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Research, Innovation and Competitiveness of the Geothermal Sector in Europe

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ABSTRACT

Geothermal heating and cooling (H&C) and power is a growing sector in Europe, with sustained growth rates in installed capacity all over Europe. This growth is carried by a lively and active European geothermal industry, were historical actors and new players alike are at the forefront of innovation. Thanks to a rich and strong know how, the presence of many large companies and a widespread bedrock of SMEs, Europe is among the leading industrial actors globally in geothermal.

Despite its relative prominence, nevertheless, the European geothermal industry is faced with harsh competition from other geographical areas. That is particularly true in export markets, where the European geothermal sector must constantly prove its competitiveness to obtain projects. Beyond competition within the geothermal sector, there is also the question of the capacity of the European geothermal sector. An issue that questions the very structure of the European market, the robustness of its geothermal sector and the capacity of the existing regulatory framework to lay out a levelled playing field. Moreover, Europe must develop new, innovative solutions to answer the next technological challenges for an accelerated deployment of geothermal across the continent. A next generation of geothermal technologies is needed to remain number one in the world.

The first Geothermal implementation plan 2013-2020 produced by the Geothermal panel (RHC platform) presents a clear strategy for developing the research, development and innovation projects required to answer the H&C challenge of the future. The first set of RD&I geothermal projects to implement the European Geothermal technology Roadmap started in 2014.

At the same time, the European Technology & Innovation Platform on Deep Geothermal (ETIP-DG) published in 2018 & 2019 a new set of strategic papers: A Vision, a Strategic Research & Innovation Agenda and an Implementation Roadmap for Deep Geothermal Energy technologies. These documents outline the research priorities that must be developed between now and 2050 if the Vision for the future of the sector is to be achieved.

This paper presents the status of the implementation with a monitoring of the first project results and an assessment of the European industrial competitiveness in this sector.

1. INTRODUCTION

Among the technological challenges for an accelerated deployment of geothermal heating & cooling and electricity across Europe, new and innovative solutions in different areas are needed. Firstly, it is especially important to develop solutions for refurbishing existing buildings, but also for zero and plus energy buildings, whereby systems need to be easier to install and more efficient at low temperature for both heating & cooling. Secondly, to develop geothermal District Heating (DH) systems in dense urban areas and other H&C applications from deep geothermal, as example for agro-industry, at low temperature is identified as a key issue amongst our sector. The objective is to contribute to the decarbonisation of DH and industry by providing competitive solutions for heating & cooling. Thirdly, a third important goal is to contribute to the decarbonisation of electricity by ensuring security of supply, affordability and flexibility in the grid.

Finally, it is important to highlight the role of geothermal in the energy transition and especially its key characteristics for a better sector coupling electricity, H&C and transport and the contribution to local economic development and social welfare.

One objective is to also keep the European industrial competitiveness in this sector. With nearly 2 million units installed of shallow geothermal systems assisted by Heat pumps (HP) also called, GSHP, Europe is the world leader in the shallow geothermal market and also a forerunner in innovation in areas such as underground thermal energy storage (UTES). Main competitors are heat pump manufacturers in China and the USA. With more than 200 geothermal DH systems in operation, Europe is also the global leader for geoDH. Global competition exists mainly for heat exchangers and pipes. Also H&C applications of deep geothermal started in Europe, although China is now leading the market due to the large demand there. New technologies such as EGS plants are only in operation in Europe up to now. Projects are ongoing in the USA and Australia.

A next generation of geothermal technologies are needed to remain number one. The European Geothermal H&C Technology Roadmap 2013-2020 and the ETIP-DG Roadmap 2020-2030, a result of the common effort of many stakeholders in our sector coordinated within the Geothermal Panel (RHC Platform) and the ETIP on deep geothermal, presented a concept for developing these research and innovation projects.

2. PRESENTATION OF THE ETIPS ON GEOTHERMAL ENERGY

2.1. ETIP RHC Geothermal Panel

The geothermal panel was established in 2009, following an initiative of EGEC, and it became integrated to the RHC-Platform from 2010. In April 2013 the RHC-Platform launched the Strategic Research and Innovation Agenda for Renewable Heating and Cooling (RHC-SRIA). The research agenda 2013 identified the state-of-the-art, the research objectives and the critical targets (e.g. in terms of performance increase / cost reduction) required to realise the potential of geothermal HC technologies defined in the Vision's document 2010. It also offers recommendations for research, development and demonstration funding in the timeframe of 'Horizon 2020' and in line with the wider EU 2020 Energy and Climate Framework. It provides stakeholders with a structured and comprehensive view of the research, development and demonstration activities able to meet diverse profiles of demand in the short (by 2020), medium (by 2030) and long term (after 2030).

The geothermal panel then worked on the implementation roadmap to plan research priorities and investigate ways of funding. It also further defined key performance indicators (KPIs). The Geothermal technology roadmap was published in March 2014. The work on an updated version of the Strategic Research and Innovation Agenda for geothermal H&C should be published end 2019.

From 2014, the geothermal R&D plan is being implemented. A first round of geothermal research projects has been launched by the European Programme Horizon 2020 in the framework of this implementation plan and new research results are expected by 2020. The implementation of the geothermal technology roadmap can be monitored by reviewing ongoing and recently achieved research projects and by assessing the impact of the first results on the key performance indicators. The objective of this paper is to present the research activities, in correlation with the research priorities mentioned in the Geothermal Technology Roadmap. Future trends are also identified, by highlighting areas in which relevant projects are being developed, which could have an expected major impact on a given KPI. This analysis is performed by research area, as identified in the Geothermal Technology Roadmap.

2.2. ETIP DG

The ETIP-DG aims at representing the entire deep geothermal energy sector at EU level, including companies, academia, research centres, and sectoral associations. It is thus uniquely placed to ensure that geothermal energy technologies can make a significant contribution to EU goals for decarbonisation, industrial development and technical innovation and excellence by 2020, 2030 and 2050. The Platform was launched in March 2016 during a Geothermal Forum of stakeholders, including large companies, SMEs, academia and research institutions. Terms of Reference (ToR) to establish the governance and procedures of the ETIP-DG were adopted in June 2016. The European Commission, DG RTD, officially recognised it as an ETIP in July 2016.

