is desirable.

44 **Priority identified in the RHC ETIP SRIA 2013 (BIO.3)**

TOPIC 5: ENERGY SYSTEMS, EDUCATION, TRAINING AND CERTIFICATION FOR DIFFERENT BUILDING CATEGORIES

SCOPE

In order to enhance competitiveness and technical skills of the installers of fossil-fuelled heating equipment, as well as to train RHC system designers:

- an EU information strategy aimed at informing the installers, architects, end-users, manufacturers, suppliers etc. of the benefits of working with RE technology must be developed
- the key success factors to make training systems attractive to installers (online, modular approach etc.) must be understood
- gaps in skills must be pinpointed
- a platform for sharing training material and best practice between training providers in different markets must be developed
- Finding out if, and in what way, certification may be an enabler for increasing interest in RE in installers and consumers

DESIRED 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

Yes, desirable.

5.

RESEARCH AND INNOVATION PRIORITIES FOR RHC IN DISTRICTS

STATE OF THE ART

Though not a new technology, District Heating and Cooling (DHC) has many advantages [45]. With EU funded projects [46], such as FLEXYNETS (Fifth generation, Low temperature, high EXergY district heating and cooling NETworkS) [47] ; STORM (Self-organising Thermal Operational Resource Management) [48], REWARDHeat (Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks) [49], or many national-funded projects, such as WarmingUP [50] in the Netherlands, 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, current research focuses on applying new technologies (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, solar PV, aquathermal, geothermal and waste heat), 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, and financial conditions. To illustrate the last point, the REWARDHeat project aims to encourage a shift in thinking where heat is viewed as a service rather than a commodity.

Current DHC networks effectively integrate 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.

© Solar Heat Europe

The networks are benefiting from prefabrication, standardisation, circularity and modularity in an effort to streamline design and installation. They also use a centralised digital management system of the DHC network to enable use of multiple and unpredictable heat sources and more complex elements (e.g. waste heat), while combining them with complex and highly efficient heat pumps [51]. This centralised system is highly adaptable and applies 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). Renewed investment can ensure higher penetration of smart DHC networks on the heating and cooling market and contribute to the European recovery plan.

Once recovery from the economic shock from COVID-19 is underway, DHC networks will gain increasing importance, driven in particular by cooling demand [52]. The R&D focus needs to be on the topics discussed below.

45 Mazhar, Liu and Shukla, 2018
46 For a review of EU DHC network projects see Saletti, Morini and Gambarotta, 2020
47 "FLEXYNETS" Project - Fifth generation, Low temperature, high EXergY district heating and cooling NETworkS, 2018
48 "STORM" Project. Self-organising Thermal Operational Resource Management, 2019
49 "REWARDHeat" Project - Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks, 2019
50 "WarmingUP" Project
51 DHC+ Technology Platform c/o Euroheat & Power, 2019
52 Colmenar-Santos, Borge-Díez and Rosales-Asensio, 2017

TOPIC 1: EFFICIENCY GAIN 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 decarbonisation in the H&C sectors, including by allowing heat to be supplied from lower temperatures sources, like waste heat. In addition, system-level approaches (i.e. heat networks) are generally more appropriate in dense districts than individual heating systems.

The design of LTDH systems and components should be adapted, through modelling of control strategies that take account of consumer behaviour. The models will have to evolve over time to keep up with changing consumption patterns and technological developments. Research areas include:

Low temperature networks: Develop, test, implement and standardise innovative and flexible concepts for low and ultra-low (energy) 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. Pathways 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-temperature 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 the whole Europe would not be helpful as the status is very different from country to country.

Innovative substations: Develop and optimise concepts for new substations 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.

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 installations. 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**[53] **(DHW), latest research developments on legionella (ultra-filtration or instant heat-up in local substations**[54]**) 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, which comes with lower supply temperatures[55].

DESIRED RESULTS

- Heat losses reduced down to 15% and even reaching 10% in case of 4GDH-5GDH[56]
- Wide-scale rollout of LTDH systems in Europe significantly boosting the integration of renewables and low temperature waste heat covering a significant portion of heat demand
- Unconventional urban excess heat sources alone covering more than 10 % of the EU's total energy demand for heat and hot water
- 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. 3rd country companies designing and building them can become experts and consultants in their deployment abroad.

