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Support to key activities of the European Technology Platform on Renewable Heating and Cooling

PP-2041/2014

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Research and Innovation

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(as a subcontractor)

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GLOSSARY

ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
CHP	Combined Heat and Power
CSP	Concentrated Solar Power
DHC	District Heating and Cooling
DHW	Domestic Hot Water
DME	Dimethyl Ether
EFB	Empty Fruit Bunches
EGS	Enhanced Geothermal Systems
ESCO	Energy Services Company
FTE	Full-Time Equivalent
GWP	Global Warming Potential
H&C	Heating and Cooling
Hellström efficiency	The Hellström efficiency indicates the overall impact of borehole thermal resistance (Rb) for a defined shallow geothermal system
LCOE	Levelised Cost of Electricity
LCOH	Levelised Cost of Heating
MFH	Multi-Family Home
MOFs	Metal Organic Frameworks
MWD	Multi-Well Drilling
nZEB	Nearly Zero-Energy Building
O&M	Operation and Maintenance
ORC	Organic Rankine Cycle
PCM	Phase-Change Material
RDF	Refuse-Derived Fuel
RHC-ETIP	European Technology and Innovation Platform on Renewable Heating and Cooling
SAH	Solar Active House
SCOHYS	Solar Compact Hybrid Systems

SCOP	Seasonal Coefficient of Performance: measures annual energy consumption and efficiency in typical day-to-day use
SCOPcooling	Seasonal Coefficient of Performance for Cooling
SDH	Solar District Heating
SFH	Single-Family Home
SHIP	Solar Heat Industrial Process
TCM	Thermo-Chemical Material
TES	Thermal Energy Storage
TRT	Thermal Response Test
UTES	Underground Thermal Energy Storage
VOC	Volatile Organic Compounds

1 REVIEW OF POLICY CONTEXT

1.1 Strategic frameworks

The Energy Union provides a comprehensive framework for EU energy policy. The Communication ***A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy*** (COM(2015) 80 final) reviewed the Energy Union strategy and set out a clear vision for the future of the EU energy market. The strategy is based on fifteen action points, which include diversifying supply in terms of energy sources, increasing resilience to supply disruption, creating appropriate EU-wide infrastructure, building a truly integrated common energy market, enhancing integration of renewable energy sources, boosting energy efficiency, investing in research and innovation, and practising climate diplomacy. The Energy Union is made up of five closely related, mutually reinforcing dimensions: i) security, solidarity and trust; ii) a fully integrated internal energy market; iii) energy efficiency; iv) decarbonisation of the economy; and v) ***research, innovation and competitiveness.*** This latter point underscores the importance of supporting breakthroughs in low-carbon and clean energy technologies by prioritising research and innovation with a view to driving the energy transition and improving competitiveness.

The decarbonisation of the heating and cooling (H&C) sector plays a strategic role in the transition towards a climate-neutral European economy envisioned in another Commission Communication, ***A clean planet for all*** (COM(2018) 773 final). The in-depth analysis supporting this Communication shows that ***about 50% of the energy consumed in the EU is currently used for heating and cooling in buildings and industrial processes***. While renewables have made an important contribution in this area, there is still a long way to go. Although the share of renewables in the sector almost doubled between 2004 and 2016, it still stands at slightly less than 20% of total energy consumption for H&C. Solid biomasses continue to account for the lion's share of renewable H&C (80%), but the last decade has seen rapid growth in other renewable solutions, such as heat pumps (using both ambient and geothermal energy), biogas, solar thermal, renewable waste and geothermal.

To support the decarbonisation of the H&C sector, in February 2016 the Commission unveiled the first ***EU strategy on heating and cooling*** (COM(2016) 51 final) as part of the Sustainable Energy Security Package. While the strategy does not include any new legislative proposals, it sets out a vision for H&C consumption in buildings and industry, aimed at maximising the use of energy released from excess heat and cold in industry processes and district heating. The strategy is based on three broad long-term goals:

I. ***Decarbonising buildings*** through high energy efficiency and renewable energy standards for new and renovated buildings, automation of heating and cooling, and increased use of renewable electricity and district heating and cooling systems. The main barriers to the renovation of buildings differ depending on the building type. Split incentives, financing constraints and a lack of awareness of the benefits are the main obstacles for privately owned buildings, while the primary challenge for rented buildings is a lack of incentive to invest. Shortage of funds prevents the renovation of publicly owned buildings, and a lack of expertise is the biggest obstacle for service buildings.

II. ***Decarbonising industry*** by implementing energy efficiency measures and making greater use of renewable energy sources (except for high-temperature industrial processes). The Communication recognises that renewable H&C applications in industry still fall far short of their current potential, that SMEs rarely view energy efficiency as a priority and that financial institutions are reluctant to provide ad-hoc financial products for projects of this kind as they perceive them as too risky.

III. ***Reusing excess heat and cold from industrial processes***, promoting combined heat and power, and channelling the resulting heat and cold through district heating and cooling systems integrated with thermal and cold storage systems to offset peaks in demand. Although the technology in this field is already mature, lack of awareness and information, inadequate business models and incentives, lack of heating networks and lack of cooperation between stakeholders are highlighted as the main barriers to its uptake.

The strategy does not include any new binding targets, nor does it announce any new legislative proposals. However, it does provide a framework for reviewing existing energy legislation in order to address the problems outlined above and align it with the climate and energy targets for 2030.

With regard to research and innovation, the Communication highlights the role of Horizon 2020 and the European Structural and Investment Funds (ESIF) in promoting research, innovation and demonstration actions to achieve the goals of the strategy on heating and cooling. Moreover, under the Strategic Energy Technology Plan, the Commission commits to integrating the results of round tables into R&D initiatives, promoting use of renewable and excess heat based on combined heat and power, examining new approaches to low-temperature heating in industry, and fostering the development of advanced materials and industrialised construction processes.

1.2 Winter Package

The ***recast Renewable Energy Directive*** (Directive (EU) 2018/2001), together with the Energy Efficiency Directive and the Energy Performance of Buildings Directive, specifies that renewables should cover 32% of total energy consumption by 2030. Some 40% of this is expected to come from the H&C sector. The Directive recognises that H&C plays a key role in accelerating the decarbonisation of the energy system, although progress in the sector has been relatively slow to date due to the lack of internalisation of external costs and the fragmentation of the heating and cooling markets. In order to reach the target, the Directive allows Member States to set up support schemes for renewable energy and to exempt small-scale installations and demonstration projects from tendering procedures. Moreover, Member States (MSs) have an obligation to put in place measures geared towards increasing the share of renewable energy in the H&C sector by an indicative 1.3 percentage points per year until 2030. With regard to DHC, Art. 24 requires MSs to provide final consumers with information on the energy performance and the share of renewable energy in their DHC systems in an easily accessible manner. Finally, MSs are invited to increase the share of renewables in DHC networks.

The promotion of energy efficiency is one of the priorities on the European Union’s climate and energy agenda. The Union has drawn up several legislative documents with a view to achieving its goal, namely the ***Energy Efficiency Directive***, the ***Energy Performance of Buildings Directive***, the ***Ecodesign Directive*** and the ***Energy Labelling Regulation***. EU legislation on energy efficiency can affect the deployment of renewable heating and cooling (RHC) technologies in several ways, such as by setting minimum requirements for renewable energy in buildings. Eco-design and energy labelling play a role in determining the efficiency level of the heating appliances on the market and the efficiency level perceived by consumers. It is also crucial that the energy savings achieved by switching fuels can be counted towards the EU’s energy efficiency target. The Energy Efficiency Directive was reviewed as part of the *Clean energy for all Europeans* package. The text sets an EU-wide indicative energy efficiency target of 32.5% for 2030. Instead of national targets, a governance framework is set by a parallel regulation to define how efforts should be spread out. However, the indicative nature of the target may pose a real threat to its delivery. To achieve it, energy sales will have to decrease by 0.8% annually after 2020, with some flexibility (for instance, in some cases, renewable energy produced on-site will be able to substitute for part of the energy efficiency improvement expected to deliver the savings). However, the text of the Energy Efficiency Directive may prove ineffective in preventing the lock-in of fossil fuel infrastructure: it does not prevent subsidies from being allocated to fossil fuel equipment in the name of marginal energy efficiency improvements. Overall, the ambitious level of the energy efficiency target is quite a welcome signal for the RHC sector, especially as it may encourage the roll-out of efficient district heating and cooling[1] or the adoption of individual RHC systems.

1.3 Support for research and innovation

As set out in the ***Clean energy for all Europeans*** package, innovation is one of the keys to fostering the development of renewable H&C. While the core investments need to come from the private sector, the EU also plays a decisive role. The Communication ***Accelerating Clean Energy Innovation*** (COM(2016) 763 final) highlights three main policy levers that the EU can apply to boost private investments in clean energy innovation:

- Setting the political tone and creating the right business environment through targeted signals, policies, standards and regulations;

- Deploying targeted financial instruments to lower the risk of private investments in untested but promising clean energy technologies or business models;

- Focusing its research and innovation funding, in particular through Horizon 2020, to push the frontiers of science and knowledge.

The policy and regulatory lever, which has generally been discussed so far, includes binding direct targets for MSs plus a range of indirect measures, such as the promotion of energy support schemes and exemption from state aid rules and public procurement.

As regards financial support for private investments, the EU has several different funding and financial instruments to support low-carbon innovation. These cover the whole innovation value chain, from research and development to roll-out of mature technologies.

Horizon 2020 is currently the main programme providing funds for innovation in the H&C sector. The *Secure, Clean and Efficient Energy* work programme addresses the energy sector directly. Since 2014, Horizon 2020 has supported projects aiming to develop new technologies for renewable H&C and DHC and the recovery and re-use of excess heat and cold, remove market barriers to the uptake of efficient H&C solutions, and create models for H&C mapping and planning. Moreover, through Horizon 2020, the Commission provides support to the European Technology and Innovation Platform on Renewable Heating and Cooling (RHC-ETIP).

EU funding must be duly complemented by national funding, and national research and innovation programmes should be coordinated in order to avoid duplication and build on economies of scale. The **SET Plan (Strategic Energy Technology Plan)**, adopted in November 2007, introduced a new model of focused cooperation based on joint strategic planning, more effective implementation, increased resources and greater international cooperation. A steering group chaired by the Commission with government representatives from the Member States oversees the implementation of the SET Plan, supported by an information system (SETIS) managed by the Joint Research Centre (JRC). In September 2015, the integrated SET Plan translated the Energy Union priorities into ten key actions. The SET Plan promotes research and innovation efforts across Europe by supporting the most impactful technologies in the EU's transition to a low-carbon energy system. It promotes cooperation between EU countries, companies, research institutions, and the EU itself, making it a useful tool to support the decarbonisation of the H&C sector and the further development of renewable H&C technologies. The members of RHC-ETIP are involved in several SET Plan Implementation Working Groups with a view to providing constructive support to the process from the renewable heating and cooling sector.

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[1] 'Efficient district heating and cooling' means a district heating or cooling system using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat, or 50% a combination of renewable energy and waste/cogenerated heat.

2 OVERVIEW OF METHODOLOGY

Within this supportive policy framework for renewable energy technologies, the European Technology and Innovation Platform on Renewable Heating and Cooling (RHC-ETIP) was officially launched in 2010 and currently brings together more than 700 stakeholders. Its members come from industry, research and public-sector backgrounds and it represents stakeholders from the biomass, geothermal, solar thermal, heat pump, district heating and cooling, thermal storage and hybrid system sectors throughout Europe. As such, it is a unique ETIP covering all existing renewable heating and cooling technologies.

The RHC-ETIP's mission is to provide a framework for stakeholders to define and implement an innovation strategy aimed at increasing the use of renewable energy sources for heating and cooling, and to foster the growth and market uptake of the relevant technologies.

Following the publication of its Common Implementation Roadmap in 2014, the secretariat of the RHC-ETIP (composed of EUREC, AEBIOM/Bioenergy Europe, EGEC, EHPA and SolarHeatEurope/ESTIF) was awarded a tender on support to key activities of the European Technology Platform on Renewable Heating and Cooling. The tender focused on three main tasks:

- ***Monitoring of the implementation of the five roadmaps*** published by the RHC-ETIP in 2014, with a view to determining the status of technological advances in the RHC sector both at EU level and with respect to the EU's main competitors at international level (Work Package 1);

- ***Analysis of the heating and cooling industry,*** concentrating on the potential of RHC technologies versus incumbent technologies (fossil fuels) (Work Package 2);

- ***Analysis of heating and cooling consumers*** with a view to identifying factors that could encourage the uptake of renewable heating and cooling technologies, while proposing recommendations to limit the effect of barriers on the adoption of renewable energy technologies in the heating and cooling market (Work Package 3).

The methodology used to perform the tasks depends on the specific Work Package. In general, the consortium used the following instruments and tools:

- ***Literature review*** (e.g. relevant ongoing projects, scientific publications, market reports and statistics, presentations and information collection during relevant events);

- ***Data collection***, which took the form of interviews and questionnaires directed at experts to collect additional data on ongoing projects and their results, the market status and consumers' acceptance of RHC technologies;

- ***Validation workshops*** with selected experts to gather feedback about the draft documents before finalising them. The main experts involved in the validation work were the members of the RHC-ETIP.

The sections below describe the methodology implemented for each Work Package in order to collect relevant results for analysis.

2.1 Monitoring of the implementation of the RHC-ETIP roadmaps

2.1.1 Introduction

The first task for the tender focused on monitoring the implementation status of the five technology roadmaps published by the European Technology Platform in 2014. The monitoring analysis was conducted in three stages:

- Stage 1 concentrated on EU co-funded projects with the participation from the following countries: EU-28, Norway, Switzerland, Israel, Turkey and Iceland (completed in November 2016).

- Stage 2 expanded the analysis conducted in Stage 1 to nationally and privately funded projects in the EU-28, Norway, Switzerland, Israel, Turkey and Iceland (completed in March 2018).

- Stage 3 further enlarged the scope by incorporating a qualitative analysis of the status of relevant KPIs in key third countries: Australia, Canada, China, Japan, India, Mexico, New Zealand, South Korea and the United States (completed in January 2019).

An excerpt from the tables used to report the data collected and information analysed for each technology is provided in annex I: MONITORING OF THE FIVE RHC ROADMAPS – EXAMPLES OF REPORTING TABLES).

2.1.2 First report on the implementation of the five RHC roadmaps

The template used to report on the implementation of the five roadmaps was the same for all technologies. The structure and content of the reporting template were agreed with the European Commission:

R&I priority		
Specific KPI in 2013	**Current value of the KPI**	**Statements and figures supporting the value provided**

Table 1: General table on the Key Performance Indicators used to report on the different RHC technologies and respective roadmaps

The table is divided into three columns:

- The first column presents the Key Performance Indicators (KPIs) as reported in the Common Implementation Roadmap, which was published in June 2014 and is available on the RHC-ETIP website (http://www.rhc-platform.org/content/uploads/2019/04/RHC_Common_Roadmap.pdf).

- The second column reports the value of the KPIs on the date of analysis and indicates whether the KPI has been achieved, is on track to be achieved, or needs to be revised.

- The third column substantiates the information presented in the second column by detailing relevant literature references and citing examples of projects in which the updated figures were made available.

A common template for collecting the relevant information was circulated to the experts involved in the work of the Platform's Technology Panels:

- Research area

- Project title
- Link to website (where relevant information is available)
- Type of research (basic, applied, development, demonstration)
- Technology Readiness Level (TRL)
- Description of RD&I activity performed
- Country(ies) of implementation
- Total budget
- Results (and their impact on the relevant KPIs)

The associations responsible for each specific technology organised the work independently, based on their experts' input. A common validation workshop was then organised on 28 June 2016 as part of a general RHC-ETIP event on ***the successful contribution of the RHC sector to the Energy Union***. Meetings of the various RHC-ETIP Technology Panels were organised in the afternoon to validate the draft analysis of the monitoring of the implementation of the RHC roadmap for each technology.

More than one hundred experts participated in this first validation workshop.

2.1.3 Second report on the implementation status of the five roadmaps

The first report focused on developing and testing a common methodology to monitor the implementation of the five RHC roadmaps. The same methodology was adopted when preparing the second report. Here, the consortium concentrated on content development and analysis of the Key Performance Indicators (KPIs). More projects were collected and analysed, with the scope being widened to include nationally and privately funded projects as well as projects jointly funded by the EU.

A common validation workshop for each Technology Panel was held on 20 June 2017 after the general event on ***innovation in the RHC sector***. It was followed, in turn, by an event featuring several presentations on innovative projects in the RHC sector, which was organised on 21 June 2017 as part of Sustainable Energy Week (EUSEW 2017). This last event was organised to showcase some of the most innovative projects, for each technology, that had responded to the questionnaire prepared by the tender consortium. This initiative was implemented with a view to attracting additional projects – and not only projects with EU funding – for analysis by the consortium.

The second report also highlights, in green, those priorities that have already been achieved.

Over fifty experts from EU and EEA countries provided direct feedback and input, while more than one hundred experts participated in the second validation workshop.

2.1.4 Third report on the implementation status of the five roadmaps

The third report built on the work previously conducted by adding relevant information about the priority areas for research and innovation in the following non-European countries: Australia, Canada, China, Japan, India, Mexico, New Zealand, South Korea and the United States. The reporting table was adapted to include additional analysis for non-European countries (fourth column), while the first three columns remained the same as in the two previous reports:

R&I priority:			
Specific KPI	**Value of the KPI at the date of submission of deliverable D1.3**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**

Table 2: General table on the Key Performance Indicators used to report on the different RHC technologies and respective roadmaps in the third report

For each section, the consortium partner responsible collected information on relevant ongoing projects in non-European countries with a view to highlighting those research areas where non-European countries could have a competitive advantage over EU countries.

Moreover, on the advice of the European Commission, the KPIs in the geothermal section were updated to reflect the recent publication of the *SET Plan – Declaration of Intent on Strategic Targets in the context of an Initiative for Global Leadership in Deep Geothermal Energy,* endorsed at the SET Plan Steering Group meeting of 14 September 2016.

Around sixty experts were interviewed to conduct the analysis at international level.

Around one hundred experts participated in the validation exercise, which was organised independently by the association responsible for each technology section.

2.2 Analysis of the heating and cooling industry

The aim of this analysis was threefold:

- To provide ***qualitative information on the structure of the heating and cooling industry*** in terms of the technologies marketed, the energy sources used and the types of companies involved;

- To deliver ***quantitative data on installations and sales*** of systems using the different technologies available on the market, and on ***turnover and employment*** in that market;

- To analyse the factors triggering or hindering each technology's market growth and gauge the intensity of competition experienced by companies on the international market.

With respect to the first item, the methodology involved taking an initial snapshot of the most relevant technologies used to deliver thermal energy in the shape of useful Domestic Hot Water (DHW), space heating and cooling to buildings, and heat suitable for processes in industry. ***This snapshot provided a highly schematic overview of the solutions available on the market***, and mainly served to set the boundaries of the investigation. The figure below is an example of a snapshot diagram: ***the yellow columns list the technologies, energy sources and applications.*** The diagram does not aim to cover the entire industry, but rather to flag the most representative applications in the heating and cooling sector and the sources of the highest turnover and employment for each technology.

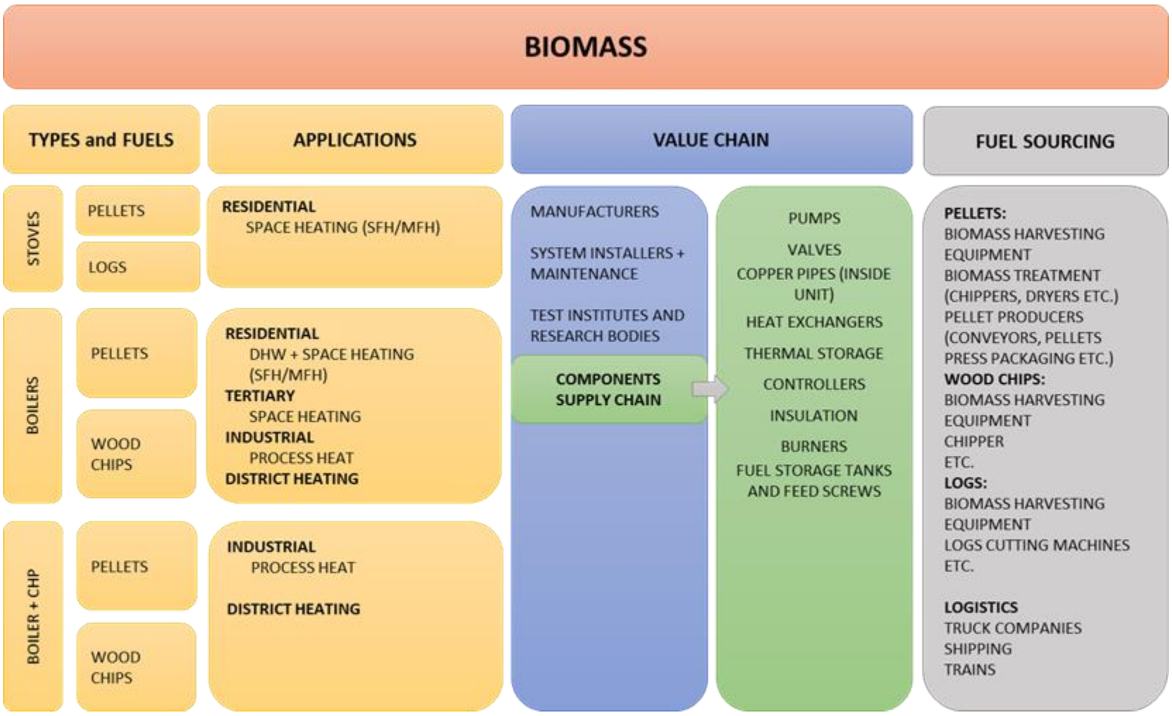

Figure 1: Example of an industry diagram – biomass-based industry

Following analysis of the solutions for each industrial sector, the report describes the types of businesses involved, starting from the main value chain. This generally includes manufacturers of the products available to the final consumer, system planners, installers, test institutes and research bodies (**blue column** in Figure 1).

Where applicable (i.e. for industries based on biomass and fossil fuels), fuel sourcing is also analysed (**grey column** in Figure 1).

The structure and composition of each industrial sector are described, with a focus on the size and location of the companies involved and on market trends.

Finally, the main components used to manufacture the final products are described to structure the analysis of the supply chain behind the main stakeholders in the heating and cooling industry (**green column** in Figure 1). This is useful for identifying and locating the indirect turnover and jobs generated by the heating and cooling industry. An insight into the heating and cooling industry was obtained by identifying the main sources of turnover and employment and their respective shares for each of the sectors assessed. The information required for this purpose was gathered by combining a bottom-up approach involving direct interviews with relevant stakeholders and a top-down method based on analysing openly available literature and company data.