The primary objective of the ETIP-DG is to foster overall cost reduction, including social, environmental, and technological costs. For this scope, the platform brings together representatives from industry, academia, research centres, and sectoral associations, covering the entire deep geothermal energy exploration, production, and utilization value chain.

Its activities focus on:
• The execution of the Vision for deep geothermal for power and/or heat.
• The development of a European Strategic Research Agenda for deep geothermal for the next decade(s).
• The implementation of the Technology Roadmap.
• Contribution to the European industry and research to maintain and consolidate its leading position in energy technologies for geothermal.

3. THE GEOTHERMAL ROADMAPS

3.1. The Roadmap on geothermal H&C

3.1.1. The Key Performance Indicators of the Geothermal Panel of the ETIP RHC

The Geothermal Panel of the RHC platform established Key Performance Indicators for developments in research, and innovation in geothermal energy for heating and cooling. On shallow geothermal, they include to:

- Decrease the energy input for operating the geothermal heat pump system by 10% in 2020 and 25% in 2030 (from 2014 value: 44.6 MWh/year electric, for a geothermal system capacity of 50 kWth in a new building, supplying heating at T = 35°C during 2200 h per year and cooling at T = 7°C during 1200 h, in western Europe climate conditions, use a SPFheating of 4);
- Reduce costs for operating the geothermal heat pump system, leading up to 20% costs reduction of the O&M in 2020, and 30 % in 2030 (from 2014 value: 9430 € per year, for a geothermal system capacity of 50 kWth in a new building, supplying heating at T = 35°C during 2200 h per year and cooling at T = 7°C during 1200 h, in western Europe climate conditions), assumed with stable energy prices (or statistically levelled)
- Increase value of Seasonal Performance Factor in the order of 4.5 for 2020 and 5 for 2030 (from 2014 value: SPFheating average of 4, for a geothermal system capacity of up to 50 kWth, supplying heating and DHW at T = 35°C, in western Europe climate conditions)
- Increase value of Seasonal COP (SCOPcooling) in the order of 5 for 2020 and 5.5 for 2025 (from 2014 value: SPFheating average of 4.5, for a geothermal system capacity of 50-100 kWth, supplying heating at T = 35°C, in western Europe climate conditions)
- Free cooling: Increase value of Seasonal COP (SCOPcooling) in the order of 22 for 2020 and 25 for 2025 (from 2014 value: SCOPcooling average of 20, for a geothermal system capacity of up to 100 kWth, free-cooling supplying cooling at T = 18°C, in western Europe climate conditions)

- Increase the overall impact of a reduced borehole thermal resistance, the Hellström-efficiency, from below 60% to about 75% in state-of-the-art installations, to more than 80% in 2020 and 85% in 2030.
- GIS database to select the best combination between the dimensions of the borehole heat exchanger and of the drilling machine, reducing the uncertainty, minimizing the costs, maximize the environmental protection and the safety for the workers.
- Improve the overall efficiency of shallow geothermal installations by at least 10% in 2020 and 25% in 2030
- Increase number of installations in the EU per year to 150,000 units/y in 2020, to more than 200,000 in 2025, compared to 100,000 units in 2014.
- Reduce investment costs for a geothermal heat pump system, leading up to 20% costs reduction in 2020, and 30 % in 2030 (from 2014 value: 68'000 €, i.e. 1360 €/kW, for a geothermal system capacity of 50 kWth in a new building, supplying heating at T = 35°C during 2200 h per year and cooling at T = 7°C during 1200 h, in western Europe climate conditions).

For deep geothermal, they relate to:
- Decrease geological risk to 2020 by 25% from 2014 and Reduce the exploration costs by 25% in 2025, and by 50% in 2050 compared to 2015
- Reduce the unit cost of drilling (€/MWh) by 15% in 2020, 30% in 2030 and by 50% in 2050 compared to 2015;
- New technologies to reduce operation costs, increase efficiency, reservoir performance;
- Reduction of capital cost by at least 25% in 2020 from 2014, and 50% in the longer term. Reduction of production costs below 120 €ct/kWh by 2020.

3.1.2 Status of Implementation of the RHC ETIP Geothermal Technology Roadmap

Horizon 2020 is the main EU Research and Innovation programme, with nearly €80 billion of funding made available over 7 years (2014 to 2020). It serves the "Innovation Union", an EU initiative that aims at promoting Europe's competitiveness. Projects at different stages of the research and innovation process can receive funding under Horizon 2020. As a matter of fact, EU R&I funding allocated to geothermal energy during the Horizon 2020 European program amounted to around € 250 million by the end of 2018. This sum was divided between an EU contribution of € 160 million and a private sector contribution of € 85 million. In total, 36 projects have been co-funded by public money from H2020 calls on RES&EE and Industrial leadership, as well as from SME-instruments, INTERREG and ERASMUS+. The new framework programme currently under negotiation, Horizon Europe, will also serve as the main EU Research and Innovation programme with a budget of around € 100 billon.

A large part of the RD&I from Industry is dedicated to innovation at a high level of technology readiness. The total number of private projects for geothermal RD&I is hard to estimate. However, it can be assumed that the private sector represents one third of the total investment for RD&I in geothermal in Europe. The geothermal sector benefits from RD&I investments in other sectors such as geosciences (oil&gas), deep drilling, turbines and heat pumps. A new powerful financing tool recently created is GEOTHERMICA – ERA NET Cofund, which currently supports eight transnational projects on geothermal energy bringing innovative geothermal (essentially deep geothermal but some projects also deal with shallow geothermal) energy solutions closer to commercial deployment. The total investment in the projects is close to € 50 million. About half is funded by GEOTHERMICA and the other half comes from project partners. The projects cover a broad range of topics such as heat storage, managing induced seismicity, EGS drilling and completion, production operations, composite casing and integrated applications of geothermal heat. Participants in the first series of GEOTHERMICA-funded projects come from the Netherlands, Switzerland, Iceland, Ireland, France, Flanders, Denmark, Slovenia, Germany, Spain and Azores Portugal. For shallow geothermal, funding from the SME-instrument, INTERREG and ERASMUS+ offers new sources for RD&I.