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 locally as much as possible) in the electricity system. 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 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 buildings in which they are needed, particularly in cities. Actions needed include:

- Capacity building and mutual exchange to increase knowledge and facilitate cooperation between thermal and electricity (e.g. utilities) stakeholders given the limited knowledge of each other´s sectors
- Integrated approach with public stakeholders 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
- Addressing 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 (e.g. 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 must be considered.
- Mainstream the concept of sector integration and its potential to facilitate the development of RES into policy, infrastructure planning and financing to achieve level playing field for all flexibility solutions
- Developing market conditions for flexibility services, e.g. adjusting tax rates and connection charges as well as the markets themselves (i.e. market access for ancillary services)
- Integral planning to achieve synergies between urban development and RES energy production in areas that improve the health of inhabitants and biodiversity.
- Flexibility provision from sector coupling solutions, which 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 also required to be able to dynamically quantify the flexibility that can be offered by multi-energy systems, either with their direct participation to energy markets or via aggregation[57]

DESIRED RESULTS

- Options to integrate heat pumps for DHC (DC) 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 CO_2 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**[58]
- Increase synergies between heat networks and the electricity system, including dynamic electricity tariffs, requiring consideration of the specificities of both systems at the local scale

53 **Priority identified in the RHC ETIP SRIA 2013 (OCT.19)**
54 **Priority identified in the RHC ETIP SRIA 2013 (OCT.20)**
55 See Report on solutions for avoiding risk of legionella by Sernhed et al., 2018.
56 Dalla Rosa et al., 2014.
57 See "MAGNITUDE project"
58 **Priority identified in the RHC ETIP SRIA 2013 (GEO.11)**

- Provision of flexibility to the electricity system to enable MES to exceed or on the contrary come below certain thresholds that allow benefiting from support mechanisms, reduction of fees, derogation as 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
- Combining thermal energy storage with P2H technologies to shave electricity peaks
- Increase of energy efficiency achieved either by internal heat recovery or by identifying additional heat demand, e.g. new clients for the district heating networks
- Electric boilers and heat pumps associated with a DH system coupled with power and heat to provide demand-side flexibility especially when associated with storage. These can facilitate the integration of large shares of renewable electricity

COOPERATION WITH THIRD COUNTRIES

System integration can be a helpful and 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.

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 the goal and vision of decarbonising H&C systems in Europe by 2050, the 100% decarbonisation of DH systems 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/ water- and air-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 the largest possible extent, i.e. make use of both the cold and the warm side of the heat pump/refrigeration cycle

Moreover, the development of technological strategies 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 to the regulatory sandbox tests and allow 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, aquathermal, geothermal, heat from heat pumps using renewable electricity on a monthly basis, industrial and urban waste heat as well as waste heat from refrigeration, biomass from local sources (while maintaining air quality). By maximising the use of waste heat sources and promoting heat cascading, the circularity principle is also adhered to. Technical and digital (e.g. control strategies) system integration of all heat sources in combination with large-scale multifunctional thermal energy storages is another 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 strategies over time

DESIRED RESULTS

- 100% decarbonised system – positive impact on health
- Waste heat utilisation as circularity principle
- Technological pathways describing precise decarbonised systems, which are economically feasible, affordable, reliable and enhance user's comfort [59]
- Best practice cases as role models for other stakeholders
- Identify synergies regions in which demand and renewable/waste heat sources coexist
- Suitability assessment of RES DH&C in comparison to individual solutions in terms of multiple factors such as:
- Primary energy savings
- €/tCO_2 reduction
- Air quality impact (PM10 and similar)

COOPERATION WITH THIRD COUNTRIES

Decarbonisation strategies for cooling could benefit from the experience of advanced economies outside of Europe with warmer climate. Modelling and data collected from pilot sites and simulations can inform 3rd countries and provide a baseline for comparison and improvement.

59 In line with Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all (United Nations, 2015)

6.