The analysis concludes with a market study for each of the industrial sectors. It sets out to highlight the endogenous and exogenous factors influencing the RHC industry (SWOT analysis) with a view to identifying the aspects affecting the success of each sector and the obstacles hindering its development. A Porter's Five Forces analysis was also executed in a bid to explain why different industrial sectors are able to sustain different levels of profitability[2].

The data on installations and sales, turnover and employment were derived from a literature review (primarily drawing from the annual statistical reports produced by the associations involved in the tender, plus other statistics from Eurostat), rounded out by the responses to questionnaires sent to selected industrial experts. The SWOT analysis was conducted by the industry associations, which also provided substantial input for the Porter's Five Forces analysis.

The industry analysis enabled the collation of pertinent, comparable and quantitative information on the relevance of the individual sectors of the heating and cooling market and served as the basis for several recommendations on the main drivers for the development of the renewable heating and cooling industry.

[2] Porter identified five forces that help to measure the competitive intensity, attractiveness and profitability of an industry or market

2.3 Analysis of heating and cooling consumers[3]

This analysis aimed to complement and build on information provided by recent projects like FROnT (http://www.front-rhc.eu/), Entranze (http://www.entranze.eu/), RESCUE (http://www.rescue-project.eu/) and STRATEGO (http://stratego-project.eu/) about the consumer dimension of RHC technologies and business models.

The unique focus of this Work Package was to enhance qualitative understanding of the barriers and opportunities for RHC technologies, addressing multiple levels of analysis: individual decision-making (consumer level), social influences (intermediary level) and other contextual factors (conditional level). The current literature provides only limited insights into these aspects, since RHC technologies are not yet recognised as 'mainstream' solutions and the end-user perspective only tends to establish itself fully once a technology is widely implemented. Because of this lack of literature data, Work Package 3 supplemented the information available from literature and relevant projects with additional qualitative research. It drew upon input from experts on the different consumer segments in various European countries, presenting what they believe will be the main barriers/enablers for the adoption of RHC technologies.

It is important to recognise that barriers and opportunities in the field of heating and cooling exist at three levels:

- ***Consumer level***: the attitudes and behaviours of an individual consumer, shaped by structural requirements and the players around him/her.
- ***Intermediary level***: the influence and activity spectrum of the actors within the individual consumer's environment.
- ***Conditional level***: the constraints and opportunities for compliance within technological, political, economic and legal structures.

[3] Consumers are defined as those individuals or organisations who have the capability and responsibility to make an investment decision on the installation of a heating or cooling system.

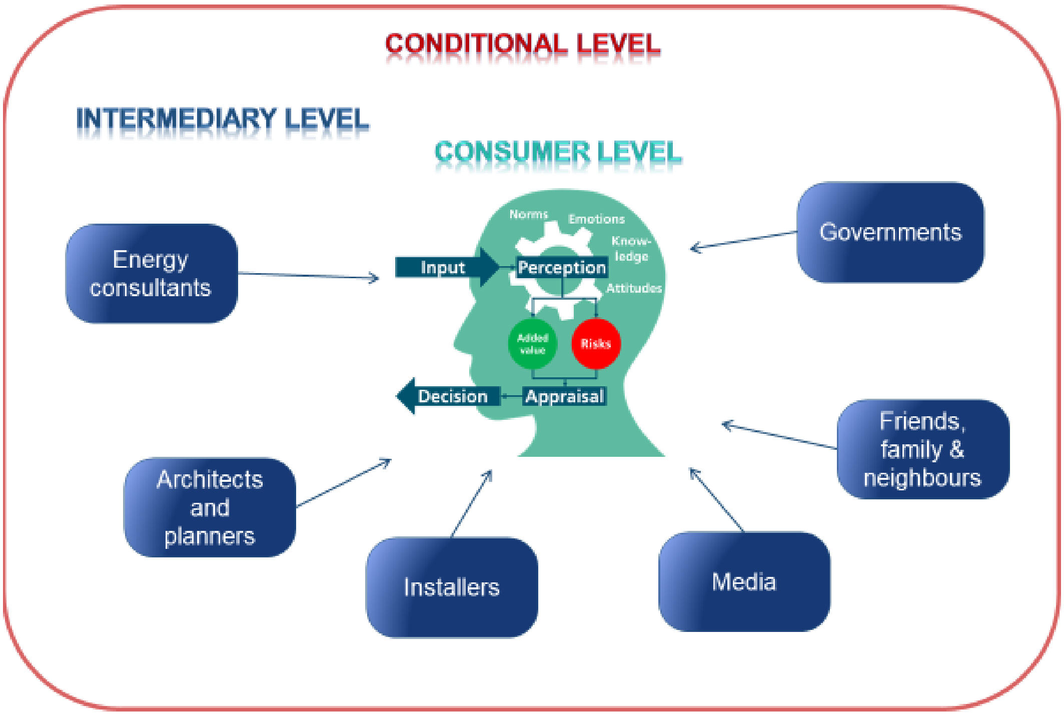

Figure 2: Analytical framework for consumer decisions

The analysis draws on three main sources: 1) findings published in existing literature; 2) experts' opinions; and 3) validation workshops gathering views from European stakeholders.

In the initial stages of the analysis, a scoping exercise was carried out with one key representative for each RHC technology in the aim of gaining an initial understanding of the issues currently influencing RHC and user acceptance in Europe. This exercise guided the design of the network of experts and aided preparations for the literature review. Five main activities were carried out:

- Activity 1 – Establishment of an expert network on consumer barriers and enablers with sufficiently broad coverage of European countries and RHC technologies
- Activity 2 – Review of existing studies to gather existing knowledge and insights
- Activity 3 – Development of the final analytical structure to serve as basis for the expert interviews and data analysis
- Activity 4 – Collection of stakeholder data through phone interviews with thirty-four experts across Europe
- Activity 5 – Recommendations and validation workshops; two workshops were organised to validate our main findings and gather views on policy recommendations for use in the last part of this study

Deliverable 3.2 (*Final report on the analysis of heating and cooling consumers and recommendations on new business models and the regulatory framework*) provides the final analytical structure, describes the survey methodology and presents the results of the expert interviews. It also provides an overview of the feedback received at the two European validation workshops and summarises the main conclusions of the analysis. The final section integrates findings on consumer aspects into a list of policy recommendations for stimulating the roll-out of RHC technologies in Europe.

An interview guide was prepared for the scoping exercise, seeking to clarify the following for each RHC technology group:

- Who are the main consumers and other influential stakeholders (i.e. 'gatekeepers'))?
- Which are the main drivers and barriers for consumer acceptance?
- Which countries have particularly interesting dynamics, and how can representative country groups be formed?
- Which strategies can be implemented to spur adoption of the technology?

At the start of the analysis, interviews were carried out with one key representative for each technology to gain an overview of all relevant RHC technologies. All but one of the interviewees were from the consortium: Bioenergy Europe/AEBIOM for biomass, SolarHeatEurope/ESTIF for solar thermal, EGEC for geothermal, EHPA for heat pumps and Euroheat & Power (not in the consortium) for district heating and cooling. EUREC also contributed, providing an overview across RHC technologies.

The interview guide formed the basis for a rather open telephone conversation ('semi-structured interview') lasting roughly one to one and a half hours and covering all the areas outlined above. The interview guide was circulated to interviewees ahead of the discussion to give them time to prepare. The conversations were recorded, then summarised by the interviewer and approved by each interviewee (the individual interview reports are on file with the authors).

When building the final network of thirty-four experts, the main challenge lay in ensuring adequate provision of expertise on different dimensions, such as different stakeholder segments (e.g. consumers and intermediaries), RHC technology groups, geographic contexts, and knowledge domains (e.g. practical versus academic). With regard to geographic contexts, representatives from each of the main country groups (Northern/Baltic, Southern, Western, Eastern) were to be included as a minimum requirement, and special care was to be taken to include experts from eastern Europe, as this region appeared to be underrepresented in the existing literature and in relevant ongoing projects. Since the number of experts had to be limited, there was a clear trade-off between obtaining in-depth expertise on specific dimensions and achieving adequate coverage across all relevant dimensions.

In the interest of balance, the decision was made to focus on establishing a core group of 30-40 experts with a clear national view, spread across three to four focus countries per country group and with approximately three experts per focus country. Each individual expert would preferably cover several RHC technologies and/or a number of stakeholder segments, thus allowing full coverage of RHC technologies for each country group (see Table 3).

Countries		Criteria for selecting the country	Technologies of interview partners					Sum
			Solar thermal	Biomass	Geo-thermal	HPs	Cross-cutting (DHC)	
Northern/ Baltic	Estonia	High per capita shares for heat pumps and solid biomass		1		1	1	3
	Finland	High per capita shares for heat pumps, best performance solid biomass		1		1		2
	Lithuania	High share of ground-source heat pumps (cf. note below)						0
	Sweden	High per capita shares for heat pumps and solid biomass		1	1	2		4
Western	Austria	High per capita shares for solar and solid biomass	1	1				2
	France	Good performance for heat pumps, big market	2					2
	Germany	Good performance for solar, big market	2	1	1	1	1	6
	UK	Weak per capita performance, but big market		1	1			2
Eastern	Czech Republic	Best per capita performance in Eastern/central Europe				1		1
	Hungary	High share of ground-source heat pumps			2			2
	Poland	Weak per capita performance, but big market			1	1		2
Southern	Greece	Good performance for solar	1					1
	Italy	Best performance of heat pumps, big market	1		1			2
	Spain	Average per capita performance, but big market	1	1		1		3
	Turkey	Important market for heat pumps, geothermal and solar thermal	1			1		2
		Totals	**9**	**7**	**7**	**9**	**2**	**34**

Table 3: Network of experts for consumer analysis

The interviews were conducted by phone between August 2017 and March 2018, taking 25 to 50 minutes each. They followed a guideline structured around open-ended questions, which was developed based on literature review and derived from the analytical framework. All the interviews were recorded. The interview questions are summarised below.

Summary of the interview questions

1. About yourself
   - Your role in your company/organisation and your engagement in a specific renewable heating and cooling solution (= [technology X] in the following questions)
   - Details of your expertise on consumer groups
2. Example of a consumer's decision process
   - A real case of a consumer who went through the decision process for renewable heating and cooling technologies
   - Conditions and situations, decision process and decision factors
3. Market situation (your PERCEPTION, no need to provide precise data)
   - Adoption rate of [technology X] in your country
   - Trends in the market for [technology X] in recent years
   - Household type which tends to adopt [technology X] today
4. Factors expected to influence consumers' decisions

4.1. Knowledge agents
   - Places or agencies from which consumers get information and advice
   - Source of information and recommendations influencing consumers' thinking
   - Role of middlemen such as installers, and other implementers
   - Influential information in different situations, such as the sudden breakdown of the current system, refurbishment for a foreseeable need, and construction of a new house

4.2. Funding and subsidies
   - Funding, subsidies and other programmes promoting [technology X]
   - Existence of supporting governmental policies

4.3. Specific marketing/promotion
   - Any efforts to raise awareness about [technology X], such as media campaigns, dedicated websites and incentives

4.4. Perceived risks and added value
   - Consumers' perception of [technology X], whether positive or negative
   - Perceived benefits of [technology X] solutions, which would drive consumers to implement [technology X]
   - Perceived risks of [technology X] solutions, which would deter consumers from adopting [technology X]

5. Conclusion
   - The key factors currently driving positive investment decisions for [technology X]
   - Any suggestions on encouraging consumers to adopt/ invest in [technology X]
   - Any other, unaddressed issues relating to the consumer dimension

Figure 3: Summary of interview questions

Two validation workshops were organised to validate the results of the analysis:

- One in Brussels on 24th May 2018, involving experts from the RHC-ETIP and associations located in Brussels.

- One in Warsaw on 21st June 2018, involving central and eastern European experts with a focus on the Polish market.

2.4 Final event

The results of the tender were presented at an event held in Brussels on 19 February 2019 and attended by around forty representatives of the RHC-ETIP, the European Commission and other stakeholders interested in the RHC sector.

The presentations are available online: here.

The event participants were given the draft Final Study Report in advance so that they could provide comments, and their input is included in this final version.

3. OVERVIEW OF COLLECTED DATA

3.1 Projects analysed for the monitoring of the implementation of the five RHC roadmaps

The results obtained from interviews with experts and/or information-gathering from literature vary from one technology to another, according to the experts' degree of involvement and the support received from them. The table below presents the number of relevant monitored projects both within and outside the EU.

Sector	**Number of relevant projects analysed in the EU[4]**	**Number of relevant projects analysed outside the EU**
Biomass	44	20
Geothermal	36	31
Solar thermal	43	21
District heating and cooling	41	27
Heat pumps	20	29
Thermal energy storage	15	25
Hybrid systems	11	9

Table 4: Summary table of monitored projects

[4] A greater number of projects, both within and outside the EU, was analysed for the different sectors. However, not all of the projects analysed were relevant for the report.

3.2 Analysis of the heating and cooling industry

The following quantitative information was collected and reported for each industrial sector (solar thermal, geothermal, heat pumps, biomass, district heating and cooling, fossil fuels):

- Stock of units and/or systems installed that use the technologies included in the analysis. The assessment considers not only of the number of devices (i.e. number of units, square meters of solar thermal collectors, etc.), but also the thermal capacity and the thermal energy demand covered. Wherever possible, the analysis was deepened to examine individual countries and applications.

- Sales of units and/or systems.

- Turnover and employment generated by each industry segment.

The collected data was retrieved in such a way as to allow comparison of the different sectors.

The study further examines the overall value chain, including:

- Supply chain of raw materials and components;

- Manufacturing industry for final products (i.e. solar collectors, heat pumps, etc.);

- Fuel sourcing and heat sales, in the case of the biomass and fossil fuel industries.

In addition to the quantitative data mentioned above, qualitative information was gathered on the composition of supply chains and overall value chains. Finally, a SWOT (Strengths – Weaknesses – Opportunities – Threats) analysis and a simplified Porter's Five Forces analysis looked into the factors influencing the markets for the different technologies and served as input for the final recommendations for both industry and decision makers with regard to the measures to be implemented to promote and stimulate the RHC market.

3.3 Analysis of heating and cooling consumers

The literature review covered the following projects:

- ***FROnT***, which analyses existing support schemes and end-user decision factors for renewable heating and cooling in different sectors (residential, non-residential, industry);
- ***ENTRANZE***, which addresses the transition to nearly-zero-energy (residential) buildings;
- ***RESCUE***, which focuses on (tertiary) district cooling;
- ***STRATEGO***, which aims to support national and local authorities in developing enhanced heating & cooling plans.

Several sources were used to develop the policy recommendations. They draw substantially from FROnT project deliverables dealing specifically with policy findings and from a recent International Energy Agency report on renewable heating and cooling policies. Various other sources were included to back up and illustrate specific policy recommendations and best practices, and the consistency of the interview results with the FROnT project's findings on consumer-level decision factors was cross-checked.

The core data for the analysis were provided by thirty-four consumer expert interviews covering multiple RHC technologies and European countries, as presented in Table 3. The two validation workshops in Brussels and Warsaw were attended by, respectively, twenty-one experts from the RHC-ETIP and Brussels-based associations and nineteen central and eastern European consumer experts with a focus on the Polish market.

4 DATA ANALYSIS AND MAIN FINDINGS

4.1 Monitoring of the implementation of the five RHC roadmaps

The five technology roadmaps do not all have the same structure, as different Key Performance Indicators (KPIs) were agreed for each technology back in 2014. Since the tender consortium used these original KPIs to monitor the technologies' performance in each research and innovation area, the main findings of the analysis are presented sector by sector.

4.1.1 Biomass

Several aspects of the biomass industry were analysed:

- Biomass feedstock: on the whole, in the EU the KPIs are improving or likely to improve, with the proposed targets being achieved or on track. For example, the biomass supply cost target for forest biomass is on track to be achieved. The INFRES project estimated the supply cost of forest feedstock at EUR 8-17/MWh (excluding stumpage), meaning that the 2020 cost reduction target will be achieved (30% reduction through the use of intelligent machinery and optimised supply chain concepts). It is more difficult to arrive at an aggregated, EU-level biomass supply cost for agro-biomass because differences in national price levels for input, such as labour and machinery, result in substantial disparities between EU-28 countries. The KPI on lowering production losses and improving biomass from forestry and agriculture has not been achieved yet, but remains relevant as several initiatives are ongoing and are expected to result in the targets being attained soon.

- The bio-oil sector has made substantial headway on cost reduction (although the production cost continues to be determined by the feedstock price) and technological advances (with progress made on taking plant availability beyond 6,500 hours, enhancing fuel quality and upgrading bio-oil). The feedstock flexibility target has not been reached yet, since woody biomass is still the main feedstock, but various initiatives are under way. For instance, Empyro is currently working with bio-oil for several improvements to the BTG-BTL pyrolysis process. The US seems to be a step ahead of the EU as regards development and performance in the bio-oil sector.

- In the research area related to thermally treated densified biomass, performance is improving across the KPIs and almost all targets have been reached (e.g. flexibility of raw material, co-firing percentage, overall energy efficiency, risks, storage)[5]. The production costs remain somewhat higher than expected, with the steam-exploded pellet industry still under demonstration.

- The biogas sector shows a lot of promise, since its performance is improving and it is achieving the targets on raw material diversification, energy efficiency of upgrading, lower upgrading costs, and load flexibility. The Bin2Grid project aims to promote the usage of food waste for biomethane production. The target on biogas use for CHP has not been attained yet, though progress has been made. Developments regarding this KPI must be monitored closely, as this technology is an important means of reducing GHG emissions by increasing overall system efficiency.

- There has also been improvement in the performance of CHP technologies (both micro-CHP and large-scale CHP), which have vast potential to increase overall energy efficiency and thus contribute to reducing GHG emissions. Several KPIs have been achieved or are well on track, depending on the scale of the CHP considered (proven

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[5] https://www.sector-project.eu/ and https://www.power-eng.com/articles/print/volume-122/issue-3/features/world-s-first-coal-to-biomass-conversion-using-advanced-wood-pellets.html

lifetime, electric system efficiency based on thermodynamic cycles, emission reduction, net nominal electric efficiency, etc.)[6]. For small-scale CHP, technologies based on the Stirling engine are still quite expensive while those based on ORC have made good progress, with their investment costs falling to EUR 2.50/W (depending on the system size).

- As regards biomass conversion systems for polygeneration, performance has improved on electricity generation efficiency and emission reduction. Research is still ongoing in this area, especially in non-EU countries such as China.

To conclude, ***the biomass energy sector is on track***. Europe is among the top players in this sector, with good performances all along the chain and within the different biomass categories. At international level, China, US and India are improving in the different technologies addressed, but the EU continues to lead the way in all sectors except bio-oil, where the US seems to be spearheading innovation.

In general, ***plant availability*** targets for the production of biomass energy carriers (e.g. bio-oil, thermally treated biomass, CHP) ***have been attained***. Similarly, the ***quality of biomass fuels has increased*** over the time period under study, resulting in a general improvement in the related sectors. However, some technologies still need to progress and further investigations should be carried out based on the lower degree of improvement and development exhibited so far. For instance, use of agricultural biomass for energy has not progressed as expected. Furthermore, production costs have not always decreased as expected, and some technologies are not yet available on a commercial scale. Section 7.1 – *Biomass* therefore lays out new recommendations geared towards enhancing performance on the aspects above and identifying ambitious new objectives and research topics (including one on market uptake) to contribute to the further development of sustainable biomass fuels and advance the decarbonisation of the energy sector.

[6] https://www.valmet.com/globalassets/media/downloads/white-papers/power-and-recovery/hofor_co2_neutrality_cfbs_whitepaper.pdf

4.1.2 Geothermal

The implementation of the Geothermal Technology Roadmap was monitored based on the first set of research, development and innovation projects launched since 2014. The data collected show that ***the sector is generally on track*** and progress has been made on all main KPIs for both shallow and deep geothermal for heating and cooling. Nonetheless, more results, particularly in terms of cost reduction, must be achieved if the targets set for 2020 and beyond are to be met.

Furthermore, heat plant costs for EGS (Enhanced Geothermal Systems) could not be assessed accurately due to the limited experience gathered from the first pilot plant.

4.1.2.1. Shallow geothermal

In terms of the overall installation rate, around 100,000 units were sold across Europe (over 80,000 in the EU) in 2017. This value is still far below the 150,000 units/y envisioned in the geothermal roadmap for 2020, and is too low in view of the number of new buildings appearing in cities. However, there has been a ***significant increase in the number of large systems*** (systems larger than 50 kWth).

With regard to costs, the ***operating costs for geothermal heat pump systems have decreased*** as control costs for annual maintenance have fallen and performance has improved, resulting in lower electricity input. Nevertheless, although O&M costs were expected to decrease by 5% between 2014 and 2018, ***the overall costs in euros have remained stable as electricity prices have risen.*** A number of ongoing research projects like GeoCollector (SME instrument phase 2) and, more specifically, GEO4CIVHIC seek to reduce the operational costs for retrofits in civil and historical buildings by installing simple, highly efficient and low-cost geothermal systems.

Investment costs also fell by about 5-10% between 2014 and 2018, driven mostly by reductions in the costs of drilling (especially in young markets), materials (-5 to 10%), installation (-10%), and heat pump units (particularly in mature markets). For large projects, the reduction in investment costs has been estimated at 10-15%, mainly in young markets. European R&D projects such as Cheap-GSHPs and GEOTeCH aim to reduce the cost of fully installed systems by 30% by 2019 (from 2014).

As regards the energy input for the operation of geothermal heat pump systems, ongoing or recently completed R&D projects, such as COST-Action GABI, BRUGEO (experimenting with enhanced TRT) and GeoFit (on energy-efficient building retrofitting) show considerable potential. As per the roadmap goals, the energy input in 2018 was below 2014 values (44.6 MWh electric[7]), corresponding to a reduction of 5-10% in mature markets and more in young markets (equivalent to a value of 40.1-42.4 MWh electric).

The performance of geothermal heat pump systems has improved substantially, particularly in Sweden, Germany and Switzerland, where they are mostly used for heating only. Research performed by projects such as ITER (Improving Thermal Efficiency of hoRizontal ground heat exchangers), GEOTABS (Model Predictive Control and Innovative System Integration) and TESSe2b (Thermal Energy Storage Systems for Energy Efficient Buildings) has contributed to improving performance through an integrated solution for residential building energy storage by geothermal resources and hybrid systems.

[7] For a geothermal system with a capacity of 50 kW_{th}, installed in a new building, supplying heating at T = 35°C for 2,200 hours a year and cooling at T = 7°C for 1,200 hours a year, in western Europe climate conditions, an $SPF_{heating}$ of 4 is used.

In the three countries mentioned above, the typical efficiency, expressed as the Seasonal Performance Factor (SPF), increased from below 3 in the 1980s to well above 4 in 2014, and, with continued R&D, average values in the order of 5 seem feasible for 2020. In 2018, the average European SPF was in the range of 4 to 4.5 for 50 kWth systems and 4.5 to 5 for 50-100 kWth systems.