The monitoring of the implementation of the Geothermal Technology Roadmap has been conducted based on the first set of research, development and innovation projects launched since 2014. The data collected show that the sector is overall 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 costs reduction, are expected in order to reach the targets set for 2020 and beyond. Furthermore, EGS (Enhanced/Engineered Geothermal Systems) heat plant costs could not be accurately assessed due to the limited experience derived from the first pilot plant.

On shallow geothermal, in terms of overall installations, around 100,000 units were sold annually across Europe (over 80,000 in the EU) in 2017. Still far from the 150,000 units/y envisioned in the Geothermal Roadmap for 2020, and too few compared to the number of new buildings at the city level. Nonetheless, there has been a significant increase in the number of large installations (system larger than 50 kWth).

On the costs side, operating costs for geothermal heat pump systems have decreased thanks to lower control costs for annual maintenance as well as to the improved performances, which have led to less electricity input. Nevertheless, despite an assumed 5% costs reduction of the O&M between 2014 & 2018, overall costs in euros have kept stable as electricity prices rose. Some ongoing research projects like GeoCollector (SME instrument phase 2) and more specifically GEO4CIVHIC target operational costs reduction for retrofitting civil and historical buildings with most easy, efficient and low cost geothermal systems.

Investment costs have also been decreasing, of about 5-10% between 2014 and 2018, driven mostly by reductions in drilling (especially in juvenile markets), materials (-5 to 10%), installation (-10%), and heat pump unit (particularly in mature markets) cost. For large projects, the estimated cost reduction in investments has been, instead, of 10% to 15%, mainly in juvenile markets. R&I European projects such as Cheap-GSHPs and GEOTeCH aim to reduce the cost of the fully installed system by 30 % in 2019 (from 2014).

Concerning the energy input for operating the geothermal heat pump systems, ongoing or recently achieved RD&I projects such as COST-Action GABI, the project BRUGEO experimenting enhanced TRT, or GeoFit on energy efficient building retrofitting are creating great expectations. In line with the roadmap goals, in 2018 there has been a general decrease in energy input compared to 2014 values (44.6 MWh electric), between 5% to 10% in mature markets and more pronounced in juvenile markets (equivalent to a value of 40.1 - 42.4 MWh electric).

On the other hand, 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 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) improves the performance with an integrated solution for residential building energy storage by geothermal resources and hybrid systems.

In the three countries highlighted above, the typical efficiency, expressed as 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 the 50-100 kWth ones.

As for cooling, some projects have reached an efficiency (Seasonal Coefficient of Performance on Cooling: SCOPcooling) of 5 already in 2018, above the European average, while free cooling projects have reached a SCOPcooling above 20. A R&I project like GeoSolCool works on improving this efficiency with continuous hybrid cooling using geothermal and solar heat sources and underground storage systems.

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

For Deep Geothermal, the expected target of decreasing the geological risk by 25% in 2020, expressed by the reduced number of abandoned projects and by reduced exploration costs, is probably one of the most daunting challenges for deep geothermal projects. Considerable improvements have surely been made, with 78 percent of wells successfully drilled in 2016 and an indicative reduction in the exploration costs by around 5% to 10% in 2018 compared to 2014 (value 2018 for the exploration costs of a deep geothermal project, without 2D or 3D seismic survey, has a range of 340 000 € – 880 000 €). Yet, progress is still limited by the use of technologies mainly based on the extrapolation of products tailored for the hydrocarbon industry (e.g., geophysical software, logging tools, etc.), as well as by the lack of a proper European geothermal resource database. The ERA-NET co-fund action should allow to better map the potential by "Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (GeoERA)". Several ongoing and recent R&D projects aims to improve exploration tools such as HYDRORIFT, Advanced 3D Geophysical Imaging Technologies for Geothermal Resource Characterization, ThermoGIS and IMAGE.

Significant improvements have also been made concerning drilling costs, which have a substantial influence on the overall economics of a deep geothermal plant with an estimated contribution to the levelized cost of electricity of 11€ per MWh. Thanks to new market conditions, drilling prices have been reduced by 30% in some markets, and there has been a decrease of the unit cost by 5 to 10% in 2018 for some drilling projects between 2015 and 2018. However, ongoing RD&I projects do not have yet an impact on the unit cost of drilling (€/MWh). The flagship research projects to improve current drilling technology are ThermoDrill, DESCRAMBLE, SURE and GEODRILL.

On the wells side, geothermal well design has reached a good standard, and specifically-designed components like pipes and pumps are now available. Production pumps cause high power consumption. However, there is room to reduce operation and maintenance cost by at least 25%, to improve system reliability and energy efficiency of operation, in particular by decreasing energy consumption of production pumps by at least 50%. In general, the cost for well design & completion, reservoir stimulation and management have been reduced by around 5-10% from 2014 to 2018, and the cost for corrosion and scaling has been slightly decreasing as well. Even more, the efficiency of geothermal wells has generally improved by around 3%, while operation and maintenance costs decreased by 5% from 2014. As for the energy consumption of production pumps, RD&I projects are ongoing. Research is this area includes SURE, DESTRESS, GEO-COAT, CHPM2030, MATChING and many innovations from the Industry.

As for Enhanced Geothermal Systems (EGS), in spite of their potential and although the concepts were already demonstrated in the 2000s, those systems 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 result, both with respect to the stimulated underground heat exchanger and the realised thermal and electrical output. Therefore, apart from necessary flanking measures with regard to training, education and public acceptance, major efforts are required for developing tools and layout procedures for a design of EGSs with reliable performance parameters, such as flow rate, temperature and thermal and electrical power. These efforts are currently performed by R&D projects such as DEEPEGS, MEET, Gemex and DESTRESS.

Geothermal energy in Europe has been developed for centuries. Heating and cooling supply is done since antique times (bathing). Europe is currently developing a new generation of geothermal technologies such as EGS, smart thermal grids and applications combining deep, shallow resources and underground thermal storage. But the geothermal potential is not enough defined and the resource characteristics are not well mapped and identified In Europe.

High temperature fields can be found in Europe only in Iceland, Italy, Turkey and some islands. The geothermal potential with high temperature is higher in many non-European countries: USA, Indonesia, New Zealand, Kenya, Mexico… The global market is then an opportunity for the European geothermal sector as new developments on power and heat can be seen in Africa, Asia/Oceania and South America.