RESEARCH AND INNOVATION PRIORITIES FOR RHC IN CITIES

STATE OF THE ART

In the context of the global energy transition, cities are facing a double challenge. Firstly, the energy system for supplying electricity, heat and cold, as well as fuels for mobility, must be fundamentally transformed and must become completely climate-neutral. Secondly, cities must play a much more active role in shaping their energy systems than up to now, as this is required to implement the necessary decentralisation. Against this backdrop, more and more cities in Europe are setting themselves the goal of achieving a climate-neutral energy supply by 2050 or even earlier.

A climate-neutral energy supply for a city must be based on four pillars. Firstly, the efficiency of energy production, distribution and consumption must be significantly increased. Secondly, the potential of climate-neutral energy sources in the city must be used to the fullest possible extent. Thirdly, most cities rely on cooperation with the surrounding rural regions to import wind energy, biomass and other renewable energy sources that are lacking or insufficiently available in the city. Fourthly, an integrated and intelligent energy system must be implemented. In such energy system, energy sectors are coupled, storage capacity is integrated, consumption is made more flexible and energy systems are intelligently managed. This includes comprehensive digitisation and the establishment of new business models. For each city, the optimal mix of resources and technologies has to be determined individually.

The design of the H&C supply system is of particular importance for cities, as it is much more dependent on local conditions than the electricity sector. Furthermore, cities can also influence the heating infrastructure (e.g. providing a heat network or enabling decentralised heat generation) and the heat demand of buildings via their energy efficiency standard. At the same time, the heating and cooling sector presents a particular challenge, as there is a high diversity of different actors, technologies, resources and heating and cooling needs.

A climate-neutral urban energy supply goes beyond the concepts for a climate-neutral heat supply for buildings and for heating districts, which are presented in the earlier chapters. It requires additional technologies and solutions to build an integrated, intelligent energy system linking the electricity, heating, cooling and mobility sectors. In doing so, higher-level questions have to be answered, such as: To what extent the electrification of the heating sector in a municipality is possible and useful; to what extent is useful a centralised heat supply with

local heating networks; how can be renewable energy sources used most efficiently for the different sectors and what role can intelligent energy system solutions and business models play, e. g. the use of energy storage systems, power-to-heat solutions, bi-directional charging of electric vehicles, demand-side management, peer-to-peer energy trading, local energy communities.

The concept of climate-neutral energy systems for cities, taking into account sector coupling, a high proportion of local climate-neutral energy sources and a smart energy system with intelligent control and use of flexibilities, has so far only taken place in exceptional cases. On the one hand, this is due to traditional planning methods, which are often based on working in silos and have to be replaced by interdisciplinary planning methods. On the other hand, there are not yet sufficient practical tools available for planning integrated climate-neutral energy systems for municipalities. In order to achieve a climate-neutral heat supply based on an optimal local energy mix in a city that is part of an integrated municipal energy system and uses innovative solutions of sector coupling and smart energy management, the further development of planning tools and technologies described in this chapter is required.

TOPIC 1: TECHNOLOGIES FOR INTEGRATED SYSTEM SOLUTIONS OF DECARBONISED ENERGY SYSTEMS OF CITIES

SCOPE

Climate-neutral energy systems require 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 will be integrated into complex energy systems easily and work together in a smart way.

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 producers as well as 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 technologies, also coupled with the electricity domain. General recommendations should be derived from living lab experiences and guidelines for platform solutions should be derived. The need for the development of a regulatory framework to enable the establishment of platforms should be evaluated.

DESIRED RESULTS

These actions will lead to increased share of integrated energy system solutions, increased system efficiency of the energy systems and to increased share of self-supply consumption 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

With regard to digital connectivity, international standards (IEEE, ISO) should be taken into account and further developed together with 3rd countries.

TOPIC 2: TOOLS AND GUIDELINES FOR THE PLANNING OF CLIMATE-NEUTRAL ENERGY SYSTEMS FOR CITIES

SCOPE

To identify the optimised climate-neutral energy system design 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 are not yet available for use by local energy experts or city administration. Existing pilot tools are lacking standardised definitions, data and methodologies, consideration of non-technical aspects, and technical details that are important to 100% RE integration, e.g. heat temperature levels and storage dynamics and model validation based on empirical data and real-world context.