As for cooling, some projects had already achieved an efficiency (Seasonal Coefficient of Performance for Cooling, SCOPcooling) of 5 – above the European average[8] – in 2018, while free cooling projects have reached a SCOPcooling of over 20. R&D projects such as GeoSolCool are working to improve this efficiency through continuous hybrid cooling using geothermal and solar heat sources and underground storage systems.

Additionally, the overall impact of reduced borehole thermal resistance in a defined shallow geothermal system, measured by the Hellström efficiency[9], has increased from below 60% to about 75% (in 2014) in state-of-the-art systems. There is still room for improvement, but the impact of ongoing R&D activities will not be clear before 2021- 2022. The GEOCOND and Green Epile projects will contribute to this.

4.1.2.2. Deep geothermal

The expected target of ***decreasing the geological risk*** by 25% by 2020, expressed as reductions in the number of abandoned projects and in exploration costs, is probably one of the most daunting challenges for deep geothermal projects. Considerable improvements have certainly been made, as in 2016 78% of wells were successfully drilled and in 2018 exploration costs were estimated to be around 5-10% lower than in 2014 (2018 value for the exploration costs of a deep geothermal project without a 2D or 3D seismic survey: EUR 340,000-880,000). Yet progress is still hampered by the use of technologies based primarily on extrapolating products developed for the hydrocarbon industry (e.g. geophysical software, logging tools, etc.) and by the lack of a proper European geothermal resource database. The ERA-NET co-fund action, *Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (GeoERA)*, should allow better mapping of the potential. Several ongoing and recently completed R&D projects aim to improve exploration tools: they include HYDRORIFT, Advanced 3D Geophysical Imaging Technologies for Geothermal Resource Characterization, ThermoGIS and IMAGE.

Significant progress has been made on drilling costs, which have a substantial influence on the overall economics of a deep geothermal plant (estimated contribution to the levelised cost of electricity: EUR 11 per MWh). New market conditions have reduced drilling prices by 30% in some markets, while the unit cost for some drilling projects fell by 5-10% between 2015 and 2018. However, ongoing R&D projects have not yet had an impact on the unit cost of drilling (EUR/MWh). The flagship research projects seeking to improve current drilling technology are ThermoDrill, DESCRAMBLE, SURE and GEODRILL.

As far as wells are concerned, geothermal well design has reached a good standard, and geothermal-specific components like pipes and pumps are now available. However, production pumps still consume a lot of power. In this area, there is scope to reduce operation and maintenance costs by at least 25% and improve system reliability and the energy efficiency of operation, particularly by cutting the energy consumption of production pumps by at least 50%. In general, ***the cost of well design and completion, reservoir stimulation and management fell*** by around 5-10% from 2014 to 2018, and the ***cost***

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[8] From the 2014 value: $SCOP_{cooling}$ average of 4.5, for a geothermal system with a capacity of up to 100 kW_{th} and an active HP supplying cooling at T = 7°C, in western Europe climate conditions.

[9] The Hellström efficiency indicates the overall impact of the borehole thermal resistance, Rb, for a defined shallow geothermal system. Where a borehole heat exchanger (BHE) is highly efficient, the temperature loss between the ground and the fluid inside the BHE is low. The temperature loss is determined by the borehole thermal resistance, Rb.

of corrosion and scaling has decreased slightly too. Moreover, the efficiency of geothermal wells has generally improved by around 3%, while operation and maintenance costs are down by 5% from 2014. A number of R&D projects are currently under way to address the energy consumption of production pumps. Research in the area includes projects such as SURE, DESTRESS, GEO-COAT, CHPM2030 and MATChING, as well as numerous innovations from the industry.

Although ***Enhanced Geothermal Systems (EGS)*** exhibit considerable potential and concepts were demonstrated back in the 2000s, they have not yet matured into a ready-to-implement technology. Experience in the few existing research facilities and operational plants revealed a ***significant discrepancy between initial layout figures and final results,*** both with regard to the stimulated underground heat exchanger and the realised thermal and electrical output. Consequently, quite apart from the necessary support measures on training, education and public acceptance, major efforts must be made to develop tools and layout procedures to design EGSs with reliable performance parameters (such as flow rate, temperature, and thermal and electrical power). These efforts are currently being led R&D projects such as DEEPEGS, MEET, Gemex and DESTRESS.

Europe has harnessed geothermal energy for heating and cooling supply (bathing) for centuries and is currently developing a new generation of geothermal technologies such as EGS, smart thermal grids and applications combining deep and shallow resources with underground thermal storage. However, its geothermal potential is not sufficiently well defined and the characteristics of its geothermal resources are not well mapped and identified.

Europe only has high-temperature fields in Iceland, Italy and Turkey and on some islands. Many non-European countries, including the US, Indonesia, New Zealand, Kenya and Mexico, have far greater potential for high-temperature geothermal applications. This being the case, the global market is an opportunity for the European geothermal sector, as new initiatives on power and heat are emerging in Africa, Asia/Oceania and South America.

One positive sign is that R&D in geothermal is thriving in Europe, with many ongoing research projects and new funding structures. The European industry also leads the way on innovation, and many new products could be exported (e.g. exploration tools and services, equipment such as turbines and heat exchangers). Europe should participate in launching an international partnership on geothermal, especially for EGS and H&C for the agro-food industry: the EGS flagship programme could include an international dimension with a view to exchanging experiences and technologies and exploring opportunities for exporting European EGS know-how. Geothermal applications in relevant agro-industrial sectors would include heat and cold demand and supply, and would ensure food security.

Attempts to explore markets outside Europe will be faced with competition from local players, though this will depend greatly on the region and the technology concerned:

- More than 2,000,000 geothermal heat pump systems are already installed in Europe, which is the global leader in the sector. Global competition is concentrated on heat pumps.

- With more than 300 geothermal district heating systems in operation, Europe is the global leader in geothermal district heating. Global competition is focused on heat exchangers and pipes.

- While H&C applications using deep geothermal started in Europe, China is now leading the market as demand there is much higher.

- 15% of installed geothermal capacity is in Europe. European companies are often technology leaders, especially on CHP, and are developing solutions for the global market and not just the European market. The main markets today are the US, Indonesia, the Philippines, Turkey, Chile and Kenya.

- At present, the only operational EGS plants are located in Europe, though projects are ongoing in the US and South Korea.

4.1.3 Solar thermal

The projects' level of alignment with the roadmap varies. While only a few projects achieve a high degree of overlap with the pathways' objectives, they all address the topics described in the roadmap. In some cases, they may even contribute to more than one pathway, such as when they address components (like collectors or controls) or enablers (like storage).

On the whole, it is still difficult to see whether the 2020 KPIs will be achieved. The number of new projects is limited and the indicative R&I budget requirements set out in the roadmap were much higher than what has been financed so far.

A number of ongoing and recently completed projects (PROSSIS2, SAM.SSA, MERITS, TESSe2b, WPSol, COMTES, UniSto, Tes4seT and SySTHEff, and especially iNSPiRE, SySTHEff, MacSheep and HP-LP-SOLAR-FAÇADE) have shown that ***SCOHYS (Solar Compact Hybrid Systems) is available on the market, with solutions covering single-family homes (DHW and combi) and small multi-family homes (DHW***). The level of price reduction attained depends on the reference price, which is not defined in the roadmap. However, the prices of the SCOHYS products on the market are above the values originally proposed in the Roadmap. The price analysis was conducted on a project-by-project basis: SySTHEff has achieved a 30% reduction on 2012 figures, while fuel parity has proven harder to secure given the drop in fossil fuel costs in recent years. A study presented within the framework of IEA-SHC (more specifically Task 54) mentioned a high-performing combi-system for MFHs with a total LCOH value of EUR 0.07/kWh over 25 years.

A few R&D initiatives focusing on cost reduction are due for completion by 2020, including TEWISol (DE), Task 54 (DE) and Zeosol (EU). Another example is SunHorizon, which is expected to publish its results in 2020. Whereas the market for single-family domestic solar systems is shrinking and facing fierce competition from PV solutions, the solar thermal industry (especially in France, Germany and Austria) believes that there is strong potential for growth in systems for multi-family homes and that the Levelised Cost of Heating (LCOH) values delivered by such systems are worthy of note (EUR 0.07/kWh for Austrian conditions). However, these former flagship countries are only running a limited number of R&D projects in the field and are dedicating little money to innovation; this situation is a direct consequence of the difficult conditions on their respective national solar thermal markets.

SCOHYS is very specific to the European market. As such, ***there are no relevant R&D projects in other markets***. Other hybrid concepts, not focused on solar, exist in markets such as Japan. A new, highly innovative trend has emerged in two different countries, namely France (Eklor Invest) and Austria (SWA). In these countries, a number of startups are developing SCOHYS projects for multi-family residential projects and commercial projects, using an ESCO model as their basis. Naturally, this approach can only be applied in specific conditions, leading to project aggregation to reach a minimum size. Nevertheless, this specific new business model is promising in Europe.

The solar active house (SAH) is not yet a standardised solution available to the market, which was the target set by the KPI for 2017. A number of projects are currently running on topics that are relevant to improvements in SAH, such as storage or components (low-cost collectors, heat exchangers, façades), but an integrated approach to the overall SAH concept is lacking. Nine projects (THERMALCOND, SCOOP, SolSys, COMTES, HP-LP-SOLAR-FAÇADE, ECOSS, SARTEA, STAID, UniSto and Tes4seT) with a total value of EUR 12.5 million were more directly related to SAH. The HeizSolar (DE) and ECOSS (FR) projects contributed more directly to the goal of standardisation, while projects such as HP-LP-SOLAR-FAÇADE (EU), Tes4seT (AT), SCOOP (EU) contributed to the goal of cost reduction. Various initiatives in Europe deal with a variation on the solar active house presented in the roadmap, combining solar thermal with PV in a bid to achieve a 100% solar energy house.

The ongoing and recently completed projects in this field are, in themselves, insufficient to achieve standardisation. Public funding is focused on generic nZEB concepts and private funding is scarce, with limited engagement and ambition from the main heating industry players.

The lack of dedicated European and/or national funding for the further development of the SAH60[10] concept indicates that there are few projects specifically addressing this topic, which provides little assurance that the target will be met. It would be advisable to combine efforts to advance the SAH60 concept with initiatives tackling individual aspects, such as storage, building integration (façades, thermal walls) and components. There are, however, several projects currently due for completion by 2020 that specifically focus on SAH (e.g. Arkol (DE) and SolSys (DE)). Other relevant projects focus more on thermal storage, but could have a positive impact on SAH.

Outside Europe, there appeared to be no R&D projects for solar active houses whose solar thermal systems achieve such high solar fractions as 60%. As is the case in Europe, research is focused on nZEB concepts. A good overview is provided by the ICEF nZEB/ZEH Roadmap, which views solar as a contributor to nZEB concepts rather than the main driver. Interesting funding programmes for nZEB or active houses with a substantial solar component were identified in Japan (NEDO).

The target prices for SHIP (Solar Heat for Industrial Processes) have been reached under research conditions, both for lower temperatures and for higher temperatures. Solarbrew reached EUR 210/m² with a solar fraction of 19%, while for medium temperatures, Fresh NRG reached EUR 412/m², which can be deemed to be within an acceptable margin of the target.

The key issues for SHIP are:

- low energy costs (fossil fuels).
- access to large machinery suppliers, to shape system design.
- availability/cost of land near relevant industries.
- the need for more data on existing systems.

Twelve ongoing or recently completed projects directly linked to SHIP were identified: SAM.SSA, SnowRESolution, Sunstore 4, helioSTEAM, SOLEGLASS, ENTHALPY, Re-Deploy, SGSTh, UniSto, Solarbrew (total value: approximately EUR 43 million). With regard to roadmap implementation, most of the projects deal with the cost optimality of SHIP systems and their integration into relevant industrial applications. The roadmap specified that a large number of projects would be needed to achieve the intended impact on price.

The 2020 price target (solar heat costs reduced to EUR 0.03-0.06/kWh for low-temperature applications and EUR 0.04-0.07/kWh for medium-temperature applications) remains attainable, subject to a number of conditions. Bearing in mind the technical lifetime of the systems, the proposed energy costs are reachable. The main challenge is that consumers expect the economic lifetime to be far shorter. However, this could improve if more trust were established in these solutions and appropriate business models were developed, which would require more and larger demonstration projects. New technologies, such as high-vacuum flat plate collectors, are paving the way for applications in higher temperature

[10] Solar active houses with a solar fraction of 60%

ranges. This could bring prices closer to the target, though the target price is not expected to be reached by 2020.

The projects currently known to be under way are not enough to promote faster deployment and ease the learning curve. IEA SHC Task 55 is dedicated to large solar thermal systems, including district heating and SHIP systems. ***Startups using an ESCO model to develop SHIP projects have emerged in various countries.*** HELIOCLIM, Newheat and SUNTI in France and established solar players like VIESSMANN, KBB and Greenonetec have developed solar thermal collectors especially for large plants. Major new European SHIP projects scheduled to be operational by 2020 are expected to provide values of EUR 0.025-0.035/kWh (with subsidies). These include commercial projects and demonstration projects (SHIP2FAIR).

Information from the Solarpayback project indicates that in one case in Mexico, pasteurisation at 78°C was achieved with investment costs of USD 250/m². No studies or projects were identified providing indications on the expected changes in solar heat costs in other regions in the coming years.

SHIP systems could be scaled up to 0.75-10 MWth and the solar fraction could be increased to 40-50% of the heat demand for industrial process. The main constraint here is the availability/cost of space near the relevant manufacturing plants. However, the combination of space requirements and solar resources mean upscaling is still feasible in southern Europe and some regions of eastern Europe. Initiatives such as INSHIP provide additional opportunities for R&D investments in this field. Europe's largest SHIP system was built in 2018, with a total capacity of 3.4 MWth and annual production of 3,900 MWh. However, the system's solar fraction is very limited (around 1%), and is thus not in line with the solar fraction target set in the roadmap (40-50%).

Most progress on large-scale SHIP systems was attained outside Europe, though European technology was used in several cases. In fact, the indicated targets have already been achieved in other regions of the world. The main competitors for such large projects are European companies and Chinese companies, which also make use of European technology and know-how.

It will be difficult to achieve the 2020 target of 700 SHIP systems and an installed thermal capacity of 875 MW (collector area of 1,250,000 m²), since deployment levels in Europe are too low to attain this. The budget outlined in the roadmap is still valid, considering the need for further deployment. Nevertheless, in some cases, there is an overlap in terms of technological development with CSP (concentrated solar power technology). CSP is the primary focus of some initiatives identified in other regions and SHIP is not addressed as clearly, even though some results can be reused.

4.1.4 Heat pumps

The R&I priorities and KPIs set for heat pumps by the Cross-Cutting Technology Roadmap have been discussed and analysed by industry and academic experts from the heat pump sector.

Their analysis revealed that ***the R&I priorities set for heat pumps by roadmap have not (yet) been taken into proper consideration by national or European research programmes, be it through direct calls for proposals or dedicated funding schemes.***

The majority of the experts voiced concerns around four main points:

- The share of funding dedicated to heat pumps at both Member State and EU level is not sufficient to accelerate the sector's development and to achieve the desired level of product improvement and system integration capacity. Moreover, where funding is available, it lacks continuity. As a result, many initiatives are privately financed.

- Electricity prices are currently high in the EU while fossil fuel prices are low (per kWh); this is a major obstacle to faster market penetration.

- Funding programmes (at both national and EU level) should be extended to provide better coverage for market uptake activities.

- The KPIs need to be revised and reset, as priorities and conditions have changed since 2012.

The projects evaluated show that the heat pump sector is greatly interested in developing a compact and cost-efficient heat pump kit for the residential building segment. Other research activities are geared towards developing mass-market ready products with:

- an average seasonal coefficient of performance (SCOP) of 3-5. In 2018, the average SCOP was 4.1. (Some examples are available from tests performed in Sweden and Denmark.)

- better cost efficiency. The 2016 KPI on the reference average cost of HP systems with a capacity of 4-8 kW is EUR 5,200-7,000. While this target has not yet been achieved, there are indications that costs may decrease in future. For instance, the French Heat Pump Association (AFPAC) foresees growth in hybrid heat pumps in residential buildings, which would lead to lower installation and unit costs.

- a smaller carbon footprint. While gas consumption has been reduced by 50 to 70% (Robur), more efforts are needed to achieve the 2020 target of a 90% reduction in gas consumption.

- more compact units that are easier to install.

- improved connectivity to enable integration into building energy systems (ventilation, heat recovery, auto-produced PV electricity) and smart grids. Both objectives will help to leverage the demand response potential of the heat pump technology (e.g. coupling heat pumps with solar PV, as in the Horizon 2020 project SunHorizon).

- a combination of the above features and a focus on the renovation sector

Residential heat pump applications have gained more and more political recognition, especially at Member State level (e.g. Italy and France's most recent energy strategies give heat pumps a central role in decarbonising heating and cooling). This is because the technology is now perceived as mature and as a key contributor to achieving EU climate and energy targets (e.g. for residential applications, the FP7 project Green Heat Pump).

The European heat pump industry expects a rise in the number of projects and funding opportunities and predicts a focus on the development and implementation of:

- ***heat pump technology ready for plug-and-play applications in the renovation sector;***
- ***heat pump solutions able to provide demand-side flexibility.***

There is increased interest in industrial heat pump applications at both national and international level. This has been expressed in a number of ways, including IEA-funded annexes to the heat pump implementation agreement. A growing number of projects and research activities are focusing on ***synergies with district heating and cooling*** and the ***feasibility of transforming low-grade waste heat into high-temperature industrial process heat***. By way of example, the Horizon 2020 project Dry-F (http://dry-f.eu) examines how waste heat could be recovered for drying purposes.

The heat pump industry's development pipeline faces a twofold challenge as a result of new legislation. On the one hand, the drive for **ecodesign** has created a strong pull for more efficient units, while on the other hand, the implementation of the **F-gas phase-down** requires a near-complete redesign of existing heat pump types so that low Global Warming Potential (GWP) refrigerants may be used. Given the limited R&D capacities, public funding is needed to prevent these two pieces of legislation from having a negative impact.

Lastly, heat pump solutions are experiencing a surge worldwide; in view of the energy transition, the need for higher efficiency, improved air quality, lower greenhouse gas emissions and systems that can handle both heating and cooling is greater than ever before:

- In US, where nearly every home is fitted with air conditioning, it is becoming increasingly common to use heat pump systems in reversible mode to provide heating and cooling, making gas boilers unnecessary.
- In Japan, the strongest development has been in the adoption of heat pump hot water heaters (EcoCute) as a replacement for gas-fired instant heating systems.
- In China, heat pumps are a component of the coal clean-up programme to reduce heating-related air pollution.

4.1.5 District heating and cooling

The 2014 Cross-Cutting Technology Roadmap set four technology priorities for district heating and cooling (DHC) networks:

- Large-scale demonstration of smart thermal grids (CCT.17 – priority group: I)
- Development and roll-out of DHC-driven white goods and low-temperature solutions for domestic hot water preparation (CCT.19 – priority group: III)
- Improved, highly efficient substations for current and future lower-temperature networks (CCT.20 – priority group: II)
- Optimised integration of renewable energy sources into DHC systems and enhancement of thermal energy storage at system level (CCT.21 – priority group: III)

To monitor the current status of the Key Performance Indicators (KPIs) on DHC, an analysis (desk research) was performed with a view to identifying national and international projects in the DHC research fields. Bearing in mind the results of the research, the number of projects and topics covered, and the current general state of the DHC sector, the DHC experts concluded that it would be advisable to revise one of the cross-cutting technology priorities for DHC *(Development and roll-out of DHC-driven white goods and low-temperature solutions for domestic hot water preparation (CCT.19))* and some of the proposed KPIs.

Further support must be provided for the development and deployment of smart thermal grids or advanced district heating and cooling systems. More attention must be paid to intelligent planning, the operation of district heating and cooling networks and the interaction between end users and DHC networks. In addition, ***smart metering and load management systems*** are needed to enable the integration of thermal and electrical grids into a liberalised energy market. One additional focus could be the ***development of neighbourhood-based refurbishment and integration solutions that can be rolled out as packages combining DHC development and its integration with refurbishment and thermal energy storage***. The KPI on the price of heat and the integration of renewable energy into DHC networks is on track, but additional research and demonstration projects should be supported in order to fully exploit the benefits of smart thermal grids. ***Overall, the KPIs on smart thermal grids have not been fully achieved.*** The H2020 STORM , Flexynets, OPti and TEMPO projects all examine smart thermal grids and show that demand-side management in district heating and cooling networks can bring additional value to district heating operators and consumers. The H2020 STORM project recorded a 13% reduction in peak heat load at two demonstration sites in Rottne (Sweden) and Heerlen (the Netherlands).

Since ***there is little large-scale uptake/production of low-temperature substations***, R&D projects are still needed to lower costs in future and enable implementation of this technology in district heating networks. Support should also be provided for smart-controlled substations, encompassing fault detection methods, smart control systems, alternative materials for substations, and so on. ***On the whole, the KPIs for the substation development have not been fully achieved***. The H2020 TEMPO project addresses the development and demonstration of fault detection and diagnosis methods for district heating substations, while the importance of such methods is also discussed in research by Sara Månsson et al., including her thesis (2018, 2019).

Further research activities are needed to enable DHC networks to efficiently integrate all types of RES without jeopardising the quality of the service provided to consumers. Similarly, it is important to explore new synergies between various consumer groups with different thermal needs. The DHC sector must be able to exploit and upgrade all available renewable energy, as well as any surplus recovery heat. ***For high RES penetration of***

DHC to be achieved, applied research must be carried out in a bid to develop smart thermal grids connecting diverse types of buildings and industrial processes, including prosumers (i.e. consumers who are also producers), whenever appropriate. ***Energy storage is key to enhancing the flexibility of district heating and cooling systems***, matching variable renewable energy sources with fluctuating thermal demand. TES solutions already exist for district heating systems, but they are mainly only suited to short-term storage. There is a need to develop flexible, efficient, multifunctional and cost-effective TES solutions and integrate them in smart thermal grids. This topic is also addressed by Bram van der Heijde in his 2019 doctoral thesis, in which he develops an integrated optimal design and control algorithm and applies it to a fictional district energy system in Belgium. The algorithm can identify optimal designs for the provision of multiple objective functions.

As regards the status of DHC outside Europe:

- The annual growth rate in the US has remained below 1% in recent years, despite the high square footage of floor space. Modest growth can be expected in the coming years. Growth is hampered by the fact that energy costs are lower than in Europe and greater use is made of natural gas. The networks are in clear need of optimisation, and the priority here is network infrastructure optimisation rather than flexibility and demand-side management.

- Japan has had DHC networks since 1970. They were initially developed for the primary purpose of combating air pollution and form an integral part of Japan's strategy for reducing greenhouse gas emissions, which is structured around improving energy efficiency, developing interconnected multi-energy networks and mobilising the country's underexploited renewable energy and recovery sources.