A good signal is that RD&I in geothermal is dynamic in Europe with many ongoing research projects and new funding structures. The European industry is also leading in terms of innovation. Many new products could be exported (exploration tools & services, equipments: turbines, heat exchangers…). Europe should participate to the launch of an international cooperation on geothermal especially on EGS and H&C for agro-food industry: the EGS flagship programme could integrate an international dimension to exchange experiences and technologies and exploring export opportunities of the European know-how on EGS, the deployment of geothermal in relevant agro-industrial sectors would integrate heat and cold demand and supply, and ensure food security.

3.2. The Roadmap on deep geothermal

Research and Innovation are two of the cornerstones for the further development of deep geothermal technologies and their market uptake. A new generation of deep geothermal systems and technologies, the adaptation of existing technologies for new applications and markets, novel applications to be demonstrated, standardised and combined in hybrid systems, and the promotion of pre-existing technologies will all contribute to an accelerated deployment of geothermal in the EU in the context of the 2030 milestones.

The targets and the expected performance of the European Technology and Innovation Platform (ETIP) on Deep geothermal (ETIP-DG) have been set during recent years of activity and are summarised below, along with Key Performance Indicators (KPI). The mission, goals and actions described in the Roadmap for 2030 and the future date of 2050 build upon the Vision and the Strategic Research and Innovation Agenda for Deep Geothermal (SRIA) which is detailed in chapter 3.2.2. As regards the Implementation plan of the Roadmap, three main aspects are considered: the identification of Research and Innovation (R&I) actions which ought to be developed as a priority (based on the work of the ETIP-DG Working Groups), the objectives of the research actions, and finally, its targets and measurable performance indicators.

3.2.1 The ETIP DG targets

The objective for all deep geothermal energy applications is to become widely distributed energy sources. As technologies are developed, their costs will decrease and their performance will increase, while risks will reduce and more plants will be deployed, meaning that the cost of producing energy (both electricity and heat) will further decrease due the market expansion of devices, tools and components. The overall objective of unlocking deep geothermal energy requires targets in the three main stages of geothermal project development.

On better prediction and assessment of geothermal resources, the overarching targets are:

- TA-1: Improve accuracy and reliability and reduce the cost of survey-based and down-hole exploration technologies
- TA-2: Improve analytical models and energy production forecasting and enhance the ability to image and characterise underground geological, physical and chemical properties throughout the life of geothermal projects
- TA-3: Minimise the uncertainty associated with geothermal energy by increasing the probability of discovering productive (i.e. fluid-filled) fractures and faults to be used as drilling targets
- TA-4: Improve resource and uncertainty reporting protocols, contributing to transparent and harmonised methods and instruments for technical and financial risk management, increased transparency for stakeholders, better and harmonised assessment of energy stocks across Europe and direct comparison with other RES projects
- TA-5: Investigate and characterise cutting-edge geothermal resources, enlarging the resource portfolio.

For efficient resource access and development, the three priority targets are:

- TD1: Reducing costs related to workovers and maintenance: The overarching performance indicator to evaluate the impact of actions relating to workovers and the maintenance of production pumps and the transfer piping/steam network is the production cost of geothermal energy. This KPI is linked to strategic target no. 3 of the SET-Plan Declaration.
- TD2: Reducing the costs of accessing and developing the resource: The overarching performance indicator used to evaluate the effectiveness of the actions affecting the way geothermal resources are accessed and developed is the total investment in the well-field (encompassing the costs of drilling and completing the injection, production and monitoring wells) divided by the energy output (€/MWh). The situation in 2016 is used as a basis for cost comparison.
- TD3: Reducing the impact of deep geothermal by improving environmental performance and avoiding unsolicited side effects: The third priority target is improving the environmental performance of geothermal plants and mitigating unsolicited side effects (e.g., induced seismicity, emissions to the environment).

For deploying heat and electricity generation and system integration, the four targets are the following:

- TS-1: Increase efficiency and reduce losses and internal consumption during energy conversion processes
- TS-2: Improve the reliability and durability (resistance to corrosion, abrasion) of surface system equipment
- TS-3: Reduce the overall cost of heat and power generation
- TS-4: Adapt plants to be baseload and dispatchable in order to facilitate larger shares of renewables in the energy system and improve the integration of geothermal energy through enhanced interaction with energy storage, demand response and smart interconnection with other technologies.

To move from R&I to deployment, the aim is to develop regulatory, financial, political and social solutions that can be implemented in order to overcome barriers to deploying innovation in the sector, as well as barriers to the broader deployment of geothermal energy solutions and their increased uptake all over Europe. This must be done in parallel to the technological research described above if geothermal energy is to be one of the main contributors to European climate and energy targets.

Regarding knowledge sharing, the main aim here is to improve access to data, information, laboratories and demo sites, improve the accuracy of research and accelerate its progress, and strengthen collaborations while also reinforcing trust in data through the use of open and shared data access.

3.2.2 ETIP DG Strategic Research and Innovation Agenda for Deep Geothermal

Research and innovation will play a fundamental role in achieving these objectives. To helps us shaping a strategic R&I plan and to define R&I priorities, the ETIP-DG members compiled a Strategic Research & Innovation Agenda (SRIA). The SRIA reflects the 'Vision' of the ETIP-DG. This SRIA document recommends that action focuses on addressing the five main key challenges.

Three challenges are technological. The first one is on prediction and assessment of geothermal resources: A better understanding of complex and deep geological processes will enhance the predictability of under-ground conditions; deep exploration technologies will have high-resolution imaging capacity and data modelling will be fully integrated; geothermal resources beyond those already in development will be further characterized for optimizing their use and increase energy production. The overall objective of R&I in exploration is to reduce the costs of exploration technologies and increase probability to successfully characterize the geothermal resources prior to drill and during geothermal development.