R&I actions are needed to develop planning tools which allow for 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, sensors 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 (organisation 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.).

DESIRED 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 urbanisation rate, income level, climate etc.

TOPIC 3: TOOLS AND GUIDELINES FOR THE DEVELOPMENT OF TRANSFORMATION STRATEGIES AND ROADMAPS TO ACHIEVE DECARBONISED ENERGY SYSTEMS OF CITIES

SCOPE

The conversion of local energy systems and especially of our urban heat and cold supply systems requires a high speed of transformation from today's fossil-based energy systems to climate-neutral energy systems. For example, district heating and cooling systems must be built up, since areas with higher levels of heat and cold demand density must be supplied by DHC systems, since they show high flexibility and adaptability and allow the integration of low-exergy sources in an efficient manner. Each city needs its own transformation strategy, but it is necessary to provide methods and tools for the development of localised strategies and roadmaps for the cities.

R&I action is needed to develop methodologies and related tools which help cities to develop transformation strategies and related roadmap to decarbonise their energy systems 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 H&C sectors since heating infrastructure solutions are competing (central or decentralised, electricity, 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 partially 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.

Besides the different technologies also the local and regional available sources on renewable energy and waste heat must be evaluated and 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 considered.

Methodologies should be developed to clarify how such a strategy development process in a city can be implemented successfully. These would include the structure and governance of the process, the steps and milestones, the stakeholders to be involved as well as the experts and the input 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.

DESIRED 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.

7.

RESEARCH AND INNOVATION PRIORITIES FOR RHC IN INDUSTRIES

The European process industries are collectively at the forefront of 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 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, which is the most utilised heat vector across process industry.

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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 that demonstrate the possibility of combination of different renewable energy sources. 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 integrated into low-temperature heat distribution systems (e.g. heat from cogeneration plants, or solar process heat). For example, SHIP is at an early stage of development, but is considered to have huge potential for solar thermal applications. Currently, CST systems, at even an earlier stage than non-concentrating systems, reach temperatures of 400°C and even above. They may directly supply steam systems by injection. 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. In Europe, the size of SHIP installations grows every year. Until 2018, the largest SHIP plant in Europe was 2MW, since then new plants became operative and reached 12MW.

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.

60 **Priority identified in the RHC ETIP SRIA 2013 (ST.8)**
61 **Priority identified in the RHC ETIP SRIA 2013 (ST.7)**
62 **Priority partially identified in the RHC ETIP SRIA 2013 (ST.11)**

TOPIC 1: HYBRIDISATION 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.) contributing to 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 utilisation of a combination of RES are missing or inadequately 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. Therefore, adaptation of existing (conventional) technologies for the combination with RES and optimised use in industrial processes is needed.

DESIRED RESULTS

Hybrid[60] solutions need to be developed. These would include 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 thermal energy 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 (possibly combined with CST)
- High temperature supercritical CO_2 plants developed to TRL 5-8
- **Solar assisted[61] cooling and refrigeration – thermally-driven sorption chillers for solar thermal cooling that provide systems with natural refrigerants at electrical efficiencies far above conventional AC systems**
- **Solar thermal process[62] heat above 150°C in combination with other energy supply technologies like heat pump and geothermal technologies**
- Concentrating solar thermal collectors operating above 250°C combined with high-temperature storage solutions (molten salts, solid sensible materials) TRL 6-8
- Greenhouse production based on the combination of deep geothermal medium temperature systems with other available bio and heat-based RES sources
- Combined geo- and solar thermal applications in systems requiring temperature supply in the range of 90°C – 180°C to accelerate the decarbonisation of sectors such as production of chemicals or ceramic industry
- Development of 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

Yes, desired. Current active cooperation between EU and Canadian institutions on reversible fuel cell technology development is a great example of 3rd country cooperation in this area.

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 for 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 flexibilisation 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 instance, 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. High-temperature residual heat can be re-used by other plants in an industrial zone if steam-condensate systems could be designed in a more cost-effective way, e.g. using relatively drilled sections instead of long above-ground routings or minimising the need for condensation traps.

