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European Geothermal Industrial Strategy

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Table of contents

1 Executive Summary

To ensure the tripling of geothermal energy capacity by 2030, an industrial strategy is required to pave its way.

Following the publication of the REPowerEU Plan, a European Solar Strategy has been released in 2022, stating for the first time a target for geothermal energy expansion at EU level. A threefold increase of geothermal energy is highlighted as an enabler for increased production of renewable energy in Europe.

In August 2025, The European Commission announced an "upcoming" call for evidence with a public consultation on third Quarter 2025 about the Heating and Cooling Strategy, with an aim to accelerating the decarbonisation of heating and cooling. It will:

- help bring renewable energy technologies and energy efficiency solutions to industry, households and businesses;
- address inefficiencies at the interface of supply and demand, and at planning level;
- advance energy system integration of heating and cooling;
- explore other actions on direct heat capture, e.g. through solar thermal energy.

For the first time the EC confirms that it will include an action plan on geothermal energy. This action plan must contain an industrial strategy.
It should contain proposals to scale up geothermal development in Europe, including a part on research and innovation agenda
The latter should promote the establishment of a skilled workforce which includes not only training for new professionals but also re-purposing jobs, especially from the oil and gas sector. That sector holds numerous skills next to equipment that can be transitioned to geothermal energy use. Additionally, capacity building goes beyond the technical knowledge and includes capacities at the level of authorities. This mainly includes more efficient and faster permit granting, which requires the right procedures to be in place to reduce bureaucratic overload.
Manufacturing capacity “made in Europe” does not only increase resilience and makes geothermal energy even more independent from external influences, but it is also a unique characteristic in the field of renewable energy sources.
Still, there is a need to empower the sector with the right support schemes. Investments remain a barrier to the expansion of geothermal energy. Public investment – which triggers considerable private support – can ensure the take-off of geothermal energy. Furthermore, targeted financial support for R&I is required to develop innovative technologies. There are numerous innovations in development, many of which are on the edge of breaking through, if the right financial support is given.

2 Introduction

This report addresses the part on research and innovation in the upcoming European Geothermal Industrial Strategy as part of the Geotherm Fora deliverable 4.4. The latter is part of Task 4.4. Towards a European Geothermal Industrial Strategy, which focuses on geothermal energy beyond energy production. The objective is to formulate a Geothermal industrial strategy to foster and improve geothermal technologies with a focus on research and innovation needs.

It includes a broader approach, considering raw materials and equipment, industrial and employment dimension, regional and international cooperation and the technological transfer of research projects from the laboratory into practice. While reinforcing the role of geothermal in the energy mix, the tasks states that the strategy will underline that sustainability and, more specifically, the protection of the environment and the social sciences and humanities dimension, which will be key principles for all related aspects concerned.

First, it provides an overview of the geothermal market, outlining the current technology status, key challenges and opportunities, market trends and nextgen technologies as well as industrial competitiveness and European leadership.

Second, the paper focuses on a vision for the future of geothermal technology. This chapter includes a discussion around targets for 2030, 2040 and 2050, the research and innovation agenda and other EU roadmaps.

Then, possibilities for scaling up geothermal development are explored. This includes an assessment of the existing policy and regulatory frameworks, financing and de-risking, the infrastructure and supply chain next to workforce development, capacity building and international cooperation.

The final chapter focuses on the future of a Geothermal Alliance.

3 Overview of the geothermal market

3.1 Current status of geothermal technologies

Over the past years, geothermal installations have become more cost-efficient and have got closer to the aim of securing provision of heat and unlocking geothermal resources in further regions. In 2024, geothermal energy delivered electricity to 11 million consumers and heating and cooling to 20 million people. 400 cities and factories received geothermal energy as well.

According to the technology readiness level (TRL) scheme, market-ready solutions at this stage are large and high temperature heat pumps, large-scale geothermal heat pump systems, composite downhole tubulars for competition, sub-horizontal drilling design, low-temperature heating systems (5th generation district heating and cooling), composite downhole tubulars for competition, large ORC turbines and district cooling.
In parallel, first demonstration technologies that are expected to be ready for the market before 2030 include medium and high temperature UTES, single well technologies, deep closed loops of multilateral well systems, cooling for industrial purposes and co-production of critical raw materials.

When it comes to lower TRLs – areas where innovation is still at the centre of attention - digital twins as one angle of digitalisation is supposed to improve production and efficiency. For geothermal energy production and underground heat storage, digital twin systems combined with real time data analysis and AI-aided decision-making during operation of geothermal systems are currently developed. Moreover, AI and machine learning are used to develop quantitative approaches and identify risks at an early stage. Hence, better operational decisions shall be taken during the exploration process which will lead to higher drilling success rates.