The second one is on resource access and development: Extraction of heat from the underground will be maximized by improved well designs, new drilling technologies, new sensors and monitoring techniques, and safe and sustainable flow enhancement. A reduction of drilling costs can be achieved by new or highly performant drilling techniques as well. Another basic challenge is to drill deeper and/or to reach very high temperature resources. There will be safe, rapid and automated technologies for accessing the underground. Lifetime of boreholes and system components will be prolonged by using materials and pumps that are tailored for deep geothermal wells, real-time monitoring, and an in-depth understanding of reservoir and thermal loop processes. Underground energy storage will be efficient, fully integrated in the energy systems and responsive to demand. Such R&I goals, to be also conjugated to environmental requirements, are of reference to the majority of European geothermal reservoirs, which often occur in densely populated areas and are characterized by low-to-medium temperature conditions.

The third technological challenge is for heat and electricity generation and system integration: Energy conversion processes, surface systems of geothermal plants and the integration of geothermal heating, cooling and electricity supply into the energy system, the challenge is to maximise the generation at the lowest life-time cost. The net efficiency, performance and cost-effectiveness of production systems will be optimized, extending the temperature range of different applications of geothermal energy. Conversion of heat to electricity and to chill will be only constrained by physical laws and the production will be totally responsive to the demand and sustainable. Hybrid, multi-source and multipurpose high-efficiency systems embedding geothermal technology will become the European standard.

Two challenges are transversal. One is about the move from R&I to deployment (environmental, regulatory, market, policy, social, human deployments). The aim is to develop regulatory, financial, political and social solutions that can be implemented for overcoming the barriers to the deployment of innovation in the sector, to the broad deployment of geothermal energy solutions and for increasing their uptake all over Europe. This must be done in parallel to the technological research described above, to enable geothermal energy to be one of the main contributors to the European climate and energy targets. It includes the support to establish a legislative framework that will sustain geothermal deployment, its penetration and profitability while guaranteeing that resources are properly managed, to provide low environmental impact technologies, to define economic evaluation criteria, including technical and economic risk assessment and finally to sustain partnerships between companies and consumers, by strengthening reciprocal trust through ethics and security.

The other one is for knowledge sharing (data harmonization and coordinated organization of data and information, shared research infrastructures). Establishing an open-access policy to geothermal information (including standard exchange formats) will ensure open and easy access to data and information. This should be achieved through progressive harmonization of national data to facilitate data disco-very and data mining. It is also vital to demonstrate throughout Europe capacity building, industrial technology transfer and science & academic partnerships via know-how, with the shared goal to develop high quality, competitive and sustainable geothermal energy projects. Information, communication and analytics capabilities will be enabled on a large scale.

Underground data will expand in number and type, will be globally organized and made easily accessible. Terms of reference for reporting and computing geothermal potential, production and capacity will be harmonized; data sharing will improve scalability and extrapolation of the information, improving the capacity to forecast techno-economic parameters and influencing energy planning.

Solving these challenges will give the geothermal sector enormous capability with regard to the key societal challenge of our energy future, and will add greatly to our ability to maintain the safety, security, wealth, and well-being of Europe. The overall Mission of the Research, and Innovation Agenda is to raise the Deep Geothermal sector to contribute to the Clean Cities and Communities of the Future, where a combi-nation of renewable energy sources, including geothermal, for local electricity, transport and heating-and-cooling supply to buildings, tertiary and industry, with underground thermal storage facilities, and electric vehicle are integrated into the system.

3.2.3 The ETIP DG Deep Geothermal Technology Roadmap

The Deep Geothermal R&D plan will be implemented with research projects funded publicly by the upcoming European Programme Horizon Europe from 2021 to 2027, by the 2nd call of Geothermica (ERANET) and European level, and by national and regional public research programmes. The industry will also participate to the implementation through co-funding of R&D project and private investment in innovation.

In the framework of this implementation plan, first research results are expected by 2023. The ETIP-DG implementation plan 2020-2025-2030 will follow the timeline of the EU programme for R&I, and will present a plan for developing different research priorities and areas.

The implementation of the Deep Geothermal Technology Roadmap will be monitored by reviewing ongoing and recently achieved research projects and by assessing the impact of the first results on the key performance indicators. Future trends are also identified, by highlighting areas in which relevant projects are being developed, which could have an expected major impact on a given KPI. This analysis is performed by research area, as identified in the Deep Geothermal Technology Roadmap.

In order to pursue the EU objective of decarbonising the power and heating and cooling sectors, there is a clear need for more resources to be invested by the European Union and the Member States. The ETIP-DG estimates that € 1.7 billion is required for the successful implementation of this Deep Geothermal Roadmap.

The following figures are the expected resources committed by European industry (38%), the European Commission (32%) and Member States & Regions (30%), respectively. Across the 2020 – 2030 period, an average of € 185 million should be allocated annually to deep geothermal research and innovation activities.