DESIRED 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 thermal energy 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 high flexibility for the heat/power ratio
- **Solar assisted [63] refrigeration 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 CHP concepts for conversion of these energy vectors
- Use of H_2 and NH_3 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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63 **Priority identified in the RHC ETIP SRIA 2013 (ST.7)**

TOPIC 3: DEVELOPING NEW PROCESS TECHNOLOGY CONCEPTS BEING SUPPLIED BY RENEWABLE ENERGY

SCOPE

Industry is heavily relying on traditional process technologies and reactors which have 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 sectors in a new, energy efficient and 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.

DESIRED RESULTS

Novel processing technologies will be available evolving to TRL 2-6, with radical impact on the RES implementation potential. These novel processing technologies will lead to:

- technologies for an exergy-optimised energy supply merging supply and process technology into “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 and 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

SCOPE

Even though RES are an established reality, RHC still needs additional awareness raising. This is especially true in the industrial sector, where most energy-focused 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 a need for showing the outstanding 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 to:

- make industrial owners aware of how much heating and cooling contributes to yearly costs
- inform about which RHC 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


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DESIRED 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; policymakers; citizens in order to build a community of experts and engineers in process industry in combination with energy use. Desired outcomes are: brochures; cell phone applications; website aggregating realised systems, including environmental performances, and others.

COOPERATION WITH THIRD COUNTRIES

Cooperation with third countries is definitely relevant for several reasons:

- Relocation of EU industries to 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 situated in regions with: high solar irradiation and/or large wood areas (and no issues with particle pollution) or moderate climate.

64 European Commission, 2019. The European Green Deal

8. CONCLUDING REMARKS

As stated in the European Green Deal Communication[64], *"The EU has the collective ability to transform its economy and society to put it on a more sustainable path."* Sustainable, reliable and affordable energy supply is imperative to the achievement of this transformation and the use of carbon-neutral energy sources for heating and cooling of buildings, districts, cities and industries is the most effective way to achieve emission reductions as well as improve energy security. Europe will not achieve climate neutrality by 2050 without a major contribution from RHC. Only holistic solutions will allow the goals to be achieved. However, despite the increased awareness, RHC industry and markets are still suffering from a lack of recognition as other sectors (e.g. hydrogen) dominate the policy discourse. Proportional attention and dedicated policy initiatives that can accelerate innovation and market uptake in the RHC sectors are needed.

This **Strategic Research and Innovation Agenda** responds to the need for an **update of the priorities** identified in 2013 and the need to **push RHC technologies** to centre stage in order to achieve carbon-neutrality by 2050. It reflects a shared vision for the future of RHC, based on the expertise of the RHC-ETIP members and stakeholders. The SRIA builds on the Vision by defining a set of ambitious objectives to turn this vision into reality. It presents the main R&I priorities to overcome current and imminent societal, technological and industrial challenges facing RHC. Specific objectives and measurable targets are identified for each research and innovation priority. The implementation of the RHC-SRIA in its entirety requires a systemic approach to produce innovative integrated solutions.

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

- Representatives of the European Institutions, for the definition and strategic planning of the Horizon Europe programme and other funding instruments for Research and Innovation
- Representatives of national governments working in the fields related to the development of the renewable heating and cooling sectors
- RHC companies and industries in their internal R&D strategies, 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 businesses
- Representatives from associations in other connected sectors such as: buildings, electricity, transport, and citizen organisations, as well as environmental NGOs and think tanks

With this RHC-SRIA, a comprehensive strategy has been put forward to support the decarbonisation of heating and cooling in the EU. It is framework on which part of the EU's recovery from the current economic downturn caused by the COVID-19 pandemic may be built. Private investors are looking for signals – from the EU and national governments – that Europe is taking serious steps towards becoming a competitive and carbon-neutral energy economy by 2050. Raising the public-private expenditure for RHC research to the average annual level close to EUR 2 billion is crucial to achieve RHC's full potential. To this end, support is required at the EU level through different funding instruments, first and foremost Horizon Europe, which should dedicate to RHC R&D the attention and resources the sector deserves.