- District heating only emerged in China in the 1980s. Since then, it has continued to develop in line with the country's growth. China, whose energy supply is mainly based on coal, could reduce its greenhouse gas emissions through district heating, particularly by boosting energy efficiency through combined heat and power. This is further supported by the State Council's *Clean winter heating plan for northern China (2017-2021)*, which covers potential heating sources, renovation of heat supply systems to boost their efficiency, and promotion of energy meters and thermal insulation of buildings.

- Russia alone accounts for 55% of the world's installed district heating capacity. It is estimated that there are more than 17,000 district heating systems in the country, serving 44 million consumers. These are generally small, relatively old networks, which suffer from technical and economic difficulties due to a lack of maintenance. 98% of them are powered by fossil fuels, and 75% of these by natural gas. Russian DH networks are inefficient and there is considerable potential to upgrade them to efficient, smart-controlled networks.

4.1.6 Thermal energy storage

The analysis covered the following research and innovation areas for thermal energy storage:

- Sensible thermal energy storage in water is the most important and most widely applied technology for thermal energy storage in the world, and there are no reasons to believe that this will change in the near future. Although the technology as such is old, ambitious targets can still be set and reached for ***heat loss reduction (energy efficiency) and improvement of thermal stratification (exergetic efficiency, primary energy savings)*** if enough high-quality work and effort is dedicated to these subjects. The MacSheep project achieved heat loss of just 86 W with VIP (Vacuum Insulation Panel) insulation, thus meeting the criteria for Label B. Label A (2020 target) is within reach, but has not been attained yet for this size of storage system (1,000 litres). Not many projects have targeted these subjects in H2020 and national programmes so far, and those projects that have targeted them only dealt with the improvement of sensible thermal energy storage remotely or as a side topic. Not enough priority is given to this technology at the moment, and people are poorly informed about the potential that still lies in the improvement of sensible TES.

- Increased storage density using Phase Change Materials (PCM) and Thermochemical Materials (TM). Several projects (such as Innostorage, MERITS and TESSe2b), mostly jointly funded by the EU, are ongoing in this area. The KPIs in the Cross-Cutting Technology Roadmap are generally on track. However, a number of projects have recently started and their main results will be available in 2020 (date of the first target). Several novel heat exchangers with PCM (Phase Change Material) are currently being developed as part of ongoing projects (both at EU and national level). The 2020 target seems within reach (proof of concept for at least five concepts).

- Underground Thermal Energy Storage. The KPIs presented in the Cross-Cutting Technology Roadmap are, in general, difficult to verify. For instance, the KPI on energy storage efficiency requires certain parameters to be set, as it depends on unloading strategies. It must therefore be given a narrower definition, and a distinction must be drawn between UTES types. This kind of analysis was missing in the original technology roadmap. In general, advances have been made in terms of efficiency, since the Geobooster project has developed a controller for BTES combined with heat pumps. The controller guarantees the power of the BTES field and the annual energy production for heating and cooling. The KPI on UTES lifetime at a high temperature cannot be verified in any way at present as very few high-temperature UTES systems are currently operational. Most of the early experimental and pilot plants from the 1980s and 1990s are no longer operational, and the oldest plants operating today are about 15 years old.

- Improving the efficiency of combined thermal energy transfer and storage. This research and innovation priority is part of Priority Group III in the roadmap, meaning that deployment and activities are to take place from 2018 onward. Consequently, no data and results are available for this priority at present. However, research is under way. For instance, the CREATE (Compact REtrofit Advanced Thermal Energy storage) project aims to develop and demonstrate a heat battery (an advanced thermal storage system based on thermo-chemical materials) to allow affordable, compact and loss-free storage of heat in existing buildings. It sets out to develop stabilised storage materials with high storage density, improved stability and a low price, and package them in optimised heat exchangers using optimised storage modules. The project is currently ongoing.

Several projects are currently under way at international level and mainly target research on PCM and TCM. In general, results at international level are in line with those achieved in the EU. Novel heat exchangers are being developed both in the US (*High-Performance Refrigerator Using Novel Rotating Heat Exchanger*) and in China (*Novel Heat Exchangers* *with Cross-Runners for Air and Water Cooling*; *A novel compact heat exchanger using gap flow mechanism*).

4.1.7 Hybrid systems

It was especially difficult to analyse the KPIs for hybrid systems because the Cross-Cutting Technology Roadmap ***did not set out clear parameters*** for such systems.

Given that the term 'hybrid systems' refers to complex energy nodes where more than one energy production technology is available and renewable energy is assisted by conventional energy, ***a more detailed classification is needed***. Since the roadmap was drawn up, standard representations of complex systems have been proposed based on defining various components and clearly setting the boundaries of the system (see, for instance, the IEA SHC Task 44/HPP Annex 38 reference framework for system simulations). This proposal states that the boundaries of the hybrid system must be defined so that the system's input/output can be quantified and taken into account, such as when heat pumps are used or photovoltaic panels are present.

In the experts' opinion, and as suggested by analysis of the relevant scientific literature, hybrid system output must be evaluated on the basis of dynamic models used to both predict performance at the design stage and perform their run-time control during operation.

Since hybrid system structures and their interactions with external markets differ, ***new KPIs must be prepared to allow uniform comparison***. The Levelised Cost of Energy is one criterion that could be used to rank different demand-matching technologies on the basis of their investment costs and energy production during their technical lifetime. Other KPIs focusing on the systems' environmental impact could also be considered; for instance, greenhouse gas emissions could be measured.

For the heating and cooling sector in general, and for the hybrid systems sector in particular, it is vital to develop a ***European dynamic system test cycle***, comparable to the driving test cycle used in the automotive sector. Using this standard thermal cycle as a basis, benchmarking exercises could be run by different research and technology entities to assess the reliability of results from separate simulations. Clear reference figures could then be identified to help consumers understand which systems are most fuel-effective and directly compare heating systems that use different technologies. The figures could also serve to justify higher investment costs in more efficient systems. For such a test cycle to be developed, a European research project would need to be conducted to allow key actors from research and technology providers to cooperate on comparing different existing test cycles and developing new ones, the ultimate aim being to implement dynamic simulations to support this process and finally arrive at one or more reference test cycles. At the same time, it would provide a common basis for a scientifically sound comparison of key performance figures for hybrid systems.

The available information indicates that EU is spearheading the development of hybrid systems, particularly those with a high share of renewables. In 2018, the estimated value for the KPI on the renewable fraction of the reference hybrid system was 50-70%, which is in line with the 2020 target. Products of this kind are currently offered by manufacturers such as Daikin, CTC, Clivet and Stiebel Eltron.

As regards the development of hybrid systems at international level:

- In South Korea, the launch of the Renewable Heat Obligation will provide a major impetus for the growth of this solution.
- In Australia, the price of gas has increased rapidly, such that it is currently more expensive than electricity. This could enhance the attractiveness of hybrid system solutions with a high share of renewable energy.

4.2 Main findings of the analysis of the heating and cooling industry

The sections below report, on a sector-by-sector basis, the main findings from the data collected on the EU heating and cooling industry. The sectors covered are biomass, geothermal, solar thermal, heat pumps, district heating and cooling, and fossil fuels.

4.2.1 Biomass industry

The biomass industry is closely linked to the value chain for biomass fuels. Annual production of biomass fuel is estimated at over 180 million m^3, of which 57% is fuelwood, 34% wood chips and 9% pellets.

Europe is a net importer of feedstocks, obtaining approximately 16 million m^3 from beyond its borders. While this is only equivalent to around 9% of the EU's total feedstock production, imports account for a particularly large share of the pellets segment, amounting to around 50% of production.

Overall, fuelwood is responsible for around 186,000 GWh/y of thermal energy made available, chips and residues for about 294,000 GWh/y, and pellets for 97,000 GWh/y.

Biomass from forestry is responsible for the production of nearly 578 TWh/y of thermal energy across Europe.

In 2014, the bioenergy sector generated about EUR 36 billion (EurObserv'ER, 2014); the current annual turnover of the entire biomass heating and cooling sector is estimated at around EUR 21.6 billion. This latter figure covers the supply chain of biofuels, the manufacturing and installation of boilers and stoves, and sales of heat through district heating, but does not include biogas and renewable waste.

The average yearly turnover relating to the sourcing of the aforementioned wood stocks is estimated at about EUR 10.8 billion, with the country distribution largely reflecting the production.

The manufacturing, system design and installation of stoves, boilers and large CHP units generate an annual turnover of around EUR 3.7 to 4.6 billion, while services account for EUR 860 million to 1.1 billion.

Bioenergy Europe (formerly known as AEBIOM) calculated employment figures based on EurObserv'ER data, concluding that the solid biomass sector (i.e. excluding biomass and renewable waste) employs 238,000 FTE (full-time equivalents).

In the ***manufacturing and installation sector, total employment is estimated at nearly 23,000 FTE***. The employment figures for feedstock sourcing confirm that biomass is a highly significant sector. ***The sourcing of solid biomass fuels employs 174,000 FTE*** (73% of the total), broken down (based on the volumes traded) into 90,000 working in the fuelwood segment (52% of the total), 60,000 in the wood chip segment (35%) and 24,000 in the pellet segment (13%).

4.2.2 Geothermal industry

The geothermal energy sector is diverse and driven by the development of new projects as it rests on a robust industrial base, although this does vary greatly across the different European markets.

The use of geothermal energy for heating and cooling is increasing rapidly across Europe, with different technologies deployed according to local resources and needs. In Nordic countries, shallow geothermal systems have proven an effective solution for the decarbonisation of the heating and cooling sector. Deep geothermal systems have demonstrated their reliability in France, Germany and Hungary and are being adopted rapidly in emerging markets such as the Netherlands.

The diversity of the markets, technologies, enabling technologies (district heating, heat pumps, etc.) and types of heating and cooling supplied by geothermal systems explains the great diversity of the players involved in the sector and the wide range of business models for project financing. Since geothermal energy is capital-intensive and has low operational costs, there is a real opportunity to develop innovative financing schemes for geothermal projects.

Some 83% of total geothermal installed thermal capacity is provided by Ground Source Heat Pump (GSHP) systems connected to shallow geothermal units, mainly with sizes ranging from 2 kW to 100 kW and an SPF greater than 3.5, and supplying heating, cooling and domestic hot water. The remaining 17% is provided by deep geothermal systems.

In 2014, individual geothermal heating systems represented a thermal capacity of over 17 GW in Europe, with nearly 1.3 million systems installed. Estimations for 2019 show a market exceeding 2 million units.

Every year, dozens of new district heating networks are set up using shallow geothermal systems combined with heat pumps to:

- raise the temperature of the geothermal energy to the level of third- or fourth-generation district heating networks (80 and 50°C respectively); or
- deliver low-temperature thermal energy to users – through the network pipelines – and raise the temperature at the user’s side to the required level (35 to 70°C).

Deep geothermal district heating accounts for a thermal capacity of over 5.1 GW in Europe (of which 2.2 GW in Iceland and 1.9 GW in the European Union, delivering at least 4.3 TWh of thermal energy every year), with 304 plants currently in operation.

Disregarding the deep geothermal power industry (devoted to electricity generation), which is not the focus of this study, most of the deep geothermal segment is focused on high- and medium-temperature (third- and fourth-generation) district heating.

The geothermal industry’s turnover in the European Union has increased to around EUR 2.7 billion, with the heating and cooling sector accounting for EUR 1.6 billion.

In terms of jobs created, the geothermal sector employs 25,000-30,000 FTE across the deep and shallow markets.

The European geothermal industry’s know-how is recognised worldwide, and consistent and robust investments in R&D have made it a world leader in the field.

4.2.3 Solar thermal industry

The solar thermal industry is an industry strongly rooted in Europe. Many countries have manufacturing plants, employ a large workforce and generate value on European soil.

Around 48 million m³ of solar collectors are currently installed in the EU-28, corresponding to around 35 GW of installed thermal capacity. These collectors provide about 23 TWh of thermal energy every year.

The total annual production of solar thermal collectors in the EU-28 is estimated at 3.0 to 4.3 million m³, while around 2.8 million m³ of collectors are installed each year.

The total annual turnover generated by the ***solar collector manufacturing*** companies analysed is ***EUR 290 million***.

The total annual turnover generated by the ***manufacturing of solar collectors and other components*** (whether produced in-house or outsourced) for solar thermal systems and by the ***services*** provided by manufacturers is estimated at around ***EUR 900 million***.

The annual turnover for the ***value chain totals EUR 3.2 billion for the entire industry across the EU-28***. This value includes turnover for the manufacturing of components produced by companies that do not specialise in solar thermal technology, but rather in a specific component (e.g. pumps, heat exchangers, pipes, valves, glass, aluminium frames). Service companies, such as engineering consultants and system designers, are also part of the value chain and are not involved in manufacturing collectors or components. Most of the turnover generated by the sector relates to the distribution and installation of systems.

There are ***1,600 FTE employed in manufacturing collectors*** alone. ***4,800 FTE are employed across the whole manufacturing sector,*** which includes commercialisation and manufacturing of components within the collector manufacturer companies, administration, marketing, after-sales services, business-related services, and so on. ***31,000 FTE are employed in component manufacturing, services, and distribution and installation***, with installers accounting for the greatest share.

4.2.4 Heat pump industry

The European heat pump industry is growing fast. Both its contribution to covering total heating and cooling demand and its provision of renewable energy to the energy system increased significantly from 2010 to 2016.

Estimates indicate that around 9 million heat pumps are installed across the European Union Member States. The overall thermal capacity made available is about 74 GW, covering thermal demand of 50 TWh a year.

The estimated yearly production of heat pumps in the countries analysed ranges between 1.1 and 1.5 million, which is in line with average sales in the EU in 2016: around 1,000,000 (EHPA, 2017).

The annual turnover generated by manufacturing heat pumps is around EUR 4.9 billion, with the components industry accounting for a significant share (about EUR 1.5 billion in 2016). ***The value of the sector as a whole is in the region of EUR 5.5 billion (2016 data, EUR 6.5 billion including VAT),*** indicating that services (system design, planning and integration, installation, service and maintenance) account for about EUR 1.6 billion.

Between 24,000 and 30,000 FTE are employed in the heat pump manufacturing industry, including administration, marketing, after-sales services, business-related services, and so on.

The European Heat Pump Association estimates ***overall employment in the sector at around 55,000 FTE***, suggesting that 25,000 to 31,000 people are occupied in associated services such as engineering, distribution, installation and maintenance.

4.2.5 District heating and cooling industry

There are around 10,600 operational district heating networks in Europe, with more than 150,000 km of pipelines and a total installed thermal capacity of 327 GW.

Looking at the district network management and energy sales segment, the total heat distributed through district heating networks in Europe is nearly 400 TWh a year.

The net balance of networks installed is consistently positive: the number of operational DH networks is growing by 100 a year. Similarly, the balance of pipelines installed and decommissioned is positive: every year, more than 2,400 km of district heating network pipelines are installed in Europe.

At the same time, however, around 900 km of district heating network pipelines are decommissioned each year. Most of these are part of large, old networks running on fossil fuels, which are operated inefficiently and at high temperature, and are no longer cost-effective. However, disconnections have also taken place in northern European countries: regulations on energy efficiency in buildings sometimes make it expensive to distribute thermal energy, since the power density of the inhabited environment shrinks progressively.

The overall balance of thermal capacity installed is positive, with more than 625 MW in new capacity installed every year.

The annual turnover generated from thermal energy sales has been calculated at almost EUR 26 billion, corresponding to about 195,000 FTE.

Given that 2,400 km of new pipelines are laid each year, the annual turnover for design, manufacturing and construction is between EUR 1.8 and 3.0 billion. The average annual turnover was calculated at EUR 2.4 billion, corresponding to about 19,000 FTE**.**

4.2.6. General overview of the European heating and cooling market

Total final energy use in Europe is estimated at about 12,350 TWh a year (see Figure 4). Electricity uses account for about 2,700 TWh of the final energy consumed every year, while a range of thermal uses account for the rest. A substantial share of final thermal energy is used for transportation (4,000 TWh a year), while various direct heat uses are responsible for the remaining 5,600 TWh. Industrial process heat (such as energy used in foundries, chemical plants, etc.) and agricultural uses total around 900 TWh a year. However, this study does not address these uses because they are not covered by products and systems traditionally handled by the heating and cooling industry.

The market assessed in this study thus accounts for about 4,700 TWh of the thermal energy consumed every year, with residential uses covering around 2,300 TWh, tertiary applications 840 TWh and industrial applications 1,560 TWh.

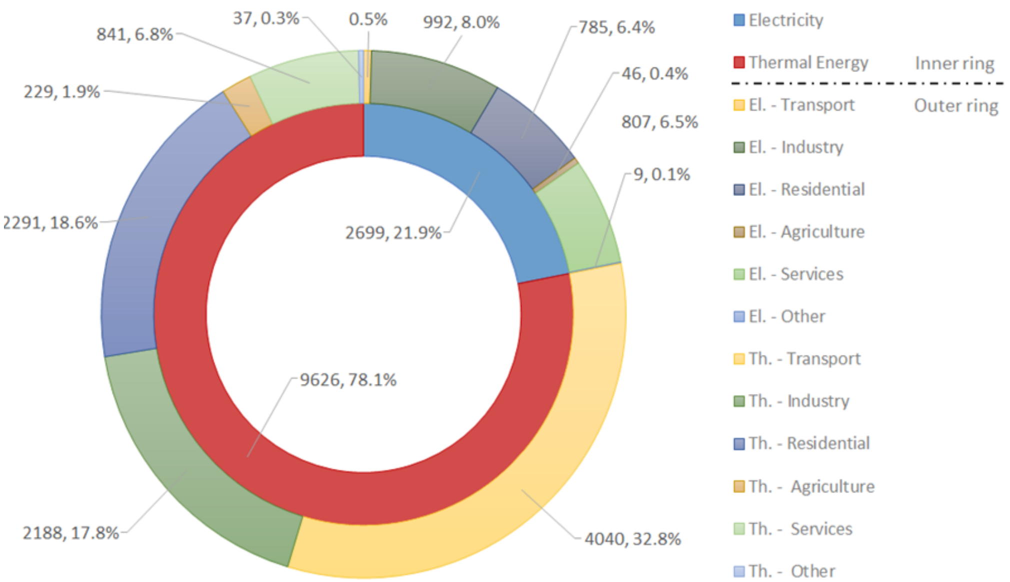

Figure 4: European final energy consumption by energy source (inner ring) and sector (outer ring), TWh in 2014 (Source: Eurostat 2017, elaborations by EURAC)

The information gathered highlights the relative weight of the specific technologies analysed in total energy uses: at present, fossil fuel systems cover 86% of energy uses in Europe each year, while the share of energy uses covered by renewable technologies (14%) is dominated by the biomass segment (12% – only solid forestry biomass is considered here).

Figure 5 shows the breakdown for solar thermal, biomass, heat pump and deep geothermal applications. It deliberately omits the district heating sector because this sector only distributes energy generated by technologies falling under the other industrial segments. Of the 400 TWh distributed by the district heating sector each year, around 170 TWh derives from biomass and a small share from deep geothermal (about 3.7 TWh/y), while nearly 55% of the total energy delivered derives from fossil fuel combustion.

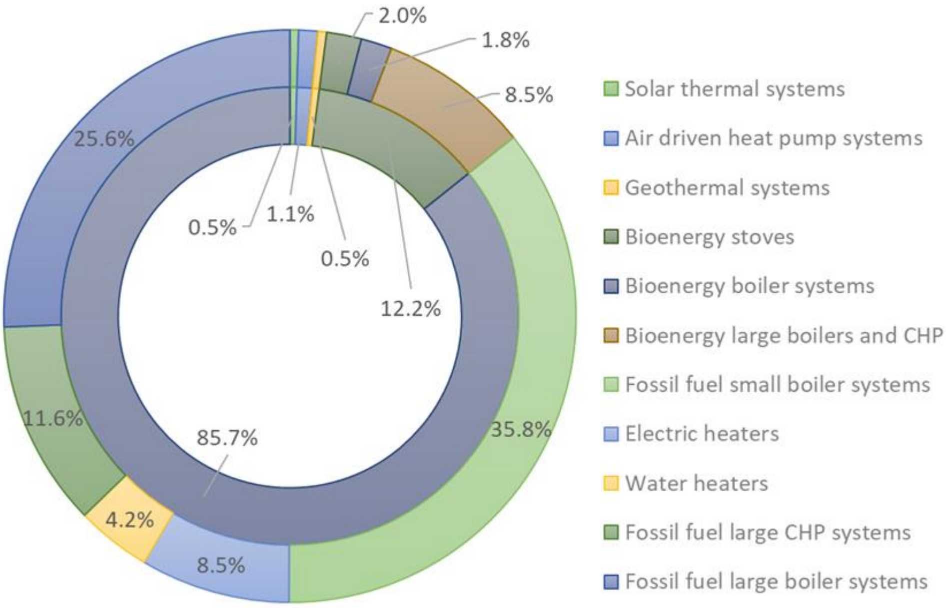

Figure 5: European final energy consumption for production, percentages in 2014. The inner ring denotes the energy sources (fossil fuels or renewables), while the outer ring specifies the technology used for production. The legend relates to the figures reported in the outer ring. Geothermal systems, including shallow geothermal heat pump applications, account for around 0.4%.

About 70% of heating demand is covered by boilers running on fossil fuels: small boilers for residential and tertiary buildings account for 40% of heat uses, while large gas boilers in industry and district heating networks cover the remaining 30%. Electric heaters and electric water heaters represent also a significant share of the market, with more than 13% of the thermal energy produced (about 650 TWh/y). Large fossil fuel-powered CHP units produce a similar amount of heat in district heating systems.

The table below provides a brief summary of the points outlined above. Data for 2014is reported to provide a fair representation: while more recent data may occasionally be available and may be discussed elsewhere in this report, all the required information is available for 2014 at the latest.

Industry sector	Stock installedTWh/y	Stock installed GW	Sales GW/y	Industry turnover EUR bn/y	Employment in industry FTE/y	Turnover from heat distribution or fuel sourcing EUR bn/y	Employment in heat distribution or fuel sourcing FTE/y
Solar thermal	23	35	2.1	3.2	37,000		
Heat pumps[11]	70[12]	74[13]	11[14]	6.5	55,000		
Geothermal	23[15]	19	1.1	1.6	25,000		
District heating	400[16]	327	0.6[17]	2.4	19,000	26.0	195,000
Biomass	578[18]	436	20[19]	4.2	23,000	10.8	174,000
Fossil fuels	4,050	3,300	132	21.3	223,000	305	-

Table 5: Key performance figures for the heating and cooling industry in 2014

The first column of the table details the amount of thermal energy covered by the different industry sectors. The thermal power installed in Europe is reported in the second column, largely reproducing the pattern identified for energy uses.

Sales (in terms of thermal power newly installed each year, third column) are once more dominated by fossil fuel solutions. When comparing newly installed capacity to the existing installed capacity, sales of renewables account for between 6% (for solar thermal) and 14% (for heat pumps) of total stocks. The same comparison, when applied to the fossil fuel solutions, shows replacement rates of 3-4% for boilers and electric heaters. Biomass

[11] The values for the heat pump industry include both air source heat pumps and heat pumps manufactured and installed in shallow geothermal systems.