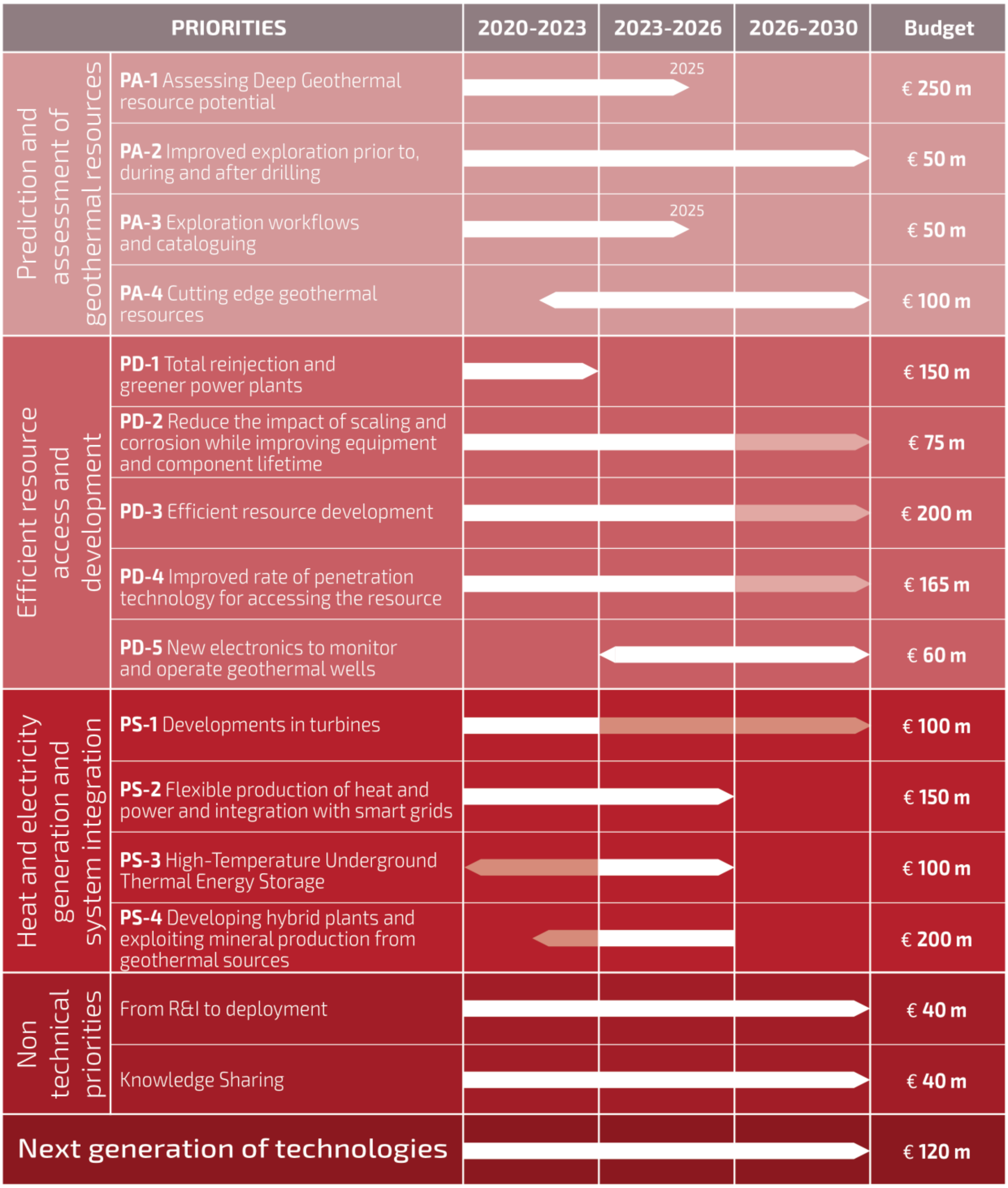

Figure 1: Priorities of the ETIP-DG Roadmap and timeline 2020-2030.

4. THE COMPETITIVENESS OF THE EUROPEAN GEOTHERMAL INDUSTRY

Most of the companies involved in the geothermal sector are SMEs. The markets of the geothermal companies are rather national. Since geothermal technologies are site specific (the geology is different all over Europe and knowledge of the local conditions is essential) and capital-intensive, the needs regarding exploration, resource development, construction and O&M are covered by the local industry and workforce. It is especially the case in the shallow geothermal sector. Designers and drillers for shallow geothermal are typically regional and just some of them are active in another country and usually for cross-border projects. In the deep geothermal industry, SMEs are active during the design phase, but mid-caps or large companies are encountered when referring to developers, drillers, manufacturers and operators.

Given the many different disciplines that are required in the industry, job opportunities are provided for people with different types and levels of skills. Scientists and engineers are needed to explore new geothermal fields. Skilled technicians are required for construction and operation of the new geothermal power plants. Development of EGS (enhanced geothermal systems) or other conventional technologies can contribute to further creation of jobs. Given the nature of the work, we can also assume that construction and O&M cannot be relocated, meaning that they are "European" jobs. Regarding equipment (rigs, turbines), the number of large manufacturers is not expected to boom internationally. In general, it can be anticipated that the sector will move from a geological approach to an engineering approach where systems can be replicated but can hardly be industrialised. Therefore, it is estimated that 85% of the geothermal value chain is going to remain in Europe, as it is now.

4.1. Assessment of the competitiveness for the 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 to an extent that varies greatly through the different European markets. The use of geothermal energy for heating and cooling is increasing rapidly across Europe, with different technologies 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 proven their reliability in France, Germany or Hungary and are rapidly adopted in emerging markets such as the Netherlands. The diversity of markets, technologies, enabling technologies (district heating, heat pumps…) and types of heating and cooling supplied by geothermal systems explains the great diversity of actors involved in the sector and business models for financing projects. Capital intensive, with low operational costs, geothermal energy presents an opportunity for developing innovative financing schemes.

Ground Source Heat Pump (GSHP) systems connected to shallow geothermal installations, mainly with sizes ranging from 2kW to 100kW supplying heating, cooling and domestic hot water with a SPF > 3.5, cover 83% of the total geothermal installed thermal capacity. The remaining 17% is covered by deep geothermal systems. Individual geothermal heating systems represented in 2014 a thermal capacity of over 17 GW in Europe, with nearly 1.3 million systems installed. Estimations show a market exceeding the 2 million units installed in 2019. Dozens of new district heating networks are set up every year, using shallow geothermal systems with heat pumps to either enhance the temperature of the geothermal energy to the level of third or fourth generation district heating networks (80 and 50 °C respectively) or to deliver low temperature thermal energy to the users -through the network pipelines- and to enhance the temperature level at user's side to the needed level (35 to 70 °C).

Deep geothermal district heating accounts for a thermal capacity of over 5.1 GW in Europe (including Iceland – 2.2 GW, 1.9 GW in the European Union, contributing at least 4.3 TWh of thermal energy delivered every year), with 304 plants currently in operation. If we disregard the deep geothermal power industry (devoted to electricity production), which is not the focus of this study, most of this segment is involved into the high and medium temperature (third and fourth generation) district heating sector. The geothermal industry has had an increasing turnover in the European Union to around 2.7 billion euros, the heating and cooling sector representing 1.6 billion euros overall. In terms of jobs created, the geothermal sector represents 25,000 – 30,000 FTE including the deep and shallow markets.

The deep geothermal industry is structured around several key technologies that focus either on the production of heating and cooling or on that of electricity or for cogeneration of heat and electricity (CHP, Combined Heat and Power). As a heavily capital-intensive investment, the value chain of the geothermal sector is overwhelmingly concentrated around the project development phases. Altogether the geothermal industry may be subdivided in several subsectors, which correspond broadly to a given aspect of geothermal projects: subsurface industry from exploration to well completion, including reservoir management; surface industry for the construction of surface equipment; legal and financial industry. The deep geothermal industry is diverse and globally the geothermal market differs greatly from one area to another. Historical so-called "high temperature" markets tend to be structured differently that other with more recent development more focused around heating and cooling projects.