Exploration tools are constantly improving, reducing uncertainties on location, size and productivity. Fibric Optic Sensors are still under development but constantly growing. Soil gas surveys are a key tool for geothermal exploration and can detect seismically active faults. Structure in volcanic systems and monitoring geothermal systems for energy production. Urban seismic geothermal exploration has greatly been taken over by URGENT project that will be able to provide data on geothermal exploration in urban areas.
Other working fluids than water such as supercritical carbon dioxide (sCO2) can be favourable to use based on characteristics such as transport properties and more. Furthermore, couples thermal, hydraulic, mechanical, chemical (THMC) and microbiological system models are being developed for better understanding of medium-depth storage. This technique is also explored for critical raw material extraction. Also, microbiological processes are being researched as those can be created within some alternative fluids of the geothermal well.
Monitoring and assessment techniques to overlook that reservoir, well integrity and pump lifetime are key when developing a geothermal installation. To ensure a sustainable and efficient operation and to guarantee longevity of geothermal production and storage, monitoring must be conducted in the context of the geological resource and the technical installations. Smart monitoring has been developed to support those procedures.
There are many research topics that aim at facilitating and optimising the co-production of critical raw material (CRM) from geothermal brine in general such as lithium. The latter is highly dependent on the type of brine and explored under different projects.
Research for utilising the crystalline basement includes laboratory experiments at high pressure to obtain unique data on the complex coupled thermal, hydraulic, mechanical and chemical processes with the challenge of simulation in-site stress filed and temperature. However, there are also several efforts to close the research gap between laboratory and field scale via underground research laboratories.

Most of those developments can be understood further when looking at specific researching projects and implementing them. Geotherm Fora deliverable 4.1: technological trends provides further insides.

3.2 Key challenges and opportunities

The geothermal sector holds immense potential. However, it still faces considerable barriers to fully expand throughout Europe. Main challenges include missing awareness among policy makers, local authorities, citizens as well as other end users such as industries and commercial building owners. Lengthy permitting procedures restrain geothermal projects from fast implementation and slow down many projects. Additionally, a complicated regulatory framework, where certain projects have to consult a high number of institutions to receive environmental permits and more. Responsibilities often range from the energy ministry, over the environment ministry to mining and/or water ministries/agencies. Furthermore, missing investments and limited public support does not contribute to an expansion of the sector. Yet, to ensure competitiveness, financial incentives and support are key to ensure mass deployments of any new technologies.

Acknowledging these barriers, there are considerable opportunities to be considered. Geothermal energy is a “made-in-Europe” renewable energy source with a local supply chain, reducing dependency on non-European actors. There are various geothermal energy technologies, providing wide possibilities of application. The four large application areas include heating and cooling provision, electricity production, energy storage and the extraction of critical raw materials such as lithium from geothermal brine. Hence, scaling up the use of geothermal energy is very diverse and addresses distinct demands in the energy sector. Thus, carbon emissions are cut, dependencies, especially on critical raw materials can be reduced and European industry is boosted.

Furthermore, the energy efficiency of geothermal is very high. It is very well suited for a variety of applications, from residential and social housing to commercial building, agriculture or industry. Particularly for urban spaces, geothermal presents key opportunities based on the little surface requirements and possibility to repurpose the area around the geothermal installations, once built. Geothermal applications rarely require maintenance and are long-lasting renewable energy solutions. From a socio-economic perspective, geothermal energy can be a key sector to create jobs and give an opportunity to the oil and gas industry to transition to clean energy production while continuously applying their knowledge skills and using existing materials. Consequently, this sub-chapter takes note of challenges to be addressed while highlighting the non-neglectable opportunities of the sector which is why a boost brings universal benefits. Further R&I activities will enlarge the list of opportunities and benefits of geothermal energy use.

3.3 Market trends and nextgen technologies

While geothermal energy continues growing in its traditional markets such as individual buildings, DHS and greenhouses, geothermal smart heat networks (5th generation) and deep closed loop and thermal storage systems keep growing. New countries and regions are being identified for geothermal energy production. Inputs from Geotherm Fora, D4.2. have been compiled in this deliverable.

Geothermal heat pump installations and sales have been increasing by ~13% in most countries, with Germany, the Netherlands, Finland and Sweden remaining at the top of the list. Though, stagnation in mature markets can be observed, which puts the reaching of the identified target of the REPowerEU Plan at risk. The latter suggest doubling annual sales by adding 10 million hydronic heat pumps by 2027 and 30 million by 2030 as well as tripling overall geothermal energy capacity, stated in the Solar Strategy.