[12] 19 TWh/y thermal energy produced from shallow geothermal heat pumps systems also counted under the geothermal sector

[13] 17 GW shallow geothermal heat pump systems also counted under the geothermal sector.

[14] Annual sales of 1 GW of shallow geothermal heat pump systems also counted under the geothermal sector.

[15] 3.7 TWh of 23 TWh and 1.7 GW of 19 GW relate to deep geothermal district heating networks.

[16] Around 170 TWh/y generated from biomass and 3.7 TWh/y from deep geothermal sources, with the rest from fossil fuel or waste-driven technologies.

[17] New district heating networks installed each year.

[18] Total thermal energy made available by burning the annual feedstock. Around 10% of this energy is converted into electricity by CHP plants.

[19] Estimated based on a replacement rate of 4-5%.

dominates the renewable heating and cooling sectors with around 20 GW of new capacity installed each year, including stoves, boilers and CHP units.

With regard to turnover, the solar thermal industry generates more than EUR 3 billion a year through the manufacturing, design and installation of collectors and systems across Europe. The heat pump industry – including both air source and shallow geothermal heat pump systems – generates turnover in excess of EUR 6 billion a year. Air conditioners are not generally considered to be part of the heat pump sector as they do not exploit renewable energy.

While the geothermal industry seems to be the smallest sector in terms of turnover, it must be made clear that the figures do not include direct uses of geothermal energy (e.g. in the agro-food and fishery sectors) or the deep geothermal power industry, which alone accounts for about EUR 1.1 billion in turnover alone and has grown substantially in the past few years.

District heating is an extremely significant sector. The figures quoted in the table refer both to systems using renewable energy (170 TWh/y) and systems using fossil fuels. While there is no straightforward way to calculate the turnover and employment generated, it can be assumed that they are roughly proportional to the heat sold.

Wood stock sales account for the bulk of turnover and employment in the biomass sector, while manufacturing and installation play a lesser role.

The fossil fuel industry leads overall in terms of turnover, mainly due to fuel sales.

The values reported in the table cannot be combined directly and cannot be used for comparison purposes because of the degree of overlap between the industrial sectors: for example, the heat pump industry includes part of the geothermal industry, while the biomass heat sector accounts for much of the renewable district heating sector.

However, looking solely at component manufacturing and system design and installation, the renewable heating and cooling industry represents roughly 40-45% of the market while fossil fuel solutions generate 55-60% of turnover.

Today, the renewable heating and cooling industry (manufacturing, design and installation) employs about 130,000 FTE, while ***the entire sector is responsible for around 370,000 FTE in Europe*** (including heat and biomass sales, excluding fossil fuel district heating networks).

Whereas the renewable industry is largely based in Europe, the global dimension of the fossil fuel industry (mainly fuel sourcing) means that the manufacturing of many low-added value appliances has been delocalised and the turnover is thus generated outside Europe. Electric storage water heaters, gas storage water heaters, electric space heaters and electric instant water heaters may be considered appliances with a lower added value because of their low level of technological content, simpler manufacturing process and high production volume. The manufacturing of these appliances has been delocalised to countries where labour costs are lower, the market share is higher and regulation policies are less strict than in the EU.

Nevertheless, the fossil fuel industry should not be viewed as opposed to the renewable industry: while the renewable industry does include thousands of small and medium-sized enterprises specialised in manufacturing and/or installing systems that use renewable technologies driven systems, it also includes large companies that produce and market systems based on both conventional fossil fuel and renewable energy.

4.3 Analysis of heating and cooling consumers

4.3.1 Main findings from literature

4.3.1.1 Consumer and stakeholder analysis (e.g. consumer segments or gatekeepers)

Within the analysed literature, there is a clear emphasis on the residential segment: ENTRANZE focuses exclusively on this segment, while most respondents to FROnT's survey were residential respondents. In fact, it was even mentioned that single-family homes (SFHs) are a very common focus of scientific research in general, implying that there is a need to include other types of residential buildings (like social housing or multi-family homes, MFHs), not to mention other consumer segments entirely. RESCUE focuses more on the tertiary sector, and STRATEGO on (relatively segment-neutral) districts.

According to the analysis of the relevant literature, ***economic savings*** seem to be a major decision-making factor for all segments, especially residential, along with ***reliability of performance*** (the most important factor for tertiary and industrial). Technological preferences vary considerably among the consumer segments and countries, though it does seem that solar thermal is commonly a popular option. When it comes to district cooling, excess heat from industrial facilities is expected to be a major energy source, though among purely renewable energies, biomass is seen to have good potential. The tertiary sector appears to dominate cooling demand, at least in colder climates (typically around 55%). Cooling loads for residential-segment, comfort-driven consumers are higher in warmer countries, though not necessarily more so than for the tertiary segment, which still accounts for about 40% of the cooling demand. About half of the cooling load seems to be a fairly stable, year-round base load (e.g. for computers, servers, refrigeration).

Some of the most prominent gatekeepers mentioned are installers and building professionals. They can act positively for RHC (e.g. being seen as the preferred source of information about heating and cooling for all three segments) or negatively (e.g. having imperfect or 'fragmented' knowledge, not sharing a 'common agenda' or even contributing to the lock-in effect and technological inertia). Similarly, it has been mentioned that banks lack the training to even recognise all the benefits of supporting RHC investments.

Building ownership seems to be a major factor (at least in the residential segment) that might either speed up decision-making (e.g. SFHs) or delay it (e.g. MFHs). The degree to which this plays a role for the tertiary or industrial segments is not addressed, but it might perhaps be less crucial. However, similar delays in decision-making can still occur in the tertiary and industrial segments due to analogous organisational issues (e.g. budgets separating investments from operational costs, not allowing long-term savings to be fully taken into account). When it comes to district systems, the primary gatekeepers – other than the building owners themselves – appear to be ***local governments and energy companies***. Local governments are important for integrating district energy into (urban) planning/regulations, issuing permits or maybe even investing.

4.3.1.2 Risks and barriers (e.g. consumer perceptions or the tenant-landlord dilemma)

Most risks appear to be associated with the decision-making criteria mentioned above. However, though ***high investment costs*** are routinely found to be a major issue for RHC across all three segments (residential, industrial and tertiary), it seems that industrial consumers are generally even more critical of RHC than other segments are, finding RHC somewhat more risky than traditional technologies not only in terms of costs, but also reliability, sometimes based on poor examples from the past. Part of the concern consumers feel towards these technologies might also be linked to the fact that they seem to have higher expectations of RHC than of non-RE technologies (e.g. higher expected rates of return). Being held to a higher standard obviously influences consumers' perceptions as to the benefit of traditional systems instead of RHC.

Further perceived risks relate to ***disruption of routines*** through the installation of new infrastructure, the riskiness of dependence on new technologies/single providers, or even the availability of the necessary RE resources. A few recommendations can already be identified with a view to overcoming the risks through the development of ***standards, quality assurance procedures, monitoring and warranties***.

Major barriers persist, including an ***overall lack of adequate awareness among consumers***, who cannot fully estimate the overall costs of heating and cooling technologies. These barriers will continue to inhibit RHC growth unless appropriate actions are taken. Incumbent competition, especially from gas, may consolidate itself at the expense of RHC growth, given that infrastructure/grids for it exist already, or even given gatekeepers' familiarity/preference to remain with existing technologies. In some cases, there seems to be competition between decentralised RHC and district systems, regardless of whether or not they are sourced from RE. A lack of RHC (or district heating) technologies in a particular region can itself be a barrier to new consumers unsure about adopting technologies not (yet) used by peers.

Policy support is an important driver for RHC, especially when coupled with financial incentives. However, its impact may be either positive (e.g. grants have the tangential effects of encouraging quicker decision-making or conveying a heightened sense of attractiveness) or negative (e.g. when grants are poorly planned; funds unexpectedly run out; payments are delayed; or rules/procedures change frequently). Other types of policies can also have indirect effects on RHC, both positive (e.g. ***carbon taxes*** make fossil fuels less attractive; restrictions on cultural façades or the prohibition of harmful refrigerants can drive interest away from traditional air-conditioning towards RHC technologies), and negative (e.g. RE obligations might be prohibitively expensive for consumers or local policies might favour on-site/decentralised energy production over district solutions).

Finally, it is also possible that ***financial austerity*** in some countries could hinder RHC growth, not just because of lowered purchasing power, but also because new real estate is not being built (otherwise, it might have been subject to mandated RHC requirements) and existing real estate is remaining empty and therefore has no energy demand of any kind to drive the change.

4.3.1.3 Business models

The projects studied in the literature review provided few details about business models for the RHC sector, with only the RESCUE project addressing this issue (although it only looked at district cooling). While it is possible that this point was not a priority for the other three projects, it may also be that detailed information on the subject is difficult to find.

4.3.2 Main findings from the empirical analysis

Based on the findings from the literature review, the barriers and opportunities for RHC consumers were further explored in the empirical analysis.

4.3.2.1 Key messages

The key messages are based upon those statements that were most frequently mentioned during the interviews. By systematically connecting the respondents' viewpoints to concrete statements and counting the frequency of these statements, the most important issues were identified and the following three key messages were formulated.

The limited decision time available after the breakdown of an existing system is a major obstacle

There are various windows of opportunity for investing in RHC technologies. When a new house is being built or an existing system is being replaced in a newly acquired home or as part of a broader renovation, there is sufficient time to make a considered decision about which heating or cooling system to choose. However, the process of installing a new heating system often starts when the existing system has a problem or breaks down. In that case, the time for decision-making is limited. This leads to the existing system being replaced with the same type of technology, which is the easiest and least complicated solution.

The conclusion is that more time for decision-making may encourage considered decision-making, in which decisions are based on a sound evaluation of the pros and cons of different alternatives.

RHC remain unable to compete at scale due to high upfront investment costs, and despite financial support

For many consumers, the main decision factor is economic in nature, taking in both the installation cost and the operating cost. However, although financial support is available and operating costs are falling, the long-term character of the investment is one of the main barriers to RHC adoption. Heating systems running on fossil fuels such as oil and gas (and hard brown coal in some countries) are still the major competing solutions because of the low price of fossil fuels. This postpones consumers' decisions to replace their existing systems and deters them from choosing RHC when the time comes to make the replacement.

Here, the conclusion is that RHC and fossil H&C are not currently competing on a level playing field, given the cost division between upfront costs and operating costs on the one hand and the low fossil fuel price and lack of external costs (CO_2 emissions) on the other hand. The present incentive structure does not give a clear advantage to RHC professionals and consumers.

Installers are influential, but are not RHC ambassadors yet

Installers play a significant role in consumers' choice of heating and cooling system. Although many consumers try to collect more information from other sources, such as the internet or friends, installers' advice often has a greater impact on their final decision.

Since installers, in particular, tend to have negative opinions of RHC technologies and advise consumers accordingly, the conclusion is that current practice among installers and other installers constitutes a major barrier to RHC adoption. Moreover, additional studies suggest that the trustworthiness of an information source is important: existing (informal) relationships and social proximity foster trust. Consequently, installers and the immediate social network (e.g. neighbours and friends) strongly influence consumers' perception of a technology.

4.3.2.2 Regional findings

The empirical analysis shows that the market diffusion of RHC technologies depends greatly on conditions linked to the national or regional context, including infrastructure development, climatic conditions and regulatory support. The following general findings can be reported for the three European regions addressed in the analysis:

- In northern and north-eastern Europe, RHC technologies (mainly heat pumps and biomass) have already achieved a significant level of market diffusion. Interviewees reported a number of policy and market support measures in Sweden (carbon tax, technology competitions), Estonia (RHC policies, web-based information system for consumers and intermediaries) and Finland, which could be used for further European diffusion.

- There is a mature solar thermal market in south-eastern Europe. Besides climatic factors (relatively low heat demand), the lack of gas for heating (and hot water) has been one of the primary factors driving the market's development.

- In several central European countries, a wide range of political and financial measures have contributed to the growing diffusion rate of RHC like biomass, heat pumps and solar thermal technologies. Nevertheless, all RHC technologies depend on support schemes when in direct competition with fossil technologies.

Region-specific conditions must therefore be borne in mind when seeking to understand the origin of different barriers and opportunities in different contexts, as well as when 'translating' a specific recommendation to a national or regional context.

4.3.2.3 Intermediaries

Information and suggestions are given to the consumer by different stakeholders described as 'intermediaries'. Different types of decision-makers generally deal with different types of intermediaries. Besides installers, the following intermediaries can be considered the most influential for consumers' decisions:

- ***Architects and planners*** play an important role because the choice of heating and/or cooling system is usually incorporated into the design phase of a new building or real estate development.

- ***Governments*** are, of course, important intermediaries for the adoption of RHC solutions, as they can set up subsidies, standards, green certificates, information campaigns, websites, and so on. An additional factor relates to the political aspects of policymaking. RHC solutions are likely to gain more consistent political support if they can convincingly offer other benefits than climate change mitigation; for instance, energy security, air quality and job creation can serve as additional arguments to maintain consistent political support for the necessary policy measures.

- ***Consultants and other expert professionals*** (e.g. universities) play an important role in introducing and disseminating new ideas such as those represented by RHC. A lack of consensus on what constitutes best practice in RHC solutions may be a factor obstructing public acceptance and creating uncertainty and confusion among the general public.

- ***Family, friends and neighbours*** play an important role in providing informal word-of-mouth information about heating and/or cooling options, and can provide visible evidence on the performance of RHC technologies that is trusted by their social networks.

- ***The media*** has a key role in terms of raising awareness about energy concerns and the need for renovation, and highlighting particular issues. However, studies show that the media does not always promote acceptance, and can instead fuel controversies.

4.3.2.4 Decision factors

The main decision factors affecting consumers' choice of heating and cooling system are drawn from several dimensions. The ***social dimension*** relates to factors such as the appearance of systems in/on the building, social status, the added value given to the building, the innovativeness of technology and energy independence. The ***economic dimension*** includes factors like implementation and operating costs (which are also associated with the ease of installing and operating a system) and the payback time of the investment. The ***technology usability dimension*** encompasses factors like the trustworthiness of the technology, the work and time required for installation, the function and quality of the system, the expected comfort level, security of supply, the physical space occupied and the effort involved in operating and maintaining the system. Finally, the ***ecological dimension*** is typically represented by consumers' ecological orientation or goals.

The interview findings on decision factors are generally consistent with findings from the literature review in general and the FROnT project in particular. For example, the interview findings confirm the general view that the initial investment costs constitute a substantial barrier, while lower operating costs provide an economic opportunity. Both the literature review and the interview findings suggest that ecological factors are generally seen as an opportunity, while visual impact and space requirements may constitute a barrier. That said, the findings also highlight that consumers do not always perceive operating costs to be lower. There may also be environmental concerns linked to RHC technologies' emission levels and source fuels. These distinctions must be borne in mind when developing policies and instruments for stimulating RHC adoption.

4.3.3 Opportunities and barriers: an EAST perspective

4.3.3.1 The EAST framework

A pragmatic approach has been taken to the clustering of barriers and opportunities and the issuing of recommendations based on the EAST framework. This framework was developed and extensively tested by the UK Behavioural Insights Team (BIT), a team specifically dedicated to informing governments on incorporating insights from behavioural science into the policy design process. The core idea behind EAST is that policy measures are more likely to succeed if they are designed to make it Easy, Attractive, Social and Timely for people to adopt certain behaviours or decisions.

The EAST framework

Source: Behavioural Insights Team (2012)

Make it Easy, for instance:

- Harness the power of defaults. Making an option the default option makes it more likely to be adopted.
- Reduce the 'hassle factor' of taking up a service. The effort required to perform an action often puts people off. Reducing the effort required can increase uptake or response rates.
- Simplify messages. Making the message clear often results in a significant increase in response rates to communications. In particular, it's useful to identify how a complex goal can be broken down into simpler, easier actions.

Make it Attractive, for instance:

- Attract attention. We are more likely to do something that our attention is drawn towards. Ways of doing this include the use of images, colour or personalisation.
- Design rewards and sanctions for maximum effect. Financial incentives are often highly effective, but alternative incentive designs also work well and often cost less.

Make it Social, for instance:

- Show that most people perform the desired behaviour. Describing what most people do in a particular situation encourages others to do the same. Similarly, policy makers should be wary of inadvertently reinforcing a problematic behaviour by emphasising its high prevalence.
- Use the power of networks. We are embedded in a network of social relationships, and those we come into contact with shape our actions. Governments can foster networks to enable collective action, provide mutual support, and encourage behaviours to spread peer-to-peer.
- Encourage people to make a commitment to others. We often use commitment devices to voluntarily 'lock ourselves' into doing something in advance. The social nature of these commitments is often crucial.

Make it Timely, for instance:

- Prompt people when they are likely to be most receptive. The same offer made at different times can have drastically different levels of success. Behaviour is generally easier to change when habits are already disrupted, such as around major life events.
- Consider the immediate costs and benefits. We are more influenced by costs and benefits that take effect immediately than those delivered later. Policy makers should consider whether the immediate costs or benefits can be adjusted (even slightly), given that they are so influential.
- Help people plan their response to events. There is a substantial gap between intentions and actual behaviour. A proven solution is to prompt people to identify the barriers to action, and develop a specific plan to address them.

Figure 6: EAST framework[20]

[20] Behavioural Insights Team (2012). EAST: Four simple ways to apply behavioural insights. Available at http://38r8om2xjhhl25mw24492dir.wpengine.netdna-cdn.com/wp-content/uploads/2015/07/BIT-Publication-EAST_FA_WEB.pdf

4.3.3.2 Make it EASY: ease of installation and operation

The first dimension of the EAST framework ("Make it Easy") primarily relates to the ***ease of installing and operating RHC technologies,*** which can be a barrier. For solar thermal, the main issues in this regard are the complicated installation process and concerns about dirt in the event that pipes have to be installed in existing buildings. For biomass, the use of biomass fuel requires ash removal and occasional cleaning of fuel storage areas. For geothermal, the planning and installation process takes several months, making it practically impossible to adopt a geothermal solution if a system needs to be installed urgently. During the validation workshops, the relative complexity of RHC systems compared to conventional solutions was identified as a major barrier to RHC adoption from a consumer standpoint. Moreover, RHC often only provides some of the heat required by homes (e.g. homes with heat pump still need a gas or electrical boiler for domestic hot water). From the installers' point of view, it is not easy to work with RHC. Installers find the installation of RHC systems relatively difficult, are generally not familiar with RHC technologies, are reluctant to undergo training in RHC installation and find the bureaucratic work of applying for financial support complex. The validation workshops stressed both the need for standardisation to facilitate technical designs and avoid design errors and the need for performance assessment.

However, some features of RHC technologies are considered easy, thus providing opportunities. For example, air-to-water heat pumps and, in many cases, solar thermal boilers are deemed easy to install and operate, and geothermal is relatively easy to maintain. To create leverage, it is therefore important to eliminate barriers, but also exploit opportunities to create a positive perception regarding the easiness of the technology.

4.3.3.3 Make it ATTRACTIVE: business model

The second dimension of the EAST framework ("Make it Attractive") covers a variety of decision factors. One feature of attractiveness is a ***viable business model***, which relates mostly to the economic decision factors and the value added to the building. For most technologies, economic factors are considered a barrier: the relatively high upfront investment costs (compared to fossil fuel options) and the long payback time are viewed as obstacles for all technologies. The operating costs of biomass solutions are often mistakenly believed to be high, while for heat pumps, the high price of electricity and low price of fossil fuels challenges the positive image of cheap operating costs.

In terms of opportunities, the low running costs and long-term benefits stand out across all the RHC technologies studied. For air-to-air and geothermal heat pumps, the advantage is all the greater when renewable energies (e.g. PV) are used to supply the heat pump with electricity. The value added to the building further bolsters the business case.

4.3.3.4 Make it ATTRACTIVE: non-monetary costs and benefits

Attractiveness requires more than a viable business model. RHC technologies deliver a host of ***non-monetary benefits*** that support the business case. This aspect relates to a variety of decision factors, some of which are considered barriers to RHC adoption (physical space occupied, system appearance), some of which are viewed as opportunities (independence from the heating supply/energy security), and some of which are both (ecological considerations, function and quality of the system).

During the validation workshops, the ability of air-to-air and geothermal heat pumps to provide cooling as well as heating (part of the function and quality of the system) was identified as giving RHC technologies an edge over conventional technologies, especially in southern Europe. However, the noise emitted by air-to-water heat pumps is still perceived to be a problem. In general, the environmental benefits of RHC technologies were highlighted as especially persuasive. For instance, the positive impact on local air quality could win consumers over to RHC solutions, particularly in countries where coal or fuel oil are commonly used. Be that as it may, these benefits may be offset by concerns about unsustainable biomass production or the use of fossil-fuel based electricity to power heat pumps. Finally, the interview results suggest that independence is an important non-monetary benefit. This encompasses the greater autonomy consumers may experience, the use of more local resources, and the lesser dependence on fossil-fuel energy prices. All in all, while some drawbacks still need to be overcome, RHC offers a number of non-monetary advantages over fossil fuel-based H&C and these could be exploited to persuade consumers to adopt RHC technologies.

4.3.3.5 Make it ATTRACTIVE: awareness and trust

Awareness and trust also feed into perceived attractiveness. Ultimately, it is consumers' perception of the performance of RHC solutions that counts, and this is greatly influenced by awareness and trust. Where technologies like solar thermal and heat pumps enjoy a high market penetration rate, trust in the technologies' performance is generally high. Consumers also tend to be familiar with biomass as an energy source, creating a positive perception of this RHC technology. However, where RHC technologies are new to the market, some scepticism may be encountered. For biomass technology, for example, some consumers fear that biomass systems might provide a lesser comfort level than old fossil fuel systems. Where heat pumps are still new to the market, many consumers view them as a risky investment. Finally, the positive perception of function and quality for solar thermal and heat pumps is, to some extent, compromised by negative past experiences resulting from a lack of maintenance or improper installation. This highlights the substantial impact that pioneering applications could have on the perception of RHC technology.

4.3.3.6 Make it SOCIAL: role of installers

"Make it Social" covers the decision factors of ***social status*** and – indirectly –***technology innovativeness*** as the main contributor to social status. For both air-based and geothermal heat pumps, consumers are often proud of having the technology and talk to their friends and neighbours about it. These positive associations with RHC technology can be embraced as an opportunity to boost RHC roll-out.

A common insight is that existing (informal) relationships and social proximity instil trust. Installers and consumers' immediate social networks (e.g. neighbours and friends) strongly influence consumers' perception of a technology. Word-of-mouth information – whether positive or negative – has a significant bearing on the spread of views on technologies. This is all the more true if the technology itself is visible, such as in the case of geothermal heat pumps; here, social proximity may have a substantial impact. These social dynamics offer an opportunity to spread a positive perception of RHC technologies. This opportunity could be more actively harnessed by stimulating local initiatives, for instance.