Altogether, the drilling of the geothermal wells represents the biggest component of geothermal project development. However, despite the importance of the subsurface industry in enabling the extraction of the geothermal resource, the surface industry is also a major component of the geothermal energy value chain. Regarding the subsurface industry, beyond the crucial step that is exploration, drilling represents between 30% and 50% of the cost of geothermal electricity and heat projects and more than half of the total cost of Enhanced/Engineered Geothermal Systems (EGS). Drilling market conditions are different all over Europe as a result of different national regulatory frameworks which creates a barrier to the creation of a European geothermal drilling market. In some countries, the number of drilling companies is not high enough to allow full competition and therefore competitive prices.

Despite the importance of the subsurface industry in enabling the extraction of the geothermal resource, the surface industry is also a major component of the geothermal energy value chain. Indeed, as we will see below, the development of binary turbine technologies is crucial in enabling the geographical spread and the scale up of geothermal power production in Europe.

4.2. Potential cost reduction: beyond the LCoE approach

The competitiveness of the deep geothermal sector must be consolidated by first developing a fair basis of cost comparison between energy sources which goes beyond a limited LCoE approach, taking into account actual system costs and external factors. It should be noted that deep geothermal projects have low systems costs and negligible externalities, which means that the LCoE accounts for almost the full costs for the project. This potential cost reduction is linked to the third strategic target of the SET-Plan Declaration. The target is set at a maximum production cost of 15 €ct/kWh for electricity and 6 €ct/kWh for heat by 2023, and 10 €ct/kWh for electricity and 5 €ct/kWh for heat by 2026. These cost targets apply to all types of deep geothermal projects, including EGS and super-hot geothermal systems (> 350°C).

As of 2019 the levelized cost of energy (LCoE) for electricity production varies between 30 and 150 €/MWh. The higher values are typical for binary plants tapping into medium temperature resources. The LCoE for flash plants typically is lower and has an average value of about 40 €/MWh.

The selling price for heat in existing geothermal district heating systems is usually around 60 €/MWh, and within a range of 20 to 80 €/MWh. The price depends on the local geothermal situation, socio-economic conditions and pricing policies. In addition, district heating networks account for a significant share of the total costs for a geothermal district heating system.

The economic potential for geothermal electricity generation in Europe in 2030 and 2050 has been estimated as part of the GEOELEC project, using an LCoE value of less than 150 €/MWh for 2030 and less than 100 €/MWh for 2050.

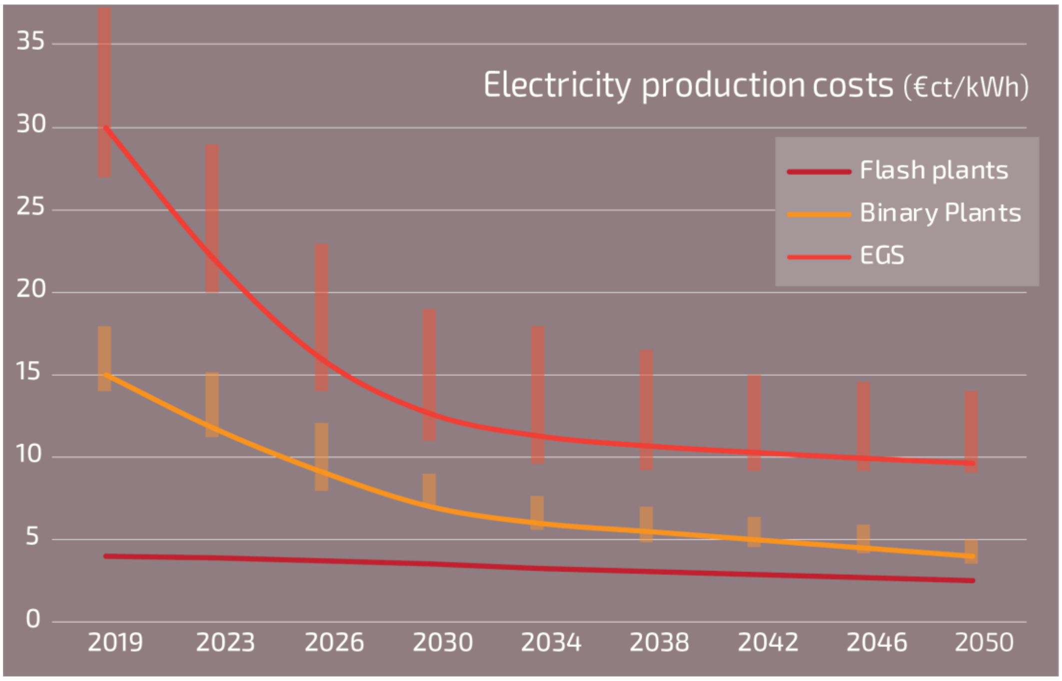

Figure 2: Potential cost reductions for electricity production.