Moreover, **geothermal district heating and cooling** projects continue to grow with 8 newly commissioned projects in 2023 in the EU. By the end of that same year, 298 DHC systems were already installed in EU Member States. For 2030, a significant increase of geothermal DHC systems is expected with 316 projects under investigation that could result in an additional capacity of 744 MWth reaching 7,352 MWth. Policy support and technological advancements are driving the market. To overcome remaining challenges, a focus has to be placed on lower temperatures systems and innovative business models.

Moreover, with tendencies to focus on low temperature district thermal networks, the role of **5th generation district heating and cooling** increases. The latter allows to integrate geothermal heating and cooling in local district heating and cooling networks which is not only more environmentally friendly but also cost-effective and efficient. Particularly with the Energy Performance of Buildings Directive, renovated or newly builds homes are being adapted to lower temperatures thermal supplies.

As for **geothermal electricity**, Italy, Croatia, Germany and Turkey have reached marked maturity and 8 new projects have stated development in 2023. In total, Europe had 3.5 GWe geothermal in 2023 resulting in 7 TWh/y for the EU alone. Currently, the policy framework is slowing down further geothermal electricity deployment. For 2030 a significant increase in geothermal electricity projects is expected based on about 50 geothermal power projects under construction. Technology wise, a shift towards larger installation with binary technologies and small-scale combined heat and power plats can be observed.

Developing advanced geothermal systems or **UTES**, the use of subsurface working fluids other than water (e.g. Co2) are explored. This could be integrated with carbon capture and storage technologies to deliver more heat/power decreasing costs and increasing efficiency.

UTES technologies can vary between borehole thermal energy storage, aquifer thermal energy storage, cave thermal energy storage, tank thermal energy storage or pit thermal energy storage. Repurposing abandoned coal mine shafts highlights the high scale of innovation surrounding geothermal energy, specifically storage.
When it comes to **mineral extraction** such as lithium, silica, zinc or other rare earth elements, geothermal dual use presents a promising future. Economic and environmental viability are key to be developed further and the sector is heavily investing in it with over €50 million of investment so far. At this stage, the market outlook focuses on few concrete projects in Germany, Italy and France but also the UK is researching on similar CRM extraction projects. By 2050, about 20% of the EU's lithium demand could be covered by geothermal lithium. Hence, research and innovation efforts in the sector is booming.

Globally, geothermal energy use has experienced a significant increase, shifting from a primary focus on electricity generation to heating and cooling. Particularly, the United States continue leading the geothermal electricity market while China is expanding the geothermal heating and cooling industry and leading the respective market. Additionally, Latin American and African countries are investigating their geothermal potential. Just as in Europe though, political hurdles are slowing down the sector's growth.

Next generations of geothermal energy can be characterised by increased capacity and diversifying applications, adapting depth with increased efficiency at lower temperatures or the right number of wells to be drilled. Moreover, Greenfields will be expanded, exploring regions with new exploration technologies. The elements listed all contribute to de-risking geothermal projects.
Via new resource identification and assessment technologies, investments are growing and use is expanding. With the help of acceleration areas in the Member States, further potential and targeted research shall help leverage geothermal growth. Characterised by long lasting installations, geothermal wells have to resist up to 50 years which drives companies to competitive development of such resistant materials. For the drilling itself, a higher rate of success will be reached by applying and evolving technologies from the oil and gas sector.

Lowering operation and maintenance costs is also getting at the centre of manufacturing for instance by developing productions not reacting with the brine such as coatings or epoxy/fiberglass tubing. Furthermore, localising the entire value chain of geothermal installation should be one of the priorities when developing the geothermal market as the unjustified Russian was of aggression again Ukraine showed supply shortages and delayed several geothermal projects by months. As such, the geothermal sector does not require critical raw materials for its functioning, yet carbon steel for instance was heavily affected by the war and consequently experienced a strong price increase.

3.4 Industrial competitiveness and European leadership

Geothermal energy holds strong potential to contribute significantly to Europe's climate and energy objectives. However, despite its long-term sustainability benefits, competitiveness remains a key challenge. The geothermal sector must build a more robust market presence to effectively compete with fossil fuels, which continue to dominate Europe's energy mix in both heating/cooling and electricity generation. The path toward enhanced competitiveness involves not only cost reduction and innovation but also the development of a consolidated internal market and stronger positioning in global value chains.