4.3.3.7 Make it TIMELY: windows of opportunity for RHC installation

The fourth dimension of the EAST framework ("Make it Timely") relates primarily to the conditional level of the analytical framework, particularly ***windows of opportunity for RHC installation.*** The limited decision time available after the breakdown of an existing system is considered a major obstacle. However, other windows of opportunity exist, such as the (energy-related) renovation of an existing building or the construction of a new building. The main lesson is to be aware of the (im)possibilities presented by particular windows of opportunity and adapt to these windows in the timeliest fashion.

4.3.3.8 Make it TIMELY: RHC policy vision and regulatory frameworks

Timeliness also relates to the ***development of an RHC policy vision and relevant regulatory frameworks.*** In the validation workshops, the lack of drive for a heating and cooling transition was recognised as a significant barrier to the deployment of RHC. However, the current consensus on long-term climate goals justifies creating such a sense of urgency and provides an opportunity for developing a clear long-term policy vision on RHC, combined with short-term actions. Political feasibility was reported as a barrier to regulatory measures (such as introducing a CO_2 tax or banning fossil fuel HC). However, examples from countries like Denmark and the Netherlands show that when the time is right, initiatives can indeed be taken in this direction. Finally, with regard to the development of subsidy schemes, over-subsidy followed by support removal was reported as a major obstacle leading to market collapse and loss of trust in innovative solutions. Timeliness is therefore a key consideration when implementing support schemes too.

5 CONCLUSIONS AND POLICY RECOMMENDATIONS

5.1 Research priorities for the RHC sector

The analysis performed by monitoring the KPIs featured in the various technology roadmaps has highlighted:

- the research and innovation areas in which projects have flourished, enabling the RHC technology in question to gain a competitive edge over international competitors;
- the research and innovation areas at which more efforts need to be directed;
- a need to update the research and innovation areas from those identified in 2014, in order to reflect the changes implemented in the past years;
- a need to revise some KPIs, as a number of them do not allow for proper monitoring – this is most notably the case for hybrid systems, where the lack of a clear definition and parameters has prevented a full analysis of the technology's status.

The latest version of the RHC-ETIP Strategic Research Agenda was published in 2012. The research and innovation priorities must be updated to reflect the new information that has been gathered through the monitoring exercise and take account of initiatives that have been launched recently and have set additional and revised targets (e.g. SET Plan Implementation Group on Deep Geothermal). To this end, some information has already been collected with this study and is reported (broken down by technology) in Annex II. However, the RHC-ETIP is planning to initiate a more general exercise under the new Horizon 2020 Coordination and Support Action launched to support the secretariat (SecRHC-ETIP); among other things, this will involve updating the following strategic documents:

- Vision (2019);
- Strategic Research Agenda (2020);
- Deployment and Innovation Strategy (2021).

The restructuring of the RHC-ETIP (started in 2017), which entails the creation of Horizontal Working Groups dedicated to cross-cutting issues instead of specific RHC technologies, will also affect the way research and innovation areas are defined in future. In fact, the new approach adopted by the RHC-ETIP is geared towards additional integration between the different technologies.

5.2 Support for the EU RHC industry

The analysis of the heating and cooling industry highlighted the need to continue implementing measures to foster the development of the RHC industry and enable it to remain competitive worldwide.

The adoption of the EU *Clean energy for all Europeans* package is an important first step. Although it is still to be transposed into national law, it opens the door for EU Member States to develop strategies that will bring them closer to achieving the Paris Agreement goals and the EU's 2050 energy targets.

Below are several recommendations on actions to encourage the further development of the heating and cooling industry at EU and international level:

- ***Fossil fuel subsidies must be phased out urgently***

- Solutions must be found to the challenge of ***financing the consumer's upfront investment*** (for instance, measures to boost energy efficiency and implement renewable energy technologies should be taken simultaneously, especially in the building sector).

- Existing legislation must be implemented and a ***new regulatory framework*** developed to ensure the integration of RHC technologies in buildings, industry and smart thermal grids (strengthening existing measures beyond 2020 to encourage the renovation of the existing building stock).

- ***2030 governance***: in the absence of binding national energy targets, a strong governance system for renewables and energy efficiency is needed. This must ensure consistency and comparability of Member States' policies and must also include indicators for tracking building renovation rates and the introduction of renewable heating and cooling technologies.

- ***Fostering research, development, and innovation***: more attention should be paid to the energy system as a whole, to the development of smart thermal grids and to new industrial processes capable of decarbonising non-ETS sectors. It is important to highlight that R&I investments for RHC should be considered separately from investments focused on electricity. While sector coupling may act as an enabler by connecting these two areas, their technology development and system integration should nevertheless be addressed separately. 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).

5.3 Eliminate barriers and exploit opportunities for RHC consumers

The literature expresses a consistent view of relevant consumer decision factors for RHC technologies in the residential sector, and this view was borne out by the analysis of heating and cooling consumers. While economic factors (high upfront investment costs and associated energy savings) and performance reliability are key, they are not the only factors to consider. Depending on specific consumer preferences, a variety of other factors play a role, including social factors, technological usability factors and ecological factors. On the whole, consumers still lack of awareness of the functioning and benefits of RHC technologies; this problem is inherent to new technologies that are not yet widespread. Quite apart from consumer-related decision factors, prominent gatekeepers like installers and building professionals have a strong influence on investment decisions for RHC. Building ownership is a significant factor for understanding consumer decision-making, as it determines who the end consumer is, which are the main intermediaries, and whether split incentives play a role. In society as a whole, RHC technologies need to overcome incumbent competition, especially from gas, and require a ***disruption of routines***, i.e. a shift away from investing in fossil fuel-based systems and towards investing in RHC systems as the new standard.

The full spectrum of opportunities and barriers identified matches well with the key dimensions of the EAST framework for understanding and promoting behavioural change:

- ***Easiness*** is reflected in the importance of the ease of installing and operating RHC technologies for both consumers and installers.

- ***Attractiveness*** relates to the importance of a viable business model, as well as non-monetary costs (like the physical space occupied) and benefits (like ecological benefits and the system's ability to provide both heating and cooling) and the role of awareness and trust in creating a positive perception of RHC technologies.

- ***Social influences*** include the influential role of installers, as well as aspects linked to social status and proximity, through which positive associations with RHC technology are easily spread among neighbours, friends and relatives.

- ***Timeliness*** concerns the relevance of windows of opportunity for RHC installation and the timely development of an RHC policy vision and regulatory frameworks to create a sense of urgency and facilitate the implementation of RHC technologies.

While the analysis identifies many barriers, it also highlights a wealth of opportunities for the adoption of RHC technologies. There is therefore much to gain from eliminating barriers and enhancing opportunities with a view to making RHC adoption easier, more attractive, more social and timelier.

This report provides a range of policy recommendations to this end. They have been grouped on the basis of the four principles of the EAST framework ("Make it Easy, Attractive, Social and Timely"). As shown in Table 6, a policy recommendation or 'policy message' is given for each major barrier or opportunity. Under each policy message, several practical recommendations are issued through which the main policy message may be implemented.

The list of policy recommendations based on the EAST principles should not be viewed as a silver bullet, nor considered comprehensive. Rather, it constitutes an extensive list of practical recommendations on operationalising the main policy messages emerging from this study. The recommendations should be weighed up and applied in the context of national or regional energy transition plans or strategies, bearing in mind the current state of the heating and cooling sector and the associated strategic priorities. Given that most RHC solutions are still more expensive than fossil-fuel alternatives, the impact on the least well-off in society should be carefully considered to avoid issues linked to social inequalities. In sum, the application of our recommendations should always be viewed in the context of the energy transition in a particular country or region, and consistency with existing (or future) transition strategies or plans should be checked thoroughly.

	Barriers and opportunities	Recommendations
Easy	Ease of installation and operation (for consumers and installers)	*Make it easy for consumers* • Introduce a one-stop shop for energy retrofits (E1) • Develop standardised RHC (package) products for the residential and small commercial sector (E2) • Promote ESCO (Energy Service Company) approaches (E3) • Develop clear energy labelling for heating and cooling solutions, including for standardised package products (E4) *Make it easy for professionals* • Provide project development support for larger projects (E5) • Improve and expand training for heating and cooling professionals (E6) • Develop and promote the use of tools that allow for easier consumer targeting (E7)
Attractive	The business model Non-monetary costs and benefits Awareness and trust	*Improve the business case* • Introduce a carbon tax (A1) • Reduce the tax on electricity for heat pump usage (A2) • Give upfront rebates for RHC solutions (A3) • Make offers with life-cycle costs and stress the 'future-proof' character of buildings with RHC systems (A4) *Communicate multiple benefits* • Emphasise the ability of RHC technologies to provide heating AND cooling (A5) • Stress the beneficial impact of RHC solutions on health (A6) *Improve trust* • Lead by example (A7) • Organise public procurement of RHC technology (A8) • Implement quality assurance for RHC solutions (A9) • Set up a consumer complaint board (A10)
Social	Role of installers Social status and proximity	*Engage installers* *See E5-E7* *Encourage local action* • Develop local RHC transition plans (S1) • Implement procurement programmes at local community level (S2) • Harness the power of cooperatives (S3)

Timely	Windows of opportunity for RHC installation RHC policy vision and regulatory frameworks	*Seize the windows of opportunity of RHC installation* • Prevent system failure (T1) • Promote or mandate RHC technologies as part of energy retrofits (T2) • Include renovation roadmaps in EPC certificates (T3) *A timely RHC policy* • Develop and communicate a long-term decarbonisation plan for the heating and cooling sector, including intermediate milestones (T4) • Introduce, as soon as possible, a requirement to install RHC technology in new buildings (T5) • Gradually phase out fossil fuels in the built environment (T6) • Adapt government incentive programmes to the development of the RHC market (T7)

Table 6: Summary of policy recommendations to drive consumers' choices

6 ANNEX I: MONITORING OF THE FIVE RHC ROADMAPS – EXAMPLES OF REPORTING TABLES

Annex I presents examples of the KPIs monitored in each technology area.

The same table was used to report on the implementation of the five RHC-ETIP roadmaps, for all the technologies:

- The first column presents the Key Performance Indicators (KPIs) as reported in the Common Implementation Roadmap, which was published in June 2014 and is available on the RHC-ETIP website (http://www.rhc-platform.org/content/uploads/2019/04/RHC_Common_Roadmap.pdf).
- The second column reports the value of the KPIs on the date of analysis and indicates whether the KPI has been achieved, is on track to be achieved, or needs to be revised (if the KPI is achieved or partly achieved, the cell is green).
- The third column substantiates the information presented in the second column by detailing relevant literature references and citing examples.
- The last column presents information on relevant ongoing projects in non-European countries with a view to highlighting those research areas where third countries could have a competitive advantage over Europe.

6.1 Biomass

The table below shows the progress made on the KPI on biomass supply costs for forest biomass

R&I priority: **SUSTAINABLE, INNOVATIVE AND COST-EFFICIENT ADVANCED FUEL FEEDSTOCK SUPPLY (for advanced fuels replacing coal, fossil oil and natural gas in heat and CHP production)**			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
Biomass supply costs for forest biomass *(2013: EUR 20-25/MWh = EUR 5.60–6.90/GJ (Nordic countries, eastern EU) EUR 25-35/MWh = EUR 6.90–9.70/GJ (central and southern EU); 2020: 30% reduction through the use of intelligent machinery and optimised supply chain concepts)*	Taking into account new and innovative methods, the INFRES[21] project estimated a supply cost of EUR 8–17/MWh (excluding stumpage) for a range of regions and feedstocks. The 2020 cost reduction target can be reached if new technologies are applied and supply chain management uses advanced technologies. **This KPI is on track.**	The biomass supply sector has developed projects focusing on improving logistics and supply chain management, often through smart systems (e.g.	**US**: Validated feedstock supply and logistics systems that can deliver feedstock at or below USD 84/dry (US) ton (2014 USD) = **USD 7.54/GJ (2018 USD with inflation of 6.82% between**

[21] https://www.efi.int/projects/infres-innovative-and-effective-technology-and-logistics-forest-residual-biomass-supply-eu

R&I priority: **SUSTAINABLE, INNOVATIVE AND COST-EFFICIENT ADVANCED FUEL FEEDSTOCK SUPPLY (for advanced fuels replacing coal, fossil oil and natural gas in heat and CHP production)**			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
		FOCUS)[22], improvements to the qualitative parameters of energy wood or increased wood waste recovery (e.g. LignoSilva[23]). SME projects have been funded to develop certain aspects of the supply. These innovations need to be deployed if the 2020 target is to be achieved in full.	**2014 and 2018)**. Same price estimated for 2020[24]. **China**: China is looking to develop its bioenergy sector. Today, the focus is more on exploiting existing feedstock (mostly agricultural). China is relying on foreign technologies (EU, US) to develop this sector. The targets are set by China's 13th Bioenergy Development Five-Year Plan (2016-2020).

[22] FOCUS 1/2014-6/2016 (EUR 4,054k, EU: EUR 3,054k): Advances in forestry control and automation systems in Europe
[23] LignoSilva 06/2015-05/2016 (EUR 178k): Centre of Excellence of Forest-based Industry http://cordis.europa.eu/result/rcn/190436_en.html
[24] https://www.energy.gov/sites/prod/files/2017/09/f36/beto_strategic_plan_december_2016.pdf

The table below shows the progress made on the KPI on co-firing percentages.

R&I priority: ADVANCED FUELS REPLACING COAL, FOSSIL OIL AND NATURAL GAS IN HEAT AND CHP PRODUCTION - Status of thermally treated densified biomass fuels production Contributors: Michael Wild (International Biomass Torrefaction Council [IBTC]), Jukka Makinen (Valmet)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
Co-firing percentages *(2013: 5-10% biomass co-firing of torrefied biomass with coal* *2020: Commercial operation of thermally treated biomass co-firing >50% of coal CHP plants using torrefied biomass)*	Successfully demonstrated: **Torrefied pellets:** 2018: EU 50% **Steam-exploded pellets:** Only limited quantities of steam-exploded pellets have been made available (one demo plant in Norway and one in the US, plus an idling commercial plant in the US). The US plant will be back in operation in 2019 (target capacity > 240 kt/y in 2020). A new commercial steam exploded pellet plant will be commissioned in 2020 in	**Torrefied pellets:** Black and Veatch report, Una Noling IBTC **Steam-exploded pellets:** https://www.power-eng.com/articles/print/volume-122/issue-3/features/world-s-first-coal-to-biomass-conversion-using-advanced-wood-pellets.html https://www.businesswire.com/news/home/20181005005397/en/Zilkha-Biomass-Fuels-LLC-Completes-59.8-Refinancing http://www.ebiomass.eu/wp-content/uploads/2018/07/Européenne-de-Biomasse-investit-100-millions-deuros-dans-la-Marne.pdf	**Torrefied pellets:** US: 100% demonstrated **Steam-exploded pellets:** Zilkha Black™ Pellets have been successfully co-fired at rates of up to 50% substitution for coal, with no changes to the processing equipment[25].

[25] https://www.businesswire.com/news/home/20181005005397/en/Zilkha-Biomass-Fuels-LLC-Completes-59.8-Refinancing

R&I priority: ADVANCED FUELS REPLACING COAL, FOSSIL OIL AND NATURAL GAS IN HEAT AND CHP PRODUCTION - Status of thermally treated densified biomass fuels production Contributors: Michael Wild (International Biomass Torrefaction Council [IBTC]), Jukka Makinen (Valmet)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
	France (capacity: 120 kt/a). Steam-exploded black pellets act like coal and can be co-fired with coal at rates of up to 70% in larger units and up to 100% in smaller units.	http://www.arbaflame.no/start-european-research-project-converting-coal-fired-power-plant-biomass/ https://www.valmet.com/more-industries/bio/bio-coal/	

6.2 Geothermal

The table below shows the progress made on the KPI on reducing the cost of drilling and underground facilities

R&I priority: DEEP GEOTHERMAL- DEEP GEOTHERMAL DRILLING *Improve current drilling technologies (GEO D 4)*			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the values provided**	**Situation in relevant third countries**
The target is to reduce the unit cost of drilling (EUR/MWh) by 15% by 2020, 30% by 2030 and 50% by 2050 (baseline: 2015).	An average reduction in drilling cost of 5-10% has been measured between 2015 and 2018.	The current market conditions for commodities are contributing to lower drilling prices: in some European countries, drilling was 30% less expensive in 2018 than in 2015. Here are some examples of projects in which a cost reduction was achieved: • ETH Zurich (spallation drilling) • Fraunhofer Institute (laserjet drilling) • University of Dresden (electro-pulse drilling): development and testing of an electric pulse-method drill head for deep geothermal (EIV) • HH300 geothermal drilling facility • DIRT Drilling with fibre-reinforced composite material	In the **US**, a specific research programme dedicated to cost reduction for drilling is supported by the DoE, targeting especially SMEs. **China** is also working in this area. The same results have been achieved in these two countries: 5-10% reduction in the cost of drilling between 2015 and 2018.

		• ThermoDrill: fast-track innovative drilling system for deep geothermal challenges in Europe • DESCRAMBLE: drilling in supercritical geothermal conditions • InnoDrill: technology platform for research-based innovations in deep geothermal drilling	

6.3 Solar thermal

The table below shows the progress made on the KPI on solar compact hybrid systems as a prototype for single-family homes.

R&I priority: SOLAR COMPACT HYBRID SYSTEMS (SCOHYS)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
By 2017, **SCOHYS** will be available **as a prototype for single-family homes** (DHW and combi systems) and for multi-family homes (DHW), with solar heat costs reduced by 35% from 2013 levels, resulting in fossil fuel parity in southern Europe (< EUR 0.10/kWh).	KPI price target defined on KPI not achieved yet: < 0.10 EUR/kWh. SCOHYS is available on the market, covering SFHs (DHW and combi) and small MFHs (DHW). The level of price reduction attained depends on the reference price, which was not defined in the roadmap. In this case, analysis must be performed on a project-by-project basis. The SySTHEff project achieved a 30% reduction from 2012 levels. Fuel parity is harder to reach given that fossil fuel prices have decreased in recent years.	The review of ongoing or recently completed projects revealed 11 projects (PROSSIS2, SAM.SSA, MERITS, SCHEFF, TESSe2b, WPSol, iNSPiRe, MacSheep, COMTES, HP-LP-SOLAR-FAÇADE, UniSto, Tes4seT and SySTHEff) focusing on SCOHYS, for a total value of approximately EUR 41 million. Four of these (iNSPiRE, SySTHEff, MacSheep and HP-LP-SOLAR-FAÇADE), with a total value of EUR 22.2 million, were mostly in line with the KPIs. Several noteworthy initiatives were identified in various countries (the SySTHEff project in France, MacSheep at European level). More projects must be funded and launched in this field to better develop the technology for the future. Cost reduction was a main goal of the SySTHEff (FR), COMTES (EU), SAM.SSA	The SCOHYS concept, as presented in the roadmap, is very specific to the European market. No relevant R&D projects addressing SCOHYS were identified in other markets. Other hybrid concepts exist in markets such as Japan, though these do not focus on solar.

R&I priority: SOLAR COMPACT HYBRID SYSTEMS (SCOHYS)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
		(EU), WPSol (DE) and STS2020 (DE) projects, while most of the projects looked at increasing the compactness of the systems. Solutions with gas or heat pumps exist on the European market, and solutions combining solar thermal with hybrid 'heat pump/gas boiler' systems have also emerged recently. However, no studies have been conducted on the performance and energy costs of these.	

The table below shows the progress made on the KPI on solar active houses with a solar fraction of 60% for new-build single-family homes.

R&I priority: SOLAR ACTIVE HOUSE (SAH)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
By 2017, **SAH60**[26] **for new-build single-family homes** will be ready for the market as a standardised solution, and it will be possible for all professional planners and construction companies to apply it using a sophisticated design tool.	No standardised solution was available to the market in 2018. The identified projects only cover some aspects of SAH60 and are not based on standardised solutions. An integrated approach to the overall SAH concept is lacking. The projects relating to SAH are, in themselves, insufficient to achieve standardisation. Public funding is focused on generic nZEB[27] concepts. Private funding is scarce, with limited engagement and ambition from the main heating industry players.	According to the review of ongoing and recently completed projects, there are no projects addressing the overall concept of SAH. There are several projects tackling individual aspects of SAH, such as storage or components (e.g. low cost collectors, heat exchange, façades). Nine projects (THERMALCOND, SCOOP, SolSys, COMTES, HP-LP-SOLAR-FAÇADE, ECOSS, SARTEA, STAID, UniSto and Tes4seT) with a total value of EUR 12.5 million were more directly related to SAH. The HeizSolar (DE) and ECOSS (FR) projects contributed more directly to the goal of standardisation, while projects such as HP-LP-SOLAR-FAÇADE (EU), Tes4seT (AT) and SCOOP (EU) contributed to the goal of cost reduction. Various initiatives in Europe deal with a variation on the solar active house presented in the roadmap, combining solar thermal with PV in a bid to achieve a 100% solar energy house.	Outside Europe, there appeared to be no R&D projects for solar active houses whose solar thermal systems achieve such high solar fractions as 60%. As in Europe, research is focused on nZEB concepts. A good overview is provided by the ICEF nZEB/ZEH Roadmap, which views solar as a contributor to nZEB concepts rather than the main driver. Interesting funding programmes for nZEB or active houses with a substantial solar component were identified in **Japan** (NEDO).

[26] Solar active houses with a solar fraction of 60%
[27] Nearly zero-energy buildings

The table below shows the progress made on the KPI on the cost of solar heat.

R&I priority: Solar Heat for Industrial Processes (SHIP)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
By 2017, the SHIP roadmap pathway will achieve **solar heat costs** in the range of EUR 0.05-0.09/kWh for systems with a solar fraction of 10-20% by reducing investment costs to EUR 350/m² for low-temperature SHIP systems (including storage) and EUR 400/m² for medium-temperature SHIP systems (without storage).	The target prices have been reached under research conditions, both for lower temperatures (EUR 210/m²) and higher temperatures (EUR 412/m²). However, under research conditions, some costs (e.g. those linked to design and engineering) are not taken into account as they would be in a commercial project. Solarbrew achieved EUR 210/m² with a solar fraction of 19%. As for medium temperatures, Fresh NRG reached EUR 412/m², which can be deemed to be within an acceptable margin of the target. The key issues are: - low energy costs (fossil fuels) - access to large machinery suppliers, to shape system design - availability/cost of land near relevant industries - the need for more data on existing systems	The project review looked into projects directly linked to the SHIP concept or addressing SHIP-related work topics. The review identified twelve ongoing or recently completed projects that ran beyond 2013 and were related to SHIP: SAM.SSA, SnowRESolution, Sunstore 4, helioSTEAM, SOLEGLASS, ENTHALPY, Re-Deploy, SGSTh, UniSto and Solarbrew (total value: approximately EUR 43 million). Most of these projects deal with the cost optimality of SHIP systems and their integration into relevant industrial applications.	Information from the Solarpayback project indicates that in one case in **Mexico**, pasteurisation at 78°C was achieved with investment costs of USD 250/m².