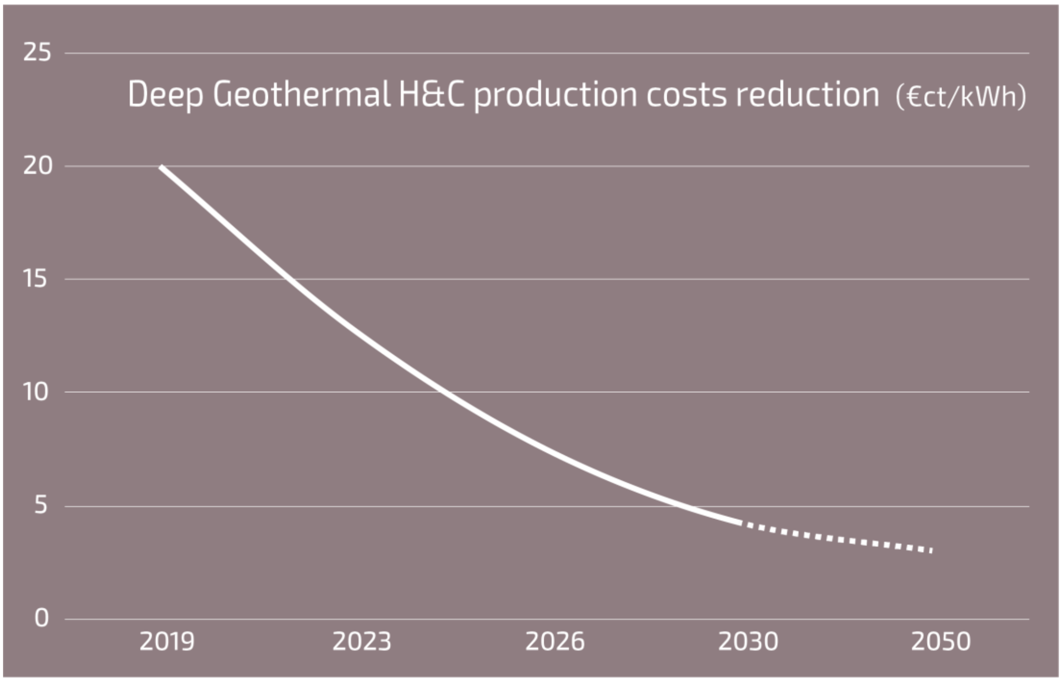

Figure 3: Potential cost reductions for h&c production.

4.3 Reinforcing competitiveness

The competitiveness of the deep geothermal sector has to be consolidated by developing a fair basis of cost comparison between energy sources, beyond a unique LCoE approach, taking into actual account system costs and external factors, analysing the ability of energy market models to properly remunerate the various benefits of geothermal energy in a industrial context of intensive capital investment (CAPEX) and marginal operational costs (OPEX) and establishing fair competition globally with the geothermal stakeholders from across the world.

Considering that the rest of the world is moving towards geothermal energy at an accelerated pace, these efforts need to be maintained and made subject to ambitious further expansion in order to maintain Europe's leading position in developing the geothermal industry of the future, both for research and commercial development.

4.3.1 Current status

As highlighted above, the LCOE is one of the criteria most used to compare the competitiveness of different energy sources, notably in policy making. It is a very partial indicator, however, as there is no consideration of system costs such as the cost of transmission, or other network costs such as impact on system balancing, impact on state/system energy security, and the costs of external factors such as government-funded research, residual insurance responsibilities borne by the government, external costs of pollution damage or external benefits (e.g. the value of knowledge for future generations). Current market models are unable to remunerate energy sources with low operational costs, hence there is a need for 'out-of-market' remuneration (feed-in tariffs, contracts for difference, premiums, capacity remunerations).

Europe has pioneered the exploitation of geothermal resources for power generation for over 100 years in Larderello, and the EU still maintains a leading role in electricity due to the development of EGS technology in many parts of the EU with the integration of national projects (in France and Germany) into a European Project at Soults-Sous-Forêts (France). In addition, the EU has the first successful commercially funded EGS project in Landau (Germany) and an EGS for industrial use (ECOGI project in France). 15% of installed geothermal power capacity is located in Europe. European companies are often technology leaders. With more than 200 geothermal DH (District Heating) systems in operation, Europe is also the global leader for geothermal DH. Global competition exists mainly for heat exchangers and pipes. The use of geothermal heat in industry, the agri-food sector and services also started in Europe.

4.3.2 Potential development

The following proposals are made in order to reinforce the competitiveness of geothermal.

- Develop a model providing proper comparison of the full costs of competitive heat and power energies; this is necessary for a rational allocation of resources between energies.
- Establish carbon pricing with taxation tools and a new ETS which also tackles large heat installations in order to integrate the costs of external factors into the full costs of an energy source.
- Develop new business models for geothermal developers and operators, allowing them to sell their heat and power on different markets.
- Support the export of European geothermal technologies via trade missions and policies to open third markets.
- Set standards and establish high quality: European industry is defined by high standards, it is important to benefit from this fact internationally.
- Promote innovation: Develop new technologies and bring them to market (innovation in energy is a long process, and is quite risky for companies); promote "Competitiveness clusters" dedicated to geothermal, recognise potential for the reconversion of professionals and industry from other energy sectors such as coal mining and oil and gas, and liaise with other sectors such as the agri-food industry, data science and robotics.

5. CONCLUSION

Geothermal energy is considered a key Renewable Energy Source to implement the EU 2020-2050 Strategy. It is recognised as a promising technology with large innovation potential in the European Commission's SET-Plan and its Integrated Roadmap. Geothermal energy has the characteristics required to play a crucial role in our future energy mix: it is decarbonised, capable of providing affordable energy for society, and allows for the competitiveness of European industry.

ETIP is a crucial instrument for the further development of geothermal technologies and their market uptake.

In March 2016, the European Technology and Innovation Platform on Deep Geothermal (ETIP-DG) was launched as a tool to strengthen cooperation under the SET-Plan. The ETIP-DG is an open stakeholder group that brings together representatives from industry, academia, research centres, and sectoral associations, covering the entire deep geothermal value chain.

The geothermal panel of the Platform on H&C was established in 2009. In April 2013 the RHC-Platform launched the Strategic Research and Innovation Agenda for Renewable Heating and Cooling (RHC-SRIA). It offered recommendations for research, development and demonstration funding in the timeframe of 'Horizon 2020'. The geothermal panel then worked on the implementation roadmap to plan research priorities and investigate ways of funding. It also further defined key performance indicators (KPIs). The Geothermal technology roadmap was published in March 2014. The work on an updated version of the Strategic Research and Innovation Agenda for geothermal H&C should be published end 2019.

The ETIP-DG members sketched their view on the development of deep geothermal in the “Vision for Deep Geothermal”. The Vision depicts that by 2050, large geothermal power plants that tap into ultra-hot, supercritical heat reservoirs supply a large part of Europe’s baseload electricity would need to be developed. In places where the geothermal resources are of lower temperature, the electricity potential is boosted by combining geothermal with other renewable resources such as solar-thermal, salt-gradient power, photovoltaics or local biomass.

The European geothermal industry has a know-how well recognised at global level and is a global leading actor in terms of innovative technologies thanks to consistent and robust investments in R&D.

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