Geothermal heating and cooling in Europe is relatively mature compared to geothermal electricity generation, and the region enjoys a number of competitive advantages. Europe hosts a highly developed supply chain for geothermal heating systems, particularly heat pumps and district heating infrastructure. Equipment for these systems is largely manufactured within Europe, allowing the industry to retain value and strengthen resilience against global supply chain disruptions. Moreover, European companies are global leaders in heat pump manufacturing and in providing services for geothermal heating system deployment. Cost remains a barrier, especially in countries where natural gas still dominates residential and industrial heating. To improve competitiveness, ongoing innovation is required in reducing installation costs, improving efficiency in heat extraction, and optimizing hybrid solutions such as ground-source heat pumps integrated with solar thermal or storage systems.

Compared to heating, geothermal **electricity** remains less present in Europe, but it holds considerable promises. It is one of the most sustainable and flexible renewable energy sources, capable of delivering baseload electricity with low emissions. It can be transported over long distances and provides reliable power to remote communities and urban centres alike. However, geothermal electricity faces challenges related to technical complexity, exploration risks, and high upfront costs. Despite these issues, the European geothermal electricity sector has carved out a competitive niche globally. European firms are net exporters of services for geothermal power plant development, particularly in areas that demand innovative technical solutions. Most of the equipment used in European geothermal power plants is also manufactured locally, further enhancing the sector's competitiveness and innovation leadership.

In sum, Europe enjoys a competitive edge in several areas of the geothermal value chain:

- Equipment Manufacturing: A large portion of the equipment used in geothermal systems—both for heating/cooling and electricity—is manufactured in Europe, providing economic value and supply chain independence.
- Service Provision: European companies lead globally in services related to geothermal project development, particularly in drilling, heat pump integration, and district heating engineering.

- Heat Pumps: The European heat pump industry is not only globally competitive but also deeply rooted in domestic capabilities, making it a cornerstone of geothermal heating competitiveness [1].

[1] Geotherm Fora, D 4.1 - Major Technological trends.

4 Vision for the future of geothermal technology

4.1 Targets for 2030, 2040 and 2050

The 2024 ETIP Geothermal Vision looks towards the future of geothermal energy development to achieve the European Union's climate-neutral milestone by 2050, and it highlights the great benefits of geothermal to decarbonise our economy. It is a unique solution to allow a sustainable energy transition with a paradigm shift for a circular economy. Geothermal is key to achieve EU **climate-neutral ambitions for 2050**. In order to reach this objective, geothermal deployment has to gradually increase.

ETIP Geothermal Vision - 2040:

Heating and Cooling
Geothermal heat with district heating and cooling, supply to industry and agriculture and buildings with collective and individual heat pumps could cover more than 30% of Europe's demand for heating and cooling of buildings, more than 20% in the agricultural sector and more than 5% in industrial and services sectors.

Electricity
Geothermal electricity can cover more than 10% of the power consumption in Europe.

Storage
Thermal underground storage (Underground Thermal Energy Storage: UTES) supports energy system integration with a UTES contribution to more than 10% of Europe's heating and cooling consumption, essentially coupled with district heating systems and industrial processes.

Minerals
Sustainable extraction of minerals and critical raw materials (CRM) from geothermal, such as geothermal lithium, are contributing to EU targets of at least 10% of the EU's annual consumption for extraction of CRM.

Made in Europe manufacturing
By 2030, the **supply chain of geothermal energy** should be 50% of European origin and by 2040 this rate should raise to 60%. Using geothermal energy, **150,000 direct and indirect jobs** can be created by 2030. By 2040, **sustainable production of minerals and critical raw materials**, in particular lithium can take a share of 25% in lithium-ion batteries from indigenous geothermal lithium.

Putting the **Strategic Research and Innovation Agenda** provided by ETIP Geothermal in place, geothermal can take over a large amount of electricity production, heating and cooling and thermal storage in 2040. For heating and cooling strong geothermal technologies can reduce emissions of sector. Thus, there is a need to upscale projects, creating more robust, reliable and efficient solutions that adapt to quickly evolving social and environmental frames, also on technology level.

As for electricity, geothermal is **available** and should be used in every region of Europe to ensure local security of supply to reduce costs for decarbonisation and provide baseload electricity. Business models and standards need to be adapted and tools and techniques for extremely deep reservoirs showing extremely high temperatures have to be developed.

Energy storage will allow to support system integration, especially when coupled with DHS and industrial processes. Different technologies will have to be used.