6.4 Heat pumps

The table below shows the progress made on the KPI on the reference thermal system (and single unit) SCOP.

R&I priority: Optimisation of thermally driven heat pumps and their integration in the boundary system (CCT.2)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
Reference thermal system SCOP (e.g. for air source) *(2012: 1.15; 2016: 1.25; 2020: 1.4)*	2018: 1.25	These two KPIs should be merged, as the reference value of electricity consumption for single units is dependent on the distribution system. These two KPIs need to be revised because the values should be measured in SGUE (Seasonal Gas Utilisation Efficiency). Unlike SCOP, SGUE takes gas burner efficiency into account. Third-party measurements are not (yet) publicly available, but the increased trajectory from 2012 to 2020 seems reasonable. For instance, Robur	**Canada: Priority relevant** Thermally driven heat pumps do not have a large market in Canada. The current decarbonisation strategy is geared more towards replacing gas boilers with efficient electrical solutions (e.g. heat pumps). The low gas price could make this solution viable as a first step towards decarbonisation, but further training for installers is needed. Work for the IEA Heat Pump Programme Annex 40 indicated that thermally driven heat pumps were a solution for nearly zero-energy buildings, but no R&D was performed on the subject. Reference: https://bit.ly/2C9eXZC **Japan: Priority relevant** Domestic applications remain relatively uncommon (accounting for only 7% of the market). Japan is a unique market for commercial thermally driven heat pumps. According to the report published by EU-funded project ProHeatPump, more than 40,000 units with capacities ranging from 20 to 100 kW have been sold and installed in Japan since 1998. These units were mainly installed in schools, offices, commercial or industrial buildings, and hotels.
Reference thermal single unit SCOP (e.g. for air source) *(2012: 1.25; 2016: 1.4; 2020: 1.5)*	2018: 1.4		

R&I priority: Optimisation of thermally driven heat pumps and their integration in the boundary system (CCT.2)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
		Advanced Heating and Cooling Technologies has achieved 1.57 SGUE for a ground source heat pump for a low-temperature underfloor heating system (A0, W35[28]). For air source units (A10, W55[29]), Robur and Bosch have achieved 1.25 SGUE at 55°C (W55[30]). **This KPI is on track for 2020.**	Four Japanese companies currently sell gas heat pumps. York (US) started marketing GHPs in the 1990s, but discontinued them due to low sales. Examples of companies selling thermally driven heat pumps in Japan: - AISIN (capacity: 14-56 kW) - MHI (capacity: 40-71 kW) - Yanmar (capacity: 33-67 kW) (Reference: https://bit.ly/2Fh7YRA)

[28] Using outside air as a heat source, with an air temperature of 0°C (A0, A = air) and a heated water temperature of 35°C (W35, W = water);

[29] Using outside air as a heat source, with an air temperature of 10°C (A10, A = air) and a heated water temperature of 55°C (W55, W = water);

[30] Water temperature of 55°

The table below shows the progress made on the KPI on demonstrating absorption heat pumps in real-life plants.

R&I priority: Process integration, optimisation and control of industrial heat pumps (CCT.13)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
Demonstration in real-life plants of absorption heat pumps using new working pairs (avoiding crystallisation effects) *(2012: N/A; 2016: one demo plant with availability rate of 70%; 2020: four plants with availability rates of 95%)*	2018: No relevant change since 2012 (no ongoing demos).	Several companies and research institutes within the EHPA network are interested in attempting to secure public funding for projects in this area (currently looking into national, EU and Mission Innovation opportunities).	**China: Priority relevant** Heat pump applications in industrial processes are a fast-growing market in China (especially for drying purposes). Reference: https://bit.ly/2AAPCrC Chinese products have already achieved most of the KPIs listed for this priority. **US: Priority relevant** Energy costs are still driving industries towards different solutions (running on gas or coal). Most of the examples found for industrial applications are in the food and beverage or paper industries, which require temperatures of 80-90°C. For instance, Kraft uses industrial heat pumps in its Iowa factory. Reference: https://bit.ly/2yS9WE0 **Australia: Priority relevant** According to the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) industrial heat pumps are rapidly gaining ground in Australia, especially for sectors such as food, pulp and paper, and dairy manufacturing. The *Electrifying Industry* report highlights the benefit of replacing gas boilers with industrial heat pumps in Australia. For instance:

R&I priority: Process integration, optimisation and control of industrial heat pumps (CCT.13)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
			- Energy savings of 66% could be achieved in milk powder and beer production; - Energy savings of up to 50% could be achieved across the food sector. Furthermore, gas and electricity prices have been rising in recent years, providing greater impetus for the adoption of industrial heat pumps. The study also mentions the potential of new heat pumps to reach temperatures of 160°C and the fact that this would widen the range of applications. Reference: https://bit.ly/2Ro8X5l A few examples in the food and drink sector: - Lobethal Abattoir, South Australia - Shene Estate Distillery, Tasmania - Salt processing facility, Victoria All these applications have secured average energy savings of 40% and deliver temperatures of up to 90°C. Reference: https://bit.ly/2FcYyqq **India: Priority relevant** There is no real market for industrial heat pumps in India. Most industries use fossil fuel solutions. No significant R&D is being conducted in the field, though the Indian Institute of Technology Bombay and the Birla Institute of Technology & Science are looking at applying the technology for industrial processes up to 100°C.

			Example: the research conducted by Simarpreet Singh from the Birla Institute of Technology and Science (*CO_2 Heat Pump System for Waste Heat Utilization in Warm Weather Condition Applied to a Milk Refrigeration Plant*). Reference: https://bit.ly/2SKwEWz A few companies have already installed heat pumps in their factories: Ashok Leyland (an Indian car company) has installed heat pumps in three of its plants in India. The heat pump replaces the electric heaters in the washing machines and delivers 80°C. Refrigerant used: R134A. Reference: https://bit.ly/2VIb9I2 Lucas-TVS Ltd (manufacturer of automotive electrical systems) decided to install a heat pump for the pretreatment component of the surface coating process. Temperature delivered: 95°C. Refrigerant used: XP140. Reference: https://bit.ly/2FkUswh **Canada: Priority relevant** There is currently little market for industrial heat pump applications, but they have recently attracted more interest and the market is expected to grow as soon as the gas price increases. Part of the final report prepared by the participants in Annex 35/13 of the IEA Heat Pump Programme showed that several industrial sectors in Canada would benefit from more industrial heat pumps. The study looked at 339 plants (in the food and drink, pulp, textile, petroleum, and lumber sectors) and found that only a little over 7% used industrial heat pumps (mostly for drying processes). The main barrier to market uptake is the low price of gas and oil, compared to the relatively high price of electricity. Reference: https://bit.ly/2CVXMN2 Canada has supported a number of R&D studies followed by in-field applications. They mainly focused on high-temperature heat pumps capable of recovering heat at

R&I priority: Process integration, optimisation and control of industrial heat pumps (CCT.13)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
			relatively low temperatures and producing hot water at temperatures between 45 and 85°C or hot air up to 95°C for high-temperature drying processes. As Canada is committed to undertaking a transition to more environmentally friendly refrigerants, these projects used natural refrigerants, such as carbon dioxide and ammonia. Reference: https://bit.ly/2SJdvUP. **New Zealand: Priority relevant** The Energy Efficiency and Conservation Authority is designing a heat pump pilot project to support broader application of high-temperature heat pumps for industrial heating processes and building heating. Reference: https://bit.ly/2QtEiCU. In its report, the Authority also advises the New Zealand Productivity Commission (with regard to the fuel switching and electrification strategies) to look into high-temperature heat pumps as a replacement for fossil fuels for low-temperature process heat (<100°). **Japan: Priority relevant** Japan is very advanced in this area, in terms of both R&D and project demonstrations. The introduction of industrial heat pumps mostly began with a view to substituting existing boiler systems for the production of high-temperature hot water or steam.

R&I priority: Process integration, optimisation and control of industrial heat pumps (CCT.13)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
			Japan was part of the IEA Heat Pump Programme (HPP) Annex 35 (*Industrial Heat Pumps*) and is one of the participants in HPP Annex 48 (*Industrial Heat Pumps, Second Phase*). Among the many best-practice examples highlighted in Annex 35 were six cases, evaluated by experts, that examined the simultaneous production of heating and cooling, vapour recompression, high-temperature heat production and the application of heat pumps in agriculture (in conventional outdoor greenhouses, where heat pump systems could replace heavy oil combustion boilers). It has been reported that in test applications of these heat recovery heat pumps, primary energy, CO_2 emissions and running costs have been reduced by 40-60%. Examples and references: https://bit.ly/2VEW49P **Turkey: Priority relevant** Industrial heat pumps are gradually making headway on the Turkish market. While the market uptake of such solutions remains low (around 100 units sold per year), they have been presented and discussed in numerous conferences and workshops throughout Turkey. Today, industrial heat pumps are mainly applied in industrial sectors requiring temperatures below 100°C (e.g. the textile sector). Products that can provide higher temperature have not yet been tested on the market.

6.5 District heating and cooling

The table below shows the progress made on the KPI on the number of smart thermal grids demonstrated in which the cost of delivered heat is less than EUR 90/MWh.

R&I priority (Priority Group I): Large-scale demonstration of Smart Thermal Grids (CCT.17)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
No. of smart thermal grids demonstrated in which the cost of delivered heat is less than EUR 90/MWh: five demonstration projects started in 2016 *(*2012: none; 2016: five large demonstration projects)	Demonstration projects (mainly EC Smart City projects and R&D projects) were launched between 2012 and 2018, but they do not fully cover all aspects of smart thermal grids or address them with a single smart thermal grid. All in all, the KPIs on smart thermal grids have not been fully achieved. There are at least five demo projects running in 2018.	Smart City projects: FP7 GrowSmarter, FP7 CITYZEN, FP7 Smartreflex, FP7 CITYFIED and FP7 Celsius (not covering all aspects of smart thermal grids). These projects cover the integration of different technologies and waste heat. EC DHC projects started in 2016: H2020 STORM , H2020 Flexynets, H2020 OPti and H2020 TEMPO on intelligent control of DHC networks and using low temperature levels and reversible heat pumps in DHC networks. H2020 H-Disnet sets out to	**Canada:** City of Guelph: in 2013, the city and Envida jointly developed the **District Energy (DE) Strategic Plan**. This document devised a strategy to build a city-wide thermal energy distribution network serving 50% of space heating and domestic hot water needs by 2041. Sheridan College project, Toronto: the college developed an integrated energy and climate master plan that laid out a framework for a seven-year investment covering a number of individual energy efficiency projects. As regards distribution upgrades, the focus was on improving the heating and hot water systems, which account for almost 41% of Sheridan's total utility consumption. The college therefore concluded that upgrades to convert the existing systems at

R&I priority (Priority Group I): Large-scale demonstration of Smart Thermal Grids (CCT.17)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
		develop thermo-chemical technology for district networks. The technology will exploit the high chemical potential of absorption processes for loss-free transport and storage of energy potential. It will be applied to form an intelligent district network with thermal, electric and gas networks. EFRO SALK Geowatt: national (Belgian) projects on fourth-generation DH networks, covering smart thermal grids.	Davis and Trafalgar into campus-wide district energy systems were the individual energy efficiency projects that could unlock the largest potential saving. Other benefits of upgrading to a new district energy system include a more flexible system with greater scope for integrating current and future renewable energy technologies. The plan aims to secure impressive reductions of 65% in campus energy consumption and 47% in CO_2 emissions by 2030 (baseline: 2010). **China:** Subsector overview. The People's Republic of China (PRC) has the largest district heating market in the world after the Russian Federation. Along with 13 provinces and three autonomous regions, the cities of Beijing and Tianjin have adopted centralised district heating systems (DHSs). However, inefficient and polluting stoves and small boilers are still widely used in cities and county towns as the coverage of existing DHSs is inadequate. Demand for heating in the PRC is rising rapidly, in line with economic growth and urbanisation. Between

R&I priority (Priority Group I): Large-scale demonstration of Smart Thermal Grids (CCT.17)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
			2003 and 2010, the total coverage area of DHSs increased from 1.9 billion square meters (m^2) to 4.4 billion m^2. Over the same period, DHS coverage increased from 199 million m^2 to 384 million m^2 in Heilongjiang. However, DHSs cover only 30% of the total floor area in the PRC, compared to a system penetration rate 55–60% in Europe. CHP plants are the most energy-efficient of all the feasible options for DHSs. CHP plants could potentially reach an efficiency of up to 90%, compared with 55% for the best conventional power plants and 80% for large, centralised heat-only boilers. Examples: Two district heating projects in Heilongjiang and Shaanxi (USD 200 million), phases 1 and 2 of the IMAR Environment Project (USD 270 million), the Guangdong Energy Efficiency Project (USD 100 million), the Shandong Energy Efficiency Project (USD 100 million) and the Tianjin IGCC Project

R&I priority (Priority Group I): Large-scale demonstration of Smart Thermal Grids (CCT.17)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
			(USD 135 million). The Liaoning Third Medium Cities Infrastructure project (north-eastern China) wrapped up in 2016. The project contributed to building a network to supply heat for 33 million m² of floor space in buildings across an area of 52 km^2 by 2020. It also sets out a new approach to the management of heat generation and distribution, a real-time tailored monitoring system for optimal network management, and a preventive maintenance system. Jinan Energy Construction Development Co., Ltd.: demonstration project on energy-efficient use of sewage source heat pumps for heating and cooling (2017). Beijing Future Science Park: this project is owned by Jingneng Future Gas & CHP Plant, an energy investor, and will use ground source heat pumps/chillers to provide a cooling area of 1.7 million m^2 with supply and return temperatures of 3 and 13°C respectively. **Japan:**

R&I priority (Priority Group I): Large-scale demonstration of Smart Thermal Grids (CCT.17)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
			The city of Osaka is contributing to the Sakishima Smart Community project, which aims to introduce renewable heat sources (including sewage biomass) and draw on the benefits of thermal storage systems to encourage the creation of a smart community with bidirectional supply and demand in Sakishima. The demonstration phase was completed in 2012. **US:** Heating and cooling project in Bridgeport: renewable power development by NUPower LLC, using a 37.5 MW biomass power plant.

The table below shows the progress made on the KPI on the reference heat cost.

R&I priority (Priority Group III): Optimised integration of renewable energy sources into DHC systems and enhancement of thermal energy storage at system level (CCT.21)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
Reference heat cost *(2012: EUR 100/MWh; 2016: EUR 90/MWh; 2020: EUR 60/MWh)*	The price of heat in smart thermal grid projects depends on the energy source used by the DH network and the applied cost method/business model; however, the variable heat price is generally less than EUR 90/MWh (status 2018). **This KPI is on track to meet the 2020 target.**	This information is reported in EC documents and scientific papers. Alberg et al. (2016) reported prices for 364 Swedish district heating systems in 2012 and arrived at an average price of SEK 0.83/kWh (EUR 83/MWh). The EC GEODH project reported on a comparison between the operating costs of geothermal, gas boilers and biomass boilers with a heat price of less than EUR 90/MWh. The manual of the Training Course on Geothermal District Heating (Amorce 2011) reports on a comparison of different sources in France with a heat price of EUR 63.80/MWh for	**US:** Chicago Lakeside development: the project is a 120-MW district heating and cooling project, utilising a fuel mix based on solar (15%), sewage (15%), biomass (60%), excess industrial energy (5%) and natural gas (5%) to satisfy the heat demand of lakeside buildings in Chicago. Storage tanks will be used to reduce the maximum heat production load. The proposed project will cut the use of fossil energy by 90%, while the use of potable water will be reduced by 60%. About 90% of stormwater will be infiltrated and channelled into Lake Michigan, and an efficient system to sort waste will reduce landfill to 1% of total waste. Dartmouth campus heat distribution system, New Hampshire: the project covers the entire campus area (128.97 km² with 120 buildings and a

R&I priority (Priority Group III): Optimised integration of renewable energy sources into DHC systems and enhancement of thermal energy storage at system level (CCT.21)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the value provided**	**Situation in relevant third countries**
		geothermal energy. http://reseaux-chaleur.cerema.fr/prix-de-la-chaleur-et-facturation EC JRC reported a heat price of less than EUR 90/MWh for EU countries. https://setis.ec.europa.eu/system/files/1.DHCpotentials.pdf	peak winter heat load of 30 MWt) and aims to renovate the buildings to make them more suited to the new energy supply. The project examined four alternative scenarios: ORC biomass, biomass heat only, biomass + solar + storage, and aquifer thermal energy storage/heat pump for heating and cooling. **Canada:** Sapperton district energy system: the project aims to develop a low-carbon heating network to serve the Royal Columbian Hospital campus and the surrounding area. There are two renewable energy sources available, namely urban-source waste wood chips and Metro Vancouver's nearby sanitary sewer trunk. The project also looked at utilising thermal storage to avoid unplanned downtime.

6.6 Thermal energy storage

The table below shows the progress made on the KPI on stable, microencapsulated salt hydrate PCM.

R&I priority (Priority Group II): Increased storage density using Phase Change Materials (PCM) and Thermochemical Materials (TCM) (CCT.8)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the values provided**	**Situation in relevant third countries**
Stable, microencapsulated salt hydrate PCM *(2012: only paraffin PCM available; price over EUR 8/kg; 2020: novel materials in pilot applications; 2030: production technology optimised; material available at <EUR 2/kg)*	2018: only paraffin PCM available; price over EUR 8/kg	The University of Bayreuth (Germany) is conducting research on medium-temperature mobile PCM storage (temperature in the region of 100°C). The first products are being launched on the market: • macroencapsulated PCM, e.g. by Rubitherm and Axiotherm in Germany) • Dutch company SALCA (http://www.salcabv.nl) was founded in May 2008 following the acquisition of a licence for the manufacturing of Thermusol and	Some commercial improvements are also being made at international level. Results for this KPI at international level are in line with results in the EU: • **China**: ○ Salt Hydrate Phase Change Material PCM TES Unit for Solar Energy Building ○ Experimental study on the effect of microencapsulated phase change coating on indoor temperature response and energy consumption • **US:** Recently, a procedure has been patented (US 2015/0284616) for the encapsulation of molten salts such as NaNO3 or KNO3 • **Canada**: Advanced large capacity thermal energy storage focuses on

R&I priority (Priority Group II): Increased storage density using Phase Change Materials (PCM) and Thermochemical Materials (TCM) (CCT.8)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the values provided**	**Situation in relevant third countries**
		Thermusol-related products. • Phase Energy (UK) has also developed microencapsulated PCMs.	the numerous challenges that exist in the effective integration of PCM or thermo-chemical storage into thermal storage systems. A review of the cost of PCM and the challenges related to its reduction can be found here: • **US**: PCM price challenge

The table below shows the progress made on the KPI on novel thermo-chemical materials at the laboratory stage.

R&I priority (Priority Group II): Increased storage density using Phase Change Materials (PCM) and Thermochemical Materials (TCM) (CCT.8)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the values provided**	**Situation in relevant third countries**

Novel TC materials at laboratory stage *(2016: 4; 2020: 40; 2030: 100)*	2018: Several new materials have been developed in at least three laboratories.
	The German-funded project EnErChem prepared, characterised and tested about 20 zeolite-based salt composites. Some of these novel TC materials are capable of being transferred to serial or mass production.
	This KPI seems to be on track for 2020.
		NIC, Slovenia: new porous sorbents have been developed, including aluminophosphates, MOFs (Metal Organic Frameworks) and composites (mesoporous iron silicate+CaCl2, mesoporous silicate+CaCl2, aluminophosphate+porous carbon). Both national projects (*New thermal energy storage materials (2010-2013)*), and bilateral projects involving Slovenia and France (*Investigations of the thermo-physical properties of composite sorption materials for solar energy storage (2014-2015)*) have been carried out.
		Other laboratories: University of Leipzig (composite materials); FhG-ISE: MOFs and composite materials.
		The novel TC materials
			Research on new thermo-chemical materials in ongoing in several parts of the world. Results for this KPI at international level are in line with results in the EU:
			• **China**:
			  ○ Development on Thermochemical Energy Storage Based on CaO-Based Materials: A Review
			  ○ Sorption Thermal Energy Storage
			  ○ 16th International Transfer conference (2018)- Panel discussion on "energy storage"
			• **US**: Doped calcium manganites for advanced high-temperature thermochemical energy storage
			• **Japan**: Kinetic Study of Ca (OH) 2/CaO Reversible Thermochemical Reaction for Thermal Energy Storage by Means of Chemical Reaction

R&I priority (Priority Group II): Increased storage density using Phase Change Materials (PCM) and Thermochemical Materials (TCM) (CCT.8)			
Specific KPI	**Value of the KPI at the date of submission of the Final Study Report**	**Statements and figures supporting the values provided**	**Situation in relevant third countries**
		prepared as part of EnErChem still require water management in the TCM storage facility. Research on transition metal ammoniates is ongoing at the Technical University of Vienna. In future, further research is needed to provide novel TC materials that allow the operation of TCM storage with easier or no water management. New concept being developed: – Tes4seT (Thermal Energy Storage for Sustainable Energy Technology)	

6.7 Hybrid systems

The table below shows the progress made on the KPI on the renewable fraction of the reference hybrid system.

R&I priority (priority Group III): Next generation of highly integrated, compact hybrid systems (CCT.5)			
Specific KPI	**Value of the KPI at the date of submission of deliverable D1.3**	**Statements and figures supporting the values provided**	**Situation in relevant third countries**
Renewable fraction of the reference hybrid system *(2012: N/A; 2020: 50%; 2030: 75%)*	2018: 50-70%.	One reference (Daikin): http://www.rehva.eu/fileadmin/REHVA_Journal/REHVA_Journal_2013/RJ_issue_2/p20-25_Hybrid_heat_pumps_RJ1302.pdf# CTC, Clivet and Stiebel Eltron currently offer similar products. An increasing number of products addressing this priority is expected on the market by Q2 2019, enabling a 50-70% reduction in gas consumption.	This priority seems to be relevant in the following countries: • **US:** This solution (high renewable energy fraction in hybrid systems) is currently not common in the US market. Homeowners tend to base their replacement decisions on the existing infrastructure (e.g. fuel type). Natural gas is widely used for heating in the US. The low gas price makes it very difficult for hybrid system solutions to penetrate the market. Incentives to boost their market uptake are becoming widespread throughout the US. Reference: https://bit.ly/2Rw35Lc • **South Korea:** The launch of the Renewable Heat Obligation will provide a major impetus for the growth of this solution. Reference: https://bit.ly/2seLJEg

R&I priority (priority Group III): Next generation of highly integrated, compact hybrid systems (CCT.5)			
Specific KPI	**Value of the KPI at the date of submission of deliverable D1.3**	**Statements and figures supporting the values provided**	**Situation in relevant third countries**
			• **Australia**: the price of gas has increased rapidly, such that it is currently more expensive than electricity. This could enhance the attractiveness of hybrid system solutions with a high share of renewable energy.