Renewable heating and cooling can help solve the huge problem of climate change, and bring other benefits like improved security of energy supply. Much remains to be done if we are to achieve our ambitions of decarbonisation and market growth, but the effective implementation of this RHC-SRIA would be a step in the right direction.

ANNEX I

R&I targets

HORIZONTAL SECTOR	MONITORING KPIS (TARGETS)
BUILDINGS	■ Overall, 90% RE H&C achieved in the individual buildings sector ■ Cost-effective and high-performance combined RE H&C solutions/systems available for all individual building categories ■ Overall, 75% of all cooling needs in individual buildings covered by RES **Heat and cold storage:** ■ Compact and system flexible thermal energy storages based on e.g. phase change materials commercially available for individual buildings in a wide range of sizes and for relevant temperature levels ■ Very compact heat batteries with at least 220 kWh/m3 (total volume of the battery) and long lifetime (i.e. at the least 25 years) (large scale prototype stage) **Policy and social innovation** ■ Policies introduced resulting in complete phase-out of oil heating systems for individual buildings all over Europe ■ Policies introduced resulting in phase-in of overall 50% green gas supply in remaining gas supply to individual buildings in Europe ■ Fossil heating systems no longer part of the curriculum of craftsmen/women education/training **Digitalisation, operation and system flexibility**: Digitalisation as an integral part of all R&C solutions/systems for new buildings and for retrofit in old buildings **Innovative financing schemes and new business models**: Consumer friendly financing schemes and business models available for all H&C solutions/systems for new buildings and for retrofit of old buildings **Circularity**: 50% overall circularity achieved for H&C systems for individual buildings **Health**: 75% overall reduction in mass of health impacting emissions from biomass combustion **TOPIC 1 – RETROFITTING OLD BUILDINGS** ■ Easy to install renovation kits available for serial renovation of all building categories, and reducing renovation time from months to days or a few weeks ■ 50% reduction of façade elements and HVAC-modules renovation costs ■ 75% of HP systems installed for heating and cooling have high COP and refrigerants with low GWP **TOPIC 2 – RETROFITTING HISTORICAL BUILDINGS** ■ 50% reduction of energy demand of the historic/special buildings due to energy efficiency measures ■ 50% RE H&C in historic/special buildings

HORIZONTAL SECTOR	MONITORING KPIS (TARGETS)
BUILDINGS	**TOPIC 3 – NEW BUILDINGS** ■ 99% RE coverage of H&C, through cost-effective and high performance solar thermal, geothermal, ambient heat and biomass, with their individual selection and contribution decided by external factors and user preferences ■ RE CHP and CHPC as a natural solution, including biomass-based ■ Overall, 90% of electricity consumed by RE H&C systems generated within the individual buildings **TOPIC 4 - CHP** ■ Development of hybrid micro CHP/CCHP for residential and commercial buildings integrating RES (close to commercialisation) ■ Development of energy efficient micro CHP/CCHP technologies for single family houses, (prototype system tested) ■ Optimised system architectures for combination with new hybrid RE sources for tri-generation of electricity, heat and cold **TOPIC 5 – ENERGY SYSTEMS, EDUCATION, TRAINING AND CERTIFICATION** ■ Online platforms with comprehensive and up-to-date training material and tools, e-learning tools for students, etc. for RE H&C solutions/systems established ■ Certification system established for installers/controllers of any RE H&C solution/system for individual buildings
DISTRICTS	■ Cost reduction in project implementation ■ 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 **SET Plan Action 3.2:** ■ Planning, deployment and replication of 100 'Positive Energy Districts' (PED) by 2025 for sustainable urbanisation **SET Plan Action 4:** ■ Increase the efficiency of heat networks on the primary side (>10%) ■ Decrease return temperatures on the building side so that the efficiency of the connecting systems is increased (>10%) ■ Deploy efficient DHC networks (>10% reduction of heat losses compared to standard grids) for the efficient exploitation of locally available sources ■ Contribute to climate goals by enabling a high level of utilisation of local energy sources (>80%) ■ Increasing the short-term flexibility of DH and DC networks and enabling its efficient utilisation: Deliver sustainable DHC by increasing flexibility and reducing expensive and fossil fuel peak technologies (reduction to 0% use of oil and gas heat only boilers) ■ Increasing the long-term flexibility of heating and cooling systems: Integrate seasonal (>4 weeks), large-scale storage systems in DHC networks to increase counter-seasonal integration of seasonal surplus heat resources (>20% of seasonal demand covered) **SET Plan Action 5:** ■ Increase the share of renewable heat to 25% compared to 2015 ■ Increase the number of 4th generation DHC networks ■ Decrease the cost of DHC substations for residential buildings by 20% compared to 2015

HORIZONTAL SECTOR	MONITORING KPIS (TARGETS)
DISTRICTS	**SET Plan Action 6:** ■ Develop and demonstrate cost-effective excess heat recovery solutions by 2025 **TOPIC 1: EFFICIENCY GAIN AND TEMPERATURE REDUCTION** ■ Min. 5°C lower network temperatures (supply and/or return) in existing systems ■ Decreasing heat losses by min. 10% ■ Increasing the supply of current renewable or waste heat sources by 10% **TOPIC 2: ENERGY SYSTEM INTEGRATION** ■ Increase the share of “green” electricity by 20% ■ Reduce LCOH (levelised costs of heat) by 10% **TOPIC 3: DECARBONISATION – SCENARIO EVALUATIONS AND DECARBONISATION STRATEGIES** ■ 100% renewable or waste heat sources by 2050 at the latest, unless national or regional legislation gives more ambitious targets
CITIES	■ Cost reduction for maintenance operation and performance optimisation **Digitalisation:** ■ Energy monitoring data platforms on city level are available at low costs, which provide data on energy demand, renewable energy generation, energy efficiency and GHG-emissions of a city automatically on a monthly basis, compare the actual progress of the city’s energy transformation with the transformation roadmap goals and analyse the possible shortcomings, provide open APIs to enable new digital services and businesses by third parties, ensure data protection and data privacy, and avoid lock-in effects. **TOPIC 1 – TECHNOLOGIES FOR INTEGRATED SYSTEM SOLUTIONS:** ■ Technical solutions and standards for interfaces of different energy components in a city are available, which provide the non-discriminatory physical and data-technical connection and communication of modules of different manufacturers easily and securely and thus enable intelligent, coupled, decentralised control of the energy systems in the city with new business models and optimal and efficient operation of the energy system. **TOPIC 2 – TOOLS AND GUIDELINES FOR THE PLANNING:** ■ Planning tools for calculating the optimal design of a city’s climate-neutral energy system are available at low cost for use by local energy experts. To calculate, the tools automatically access freely available data sets on energy consumers and renewable energy potentials, enabling easy use and fast results. ■ 50% of cities in Europe have used the tool, thus calculating a target energy system to achieve a climate-neutral energy supply. **TOPIC 3 – TOOLS AND GUIDELINES FOR THE DEVELOPMENT OF TRANSFORMATION STRATEGIES AND ROADMAPS:** ■ Digital tools are available to develop and optimise roadmaps for the transformation of municipal energy systems by local experts. Users are supported in deciding which measures should be taken at what time in order to achieve the objective of a climate-neutral energy supply in an efficient and timely manner, what costs a measure has and what results will be achieved with it. ■ 50% of the cities in Europe have used the tool, thus calculating a roadmap for transforming their energy system to achieve a climate-neutral energy supply