7 ANNEX II: UPDATED RESEARCH PRIORITIES FOR THE RHC SECTOR

Based on the analysis of roadmaps' implementation, the experts of the RHC-ETIP have determined that most of the research and innovation priority areas identified in 2013-2014 need to be reviewed and adapted. The sections below outline the updated research and innovation priorities for each technology area.

7.1 Biomass

- **Biomass feedstock**

  Research topics:

  - Development of biomass treatment technologies for abundant low-cost feedstock (bark, agro-residues, empty fruit bunches (EFB), bagasse).
  - Development of a technology for processing unsorted waste from the agro-food industry, preferably into bio-oil.
  - Development of an efficient methane fermentation technology for unsorted municipal waste and a method of managing waste CO_2.
  - Market uptake for collaborative actions by small forest owners in biomass supply; this should reduce biomass supply costs for forest biomass from small and private forests, which make up a large share of Europe's forests.
  - Market uptake for technologies to reduce fossil fuel consumption in biomass supply chains.
  - Electrification of biomass supply equipment in bioenergy supply chains (these could be agriculture-based, forestry-based or waste-based supply chains; the areas studied could include vehicles, but also seeding, harvesting and logistics equipment; electrification should be based on renewable energy sources alone).
  - Utilisation of ICT tools and smart farming techniques to reduce costs reduction (order of magnitude: 20-30% from reference levels).

- **Bio-oil**

Research topics:

  - Development and performance of bioDME (dimethyl ether), which can be obtained from various sources (including biogas and biomethane).
  - Development and performance of solar fuels.

- **Production of thermally-treated biomass fuel**

Research topics:

  - Commercial production and use of steam-exploded pellets will start in the EU in 2020.
    - Evaluation of scaling in industrial boilers fuelled with steam-exploded pellets.
    - Evaluation of corrosion in industrial boilers fuelled with steam-exploded pellets.
    - Evaluation of emissions from industrial boilers fuelled with steam-exploded pellets.

    - Evaluation of self-heating behaviour of steam exploded-pellets.
    - Evaluation of VOC (Volatile Organic Compound) emissions at storage of steam-exploded pellets.

Other recommendations:

- It will be difficult to attain a trading volume of 1-2 Mt/y for thermally treated pellets in the EU by 2020. More commercial projects should be undertaken to reach this trading level. Financial support is required to mitigate the risks associated with the commercialisation of projects for thermally treated pellets (or briquettes).
    - Financial support for pilot runs prior to commercial projects.
    - Financial support for commercial scale-projects to reduce risk for investors.

- **Biogas**

Research topics:

- Steam explosion could be an effective choice for breaking up low-cost lignocellulosic materials to render them digestible for biomass production. Eligible materials could include wood residues, bark and straw. Combined production of biogas and pellets/briquettes may be feasible in many cases.
- Performance of the biogas upgrading process with regard to the CO_2 released during the process, plus a method for managing this CO_2.
- Market uptake of biomethane on the gas market (transport and technological needs).
- Market uptake and promotion of cropping mixes as alternative for maize for the biogas sector: need for more ecologically friendly crop mixes that can be seeded as a substitute for maize. While the yields for such mixes are generally lower than for maize, numerous ecoservices (in terms of wildlife, biodiversity, beekeeping and carbon accumulation) and other benefits (decrease of fertilisers and pesticides, water protection) could be provided. Mixed cropping, multiple cropping or intercropping may involve both annual and perennial crops. Real ecological benefits must be demonstrated.
- New annual and perennial crop mixes for biogas production: new crop mixes should be developed that both deliver high yields and offer greater ecological value than maize monocultures.
- Use of digestate in the production of high-quality fertiliser.

- **Micro and small- and medium-scale CHP**

Research topics:

- Power conversion efficiency of high temperature (>150°C) small- and medium-scale CHP systems. In 2018, there were almost no small-scale CHP installations generating high-pressure (>10 bar) steam in Europe. Many manufacturing industries (food & beverage, chemical & pharmaceutical, plastic & rubber, textile, paper & wood industry, oil & gas) require a high-temperature thermal vector, usually steam, to run their processes, yet current technologies do not allow a large volume of steam and a generally efficient process to be obtained with a relatively high electrical efficiency (current technologies can only achieve an electrical efficiency of less than 10%). In this respect, innovation will aim to develop new CHP technology solutions to enable the simultaneous generation of electricity and medium- to high-pressure steam with a very high overall energy efficiency (>10%), allowing manufacturing processes to achieve energy independency and be more efficient and sustainable (TRL from 5-6 to 7-8).

– Development of cost-effective micro-CHP units for solid biomass in households and integration of both heat and electricity into household energy systems: the process integration of the CHP and the fuel processing step should be targeted to increase the overall efficiency of CHP plants running on solid biomass (gasification, pyrolysis); ideas for process integration with turbines are in an early stage of development at present (TRL 1-3 -> TRL 3-4)).
– Greater robustness of CHP systems with respect to minor components and particles in the fuel with a view to reducing costs linked to fuel cleaning and filtering; minor components and particles can damage the CHP system and reduce its reliability.

Other recommendations:

– Target for residential small-scale heating: 20% of biomass fuel consumed in the EU-28 to originate from agro-biomass resources (2030).
– Target for agro-industries: 20% of biomass residues to be utilised (self-consumption or upgrading) within a 50-km radius of the point of operation (2030); increase to 50% (2050).
– Since the KPI on electricity generation costs depends greatly on the technology used, it may be useful to split it for different technologies.
– The fuel flexibility of CHP systems should be increased to cope with fluctuations in fuel gas composition and heating value caused by plant operation, especially in small plants. This is necessary to further increase the reliability of the CHP systems.

- **Large-scale CHP**

Comments: the application scope of large-scale CHP is clearly more limited than for a small-scale CHP. Large-scale CHP requires stable, plentiful sources of biomass and other RES, which are not always available for technological, technical and environmental reasons.

Research topics:

– Ash utilisation: RTD on streamlining biomass ash use as fertiliser; RTD on biomass ash use in novel applications.

- **Polygeneration**

Research topics:

– Increase of the fraction of RDF (Refuse-Derived Fuel)/tars in co-gasification processes with agrobiomass or coal.
– Establishment of energy crops/use of prunings in the production of advanced biofuels.

7.2 Geothermal

Many changes relevant to the KPIs have taken place since 2014. The Steering Committee of the Geothermal Technology Panel agreed a new set of KPIs for shallow geothermal, while an ETIP on deep geothermal was established in 2016 and the SET Plan Steering Group endorsed a Declaration of Intent on deep geothermal energy in 2017. The Declaration of Intent records the agreement reached between representatives of the European Commission, representatives of the EU Member States, Iceland, Norway, Turkey and Switzerland (i.e. the SET Plan Steering Group) and representatives of the SET Plan stakeholders on the implementation of the actions contained in the SET Plan Communication. Finally, an Implementation Plan was published in 2018 and is now being put into effect.

A vision document on deep geothermal was published in March 2018, followed by a strategic research and innovation agenda (SRIA) on deep geothermal in March 2019 and a roadmap on deep geothermal in June 2019.

The ETIP-DG is also preparing new KPIs on deep geothermal; these will be presented in 2019.

Shallow geothermal priorities

The Steering Committee of the RHC-ETIP Geothermal Technology Panel presented the following proposals for the updated SRIA to members at the meeting in Offenburg on 15th February 2019:

1 – Improving shallow geothermal ground-coupling technologies

- Europe-wide Geoactive Structures Alliance focusing on integrating shallow geothermal into foundation piles or underground structures, including the establishment of a network of laboratories to create four testing and demonstration sites.

- Improvement in shallow geothermal drilling technology and machinery with a view to reducing the cost and impact of drilling (automation, minimum invasiveness, drilling for refurbishment (including historical buildings)).

- Borehole characterisation by multi-well drilling (MWD), geophysical logging, tools for quality control and monitoring.

- Optimisation of the borehole-grout-pipe system, with a focus on solving current grouting problems (fractures, freezing, and others), and developing measurement and control tools.

- Methods and materials to enhance the thermal properties of the ground.

2 – Innovating in shallow geothermal – GSHP systems, integration and environment

- Integration of shallow geothermal systems with other renewable technologies, covering both electricity (e.g. deep geothermal, wind, PV) and thermal (e.g. solar thermal, biomass, deep geothermal); demand response and storage technologies.

- Integrated control of ground source heat pump systems (GSHP), including the ground side, the heat pump, the building circuits and the building characteristics; multiple input – multiple output control approaches (linking up with R&D in ICT).

- Integration of shallow geothermal systems into old and inefficient buildings, including historical buildings.

- Shallow geothermal systems for infrastructure (e.g. roads, bridges, tunnels, pipelines and other) and supply of low temperature to industry and services (e.g. agro-food, tourism).

3 – Developing new concepts and materials for shallow geothermal ground coupling

- Materials research on improved materials for borehole heat exchangers (e.g. bespoke thermal properties, handling, long-term stability, lower cost).

- New or improved heat carrier fluids (environmentally friendly, low freezing temperatures, low viscosity, high specific heat, low cost, and so on).

- New and advanced, environmentally friendly grouting material with bespoke thermal and hydraulic properties; inclusion of recycled materials in a bid to reduce costs and participate in the circular economy.

- Innovation in heat exchanger configurations and installation methods in the aim of reducing capital investment costs, supported by ICT.

4 – Combining shallow geothermal with renewable technologies in district heating and cooling systems

- Optimised shallow geothermal technologies as part of a combined energy system: heat supply, cold supply, thermal storage.

- Demand-load response systems and integration of ground source heat pumps and underground thermal energy storage (Borehole Thermal Energy Storage (BTES)/ Aquifer Thermal Energy Storage (ATES)) into fourth-generation district heating and cooling networks.

- Optimal integration of Underground Thermal Energy Storage (UTES) systems into the thermal energy supply for DH.

5 – Improving and developing technologies to harness untapped geothermal energy resources for heating and cooling

- Demonstration sites with a complex (well completion – reservoir engineering – hydrogeology) methodology of 100% brine reinjection, particularly into sandstone reservoirs.

- Demonstration of innovative heat energy optimisation in operating balneological systems supplied with thermal water.

- Innovative tools to handle extremely polluted geothermal brines.

6 – Improving energy storage underground and providing flexibility for the energy system

- Integrated control of UTES systems, including the ground side, the heat pumps, and the circuits and characteristics of the building or network; multiple input – multiple output control approaches; real-time optimisation procedures and adjustment to the weather forecast (linking up with R&D in IT).

- High-efficiency combined heat and power (CHP) and ground source heat pump (GSHP)/UTES systems for small and medium-sized heating and cooling networks.

- Demonstration of the practical feasibility, reliability, efficiency and economic benefits of wider use of UTES for seasonal storage of energy.

- Optimum integration of UTES systems into thermal energy supply for industry and municipalities.

7 – Fostering market uptake

- Modelling on the decarbonisation of the heat sector, buildings and industry; development of a methodology to determine the cost of RHC technologies and RHC enablers such as storage.

- Promotion, training and information activities for small-scale RHC installers; certification of installers.

- Support for regional and local authorities with a view to optimising the integration of RES H&C through the introduction of incentives and codes and/or obligations affecting the planning of residential, commercial and industrial areas.

- Assistance for housing associations, owners of large building stocks and consumer cooperatives to help them adopt approaches facilitating the large-scale uptake of RES heating and cooling systems, together with the energy-efficient retrofitting of existing buildings. This could include the creation of new district heating and cooling networks using RES and the modernisation and retrofitting of RES in existing networks combined with sound end-use management practices.

- Development of nearly zero-energy neighbourhoods: the concept of nearly zero energy-buildings is more easily adopted when several buildings are considered in an integrated way, exploiting a combination of renewable energy sources, including renewable heating and cooling solutions.

Deep geothermal priorities

The ETIP-DG's Strategic Research And Innovation Agenda includes the following research topics:

A. Prediction and assessment of geothermal resources

- Topic 1: Improved exploration prior to drilling

- Topic 2: Advanced investigation and monitoring technology

- Topic 3: Exploration workflows – conceptual models, reservoir characterisation, performance and decision models

- Topic 4: Exploration catalogues – reservoir analogues, rock properties and model constraints

- Topic 5: Resource potential assessment

- Topic 6: Beyond conventional resources

B Resource access and development

- Topic 1: Customised drilling technologies

- Topic 2: Novel methods to break hard rock

- Topic 3: Adapted and greener drilling fluids

- Topic 4: Custom casing and cements

- Topic 5: Monitoring and logging while drilling (including looking ahead of the bit)

- Topic 6: High-temperature electronics for geothermal wells
- Topic 7: Effective and safe technologies for enhancing energy extraction
- Topic 8: Total re-injection and greener power plants
- Topic 9: Optimisation and monitoring and controlling of corrosion and scaling
- Topic 10: Efficient resource development
- Topic 11: Enhanced production pumps

C. Heat and electricity generation and system integration

- Topic 1: Advanced binary plants
- Topic 2: High-temperature binary power plants
- Topic 3: Power cycles and mitigation for super high-temperature resources, high-enthalpy steam direct expansion
- Topic 4: Flexible production of heat and power
- Topic 5: High-temperature thermal energy storage (HT-TES)
- Topic 6: Innovative design and integration of binary cycle technology in existing and new flash plants
- Topic 7: Development of hybrid plants
- Topic 8: Exploitation of mineral production from geothermal sources
- Topic 9: Generation at different voltages for smart grids

D. FROM RD&I TO DEPLOYMENT

- Topic 1: Adoption of the right policies
- Topic 2: Public and other stakeholders' engagement
- Topic 3: Enhancement of competitiveness
- Topic 4: Establishment of financial risk management schemes
- Topic 5: Support schemes for the deployment of geothermal
- Topic 6: Establishment of a legal and regulatory framework
- Topic 7: Embedding of geothermal energy in the circular economy
- Topic 8: Harmonised protocols for determining the environmental and health effects of geothermal energy and mitigation planning
- Topic 9: Human deployment

E. KNOWLEDGE SHARING

- Topic 1: Underground data sharing to unlock existing subsurface information
- Topic 2: Organisation and sharing of geothermal information

- Topic 3: Shared research infrastructures

F. Next generation of technologies

- Geothermal resource assessment through deep probing earth observation
- Geothermal energy buffers (GEB): hybrid energy systems involving solar-thermal and electricity storage to supplement the geothermal heat flow
- Development of bio-inspired robots for revolutionary drilling: more efficient, less costly with automation, safer, environmentally friendly
- Creation of an underground energy system
- Use of IT tools based on data mining and machine learning for resource assessment, resource access and energy production
- Connection between the reservoir and the surface: reliable and resilient data transfer
- Production of energy with geothermal offshore installations

7.3 Solar thermal

As regards funding programmes, it is important to underline that R&I investments for renewable heating and cooling should be considered separately from investments focused on electricity. While sector coupling may act as an enabler by connecting these two areas, they should be nevertheless addressed separately and in a more targeted manner. Furthermore, 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.

Solar heating and cooling require both large demonstration projects (for process heat or applications in different sectors) and low and medium TRLs. This applies to solar cooling, materials, collector types and thermal storage, among other things.

The updated research priorities should also focus on large-scale and innovative ST applications, such as the development of the next generation of solar heat for industrial process (SHIP) and solar district heating (SDH) with an increased solar fraction.

Research should promote innovation geared towards better integrating thermal storage systems with solar thermal systems and solar thermal with solar power (Solar Active House plus, SAH+) and improving solar compact hybrid systems (SCOHYS), especially in terms of their capacity to utilise advances driven by digital technologies to dramatically reduce O&M costs and increase long-term reliability and durability.

Other instruments should be considered too, such as a roadmap to bankability (system data collection and validation, financial risk assessment, performance guarantees), the SME Instrument, and the successor of the Fast Track to Innovation scheme.

7.4 Heat pumps

The European heat pump industry recommends an increase in projects and funding opportunities. These should focus on the development and implementation of:

a. heat pump technology ready for plug-and-play applications in the renovation sector;

b. heat pump solutions able to provide demand-side flexibility;

c. standardised high-temperature heat pumps for industrial processes and combination with district heating.

In the residential segment, research activities should concentrate on mass-market ready products with:

- an average coefficient of performance of 3–5;
- better cost efficiency;
- more compact units that are easier to install;
- better connectivity to enable integration into building energy systems (ventilation, heat recovery, auto-produced PV electricity) as well as in smart grids. Both objectives will help leverage the demand-response potential of heat pump technology;
- low-GWP (Global Warming Potential) refrigerants;
- lower noise emissions at (or slightly above) current cost levels to improve acceptability in heavily built-up areas;
- in the case of hybrid heat pumps, reliable calculation procedures for planners (for integration into current software packages).

There is increased interest in industrial heat pump applications at both national and international level. This has been expressed in a number of ways, including IEA-funded annexes to the heat pump implementation agreement. A growing number of projects and research activities are focusing on synergies with district heating and cooling and the feasibility of transforming low-grade waste heat into high-temperature industrial process heat. By way of example, the Horizon 2020 project Dry-F (http://dry-f.eu) examines how waste heat could be recovered for drying purposes.

The production costs of such units have not changed substantially; this is mainly due to current energy prices, which are preventing more widespread deployment of this solution.

New research should focus on the following objectives:

- Development of high condensing temperatures (200°C and above);
- Increased efficiency at higher temperatures;
- Concepts, components, and refrigerants for high temperatures;
- System integration in the process;
- Development of hybrid systems for industrial processes.

In the commercial sector, heating and cooling are currently provided by separate units. Future projects should look at the application of high-capacity heat pumps in hotels, hospitals, schools or fitness centres as these have considerable potential for multiple uses and would benefit from more integrated solutions. These projects may benefit from improved controls providing demand-side flexibility.

However, current R&D capacity in the sector (in industry, labs and universities) is insufficient to allow both avenues of development to be pursued at the same time. **Continuous and robust EU and national support for research is deemed essential for overcoming this limitation**. Furthermore, it is vital that a larger share of the budget be dedicated to helping the solution access the market (TRL 7-9).

7.5 District heating and cooling

The following research priority recommendations have been identified for district heating and cooling networks. The proposed priorities are in line with the implementation plans for SET Plan actions 3.2, 4.1, 4.2, 5 and 6.

R&I priority (Priority Group I): Large-scale demonstration of Smart Thermal Grids (CCT.17)

Demonstration projects for smart thermal grids were launched between 2012 and 2018, but do not address all aspects. Going forward, research should focus on demonstrating all aspects of smart thermal grids and on the following topics:

- Technological investments in the digitalisation of energy infrastructure, i.e. district heating (and cooling) systems (remote control & monitoring, mapping, and fault detection); development of artificial neural networks/thermo-hydraulic network hybrid models for optimal, efficient control of thermal networks.
- Integration and interaction of low-temperature sources in district heating networks (e.g. utilising excess heat from data centres). Heat recovery equipment in data centres should be designed in such a way that any operational faults or other interruptions will not jeopardise server operations at any time. The integration of other low-temperature sources for district heating applications should be investigated.
- Consumer-side digital solutions. These not only enable consumers to respond to price signals, they also allow for peak shaving and demand shifting and thus permit more efficient use of generation capacities. By shifting loads, operators can fully exploit the benefits of intermittent supply solutions while avoiding the use of expensive, often fossil-based, peak-load supply capacity. Moreover, consumer-side digital solutions may allow for lower return temperatures and lower supply temperatures, which would increase the efficiency of the network.
- Empowerment of energy providers to take more responsibility, rather than just visualising end-user data and trusting that they will change and improve.
- Facilitation of R&D programmes to further stimulate and optimise the control strategy and improve the operation of such technology systems; this will, in turn, maximise flexibility.
- District cooling networks and their interaction and integration with district heating networks.

R&I priority (Priority Group II): Improved, highly efficient substations for both present and future lower-temperature networks (CCT.20)

Research for this topic should focus on:

- Handling, processing and visualisation of data in district heating substations, integration of digital control of networks and substations, integration of fault detection, correction and diagnosis of substations in district energy management systems.
- Development of automated fault detection and diagnosis monitoring systems to detect anomalies in networks and building substations.

R&I priority (Priority Group III): Development and roll-out of DHC-driven white goods and low-temperature solutions for domestic hot water preparation (CCT.19)

In view of results obtained so far, the number of projects and topics covered and the general current state of the DHC sector, the DHC experts advised that this topic should be removed as it was no longer a valid research priority.

R&I priority (Priority Group III): Optimised integration of renewable energy sources into DHC systems and enhancement of thermal energy storage at system level (CCT.21)

Research on this topic should focus on:

- Integration and control of thermal energy storage systems in thermal networks, including means of determining buffers' charge status and systems for the smart charging/discharging of decentralised buffers.
- Development and deployment of industrial pilot projects in various regions and configurations to review the real flexibility options that these technologies and systems can offer the electricity sector, in line with current regulations and market design.
- Development and roll-out of integrated control solutions while ensuring interoperability and communication standards between heating grids, electricity grids and thermal energy storage systems.

7.6 Thermal energy storage

The research priorities are the same as those originally proposed in the RHC-ETIP's Strategic Research Agenda (SRA) in 2014. Some KPIs need to be revised and updated. This work will be continued with the revision of the SRA, which is expected in 2020.

7.7 Hybrid systems

Hybrid energy systems, integrating more than one energy source into a single system, can accommodate renewable energy sources and overcome the limitations of individual technologies. This priority is applicable at different scales: small-scale applications such as heating and cooling systems for single-family homes, or large-scale systems suitable for district heating and cooling or industrial processes. These new energy systems present new challenges in terms of their integration and management at different stages. At thermo-hydraulic level, for instance, the issues to be addressed include the combination of different thermal cycles and the inclusion of efficient energy storage units.

New control strategies must be implemented; these must be taking into account the weather forecast, the heating and cooling load forecast, the cost of primary energy consumed, the energy efficiency and the GHG emissions, and include new supervising algorithms controlling the efficiency and cost-effectiveness of the hybrid systems, intuitive user interfaces able to provide system information to users in understandable terms, and tools to monitor and assess energy production. These measures should all seek to assess system capabilities so that performance guarantees can be issued.

We expect that research into these two areas will deliver a 20% cost reduction and a 20% increase in thermal efficiency in the short term, thus leading to a decrease of approximately 40% in the overall system cost.

In order to support the activities of the European Technology and Innovation Platform on Renewable Heating and Cooling (RHC-ETIP), the associations making up its secretariat performed a number of analyses focused on:

- monitoring the implementation of the RHC-ETIP's five roadmaps with a view to examining the technological advances made since the roadmaps' publication between 2013 and 2014;
- analysing the heating and cooling industry to gain an overview of the technologies' supply chains, the R&D capacities, the prevalent business models and the status of global competition in the heating and cooling sector;
- analysing heating and cooling consumers to arrive at a sound basis for recommendations on new business models and regulatory interventions aimed at removing barriers to consumer acceptance of RHC technology solutions.

Their findings will serve as a basis for the RHC-ETIP to continue and improve its efforts to ensure that the heating and cooling sector is fully decarbonised by 2050.

Studies and reports

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