HORIZONTAL SECTOR	MONITORING KPIS (TARGETS)
INDUSTRIES	**SET Plan Action 6:** ■ By 2025, develop and demonstrate (close to commercialisation) solutions enabling small and large industries to cost-effectively reduce their energy consumption by 5% by cost-effectively upgrading excess heat/cold for more valuable application elsewhere in the process ■ Develop hybrid plants for waste heat upgrade integrating renewable energy into industrial plants and processes ■ Develop advanced compact CHP plants of industry scale ■ RES based CHP systems providing flexible heat in a temperature range up to 400°C flexible power/heat ratio (close to commercialisation) ■ High temperature ORC plant developed (close to commercialisation) ■ High temperature supercritical CO_2 plants developed (close to commercialisation) ■ Improve reversible fuel cell technology in combination with energy vectors like H_2, NH_3 and CH_4 (prototype stage) ■ Processing technologies with exergy-optimised energy supply properties will be available(prototype stage), with radical impact on the RES implementation potential ■ 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 ■ 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 Nexus Energy – Industry – Water: RES for Industrial Water treatment and purification of process water streams (prototype stage) ■ High temperature heat storage up to 1000°C (prototype stage) ■ Developing a new type of future facility that is designed and operated as a combined RES heat, power and mineral extraction system from the outset ■ Dedicated industrial policies in line with the EC Energy System Integration Strategy to speed-up the deployment of green technologies (e.g. Heat Pump Plan for Europe)

ANNEX II

Data used for graphs in "RHC in the future EU energy system"

Data extracted on 20/06/2020 21:29:37 from [ESTAT]

Dataset:	**Final energy consumption by product [TEN00123]**
Last updated:	06/06/2020 23:00
Time frequency	Annual
Energy balance	Final consumption - energy use
Unit of measure	Thousand tonnes of oil equivalent (TOE)

	2007	2010	2015	2018	2030		2040 50% RHC		2040 100% RHC	
Non-RES heat	425 588,5	424 395,5	364 727,4	368 225,2	257 116,4		155 847,8		0,0	
RES heating & cooling	73 954,8	87 084,2	93 339,0	98 658,9	124 361,9	32,6%	155 847,8	50%	311 695,6	100%
RES electricity	45 094,6	54 279,4	73 262,3	81 060,9	110 721,1	55,5%	116 237,8	75%	116 237,8	75%
Non-RES electricity	210 234,0	200 413,8	173 806,8	170 670,7	88 776,4		38 745,9		38 745,9	
RES transport	9 309,0	14 519,8	17 547,2	22 473,0	43 614,8	17,2%	78 003,1	33%	78 003,1	33%
Fossil transport	267 567,5	251 262,2	242 315,8	249 554,5	209 959,6		158 369,9		158 369,9	
Graph	1 031 748,336	1 031 954,866	964 998,431	990 643,343	834550,273		703052,379		703052,379	
* RES non-electric HC + Derived heat + Heat pumps					EUCO3232.5 Scenario		RHC 2040 Vision			

65, 66

Non-RES heat	425 588,5	424 395,5	364 727,4	368 225,2		257 116,4		155 847,8		0,0	
E-gases, hydrogen	0,0	0,0	0,0	0,0		0,0		0,0		15 584,8	
Heat pumps (amb.air & geothermal)	3 516,3	5 464,5	9 248,6	11 351,5		14 403,8		18 081,5		72 377,2	
Solar Thermal heat	1 086,0	1 370,0	2 055,0	2 467,0		3 130,3		3 929,6		31 169,6	
Geothermal heat (mainly deep geothermal)			492,1	590,8		749,7		941,1		24 935,6	
Biomass heat	67 900,0	65 975,0	64 875,0	67 877,0		86 128,4		108 119,2		110 000,0	
RES fraction of derived heat	7 325,0	10 113,7	13 208,2	15 002,1		19 036,0		23 896,4		57 628,4	
					2,4%	2,3%		9,6%			
Non renewable	425 588,5										
Renewable	79 827,3	82 923,2	89 879,0	97 288,4	0,0	123 448,2	1,0241	155 847,8	1,023579547	311 695,6	1,097045395

67

65 The data for the 2040 (50% BAU scenario) are elaborated projecting exactly the same foreseen growth or decrease rates from the 20-30 period into the 30-40 period. The figures for the 2040 100% RHC scenario are elaborated taking into account the Heating potential by renewable energy source in EU shares described in the Common Vision for the Renewable Heating & Cooling sector in Europe and other boundary conditions as shown above.

66 European Technology Platform on Renewable Heating and Cooling, 2011

67 EUROSTAT, 2020. Simplified energy balances; European Commission, 2019. Appendix: EUCO3232.5 - Summary energy balances, emissions and indicators; SHARES tool, 2020. SHARES summary results 2018

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