4.2 Research and Innovation agenda

Research and innovation are key to deploy geothermal energy at the needed scale. It can allow to improve next generation geothermal systems and technologies event further and adapt them to the needs of the market. One of the key messages focusses on increased funding, not only at private level but also from European, national and regional entities.

First, **resource assessment** via exploration and risk reduction should be addressed. Topics to be addressed touch upon technologies for improving resource assessment and prediction of pre-drilling steps such as cost-effective resource assessment, reservoir characterisation and performance assessment and establishing catalogues and databases on knowledge sharing on comparable productive reservoirs and geological analogues.
Additionally, frontier resource development and identification of resource potential to use or reuse existing subsurface infrastructure shall be explored. The latter includes exploration of medium-deep sedimentary reservoirs, closing the research gap of low depth geothermal. Deep sedimentary reservoirs with low natural permeability and cutting-edge reservoirs with high enthalpy resources should be explored. Innovative geo-structure shall be included on the research and innovation agenda next to the transformation of hydrocarbon assets. Advancing methods for identification and de-risking of resource potential needs to be addressed. This can include play-based portfolio exploration for heating and cooling and assessment of resource potential.

Second, **drilling and subsurface engineering** require innovative approaches to reduce costs and risks. Financial hurdles remain one of the major barriers to increased geothermal deployment. Via monitoring of existing projects and innovation, those requirements can be attired. Concretely, enhanced technologies for drilling and competition of wells are needed. This includes robot and AI assisted drilling technologies, optimisation of penetration rate technologies, research on drilling fluids, materials for casing, cementing and competition. It also refers to monitoring, logging while drilling and geosteering as well as research on high temperature electronics. Enhanced design and subsurface engineering next to improving of productivity of wells can be reached via research and innovation for well architectures and stimulation, upgraded shallow closed loop technologies (<500m) and deep closed loop technologies (>500m) and enhanced production pumps.

Third, **efficiency of resource use and system integration** requires research and innovation. This element addresses the transformation of geothermal energy into power, heat, storage etc. The result will be further increased by energy efficiency. Particularly, underground energy storage and lithium extraction shall play a central role on the geothermal research and innovation agenda. Therefore, increased focus on enhancement and cost reduction of energy conversion, heat storage and coproduction are needed. This includes advanced binary cycle, power cycles and efficiency improvements, flexibility in combined heat and power production, high-temperature underground thermal energy storage, lithium and other mineral exploration and chemical production and other uses.
Moreover, research and innovation for enhanced embedding of geothermal resource use in energy systems require smart integration into different generation of DHC networks, resource management in dense installation environments, heating and cooling usage and flagship projects for DHC Networks in metropolitan heating and cooling.

Forth, **market uptake and resource management** shall remain central to the geothermal research and innovation agenda. This includes increasing environmental sustainability of geothermal energy, bringing down high investment costs and effective communication strategies. Circularity, life cycle assessments and reservoir management can contribute to those agenda points. Further, water use management and groundwater protection as well as sustainable reservoir management should be included. Innovating with and for society is key which aligns with financing and risk mitigation, policy and regulatory adaption, qualifications and training and communication connected to public awareness should be enhanced via the strategic research and innovation agenda.

Lastly, the research and innovation agenda for geothermal energy must include **incentives and tools for data and knowledge sharing** focussing on underground data, organisational and informative knowledge and research infrastructure. ETIP-Geothermal showcases the research and innovation agenda in its report published at the end of November 2023. More details and concrete research and innovation requirements are outlined in this report.

4.3 Towards an EU geothermal Action plan

Over the past years, the European Commission has published a variety of roadmaps and strategies dedicated to specific renewable energy sources. These strategies are a major boost to the respective technologies, as they do not only acknowledge the potential and viability but are necessary market drivers. Despite not being obligatory, the strategies provide planning security and project the industries to go bigger as they present specific targets and EU actions to help achieving those.

The European Solar Strategy[2], published in 2022 sets the following objectives: over 320 GW of solar photovoltaic by 2025 (more than doubling compared to 2020), almost 600 GW by 2030, an installation average of ~45 GW per year. By 2025 58TWh of additional electricity shall be produced. Key EU actions include the set up of an EU Solar Industry Alliance[3], which came to light in 2022 to accelerate solar PV deployment in the EU. Bringing together various stakeholders, it developed a strategic action plan and creates an ecosystem to support securing and diversifying supplies of solar PV amongst other activities. Additionally, shorter and simpler permitting is addressed, a European Solar Rooftop Initiative, support to innovative solutions and the removal of trade barriers.

The European Off-Shore Strategy[4], released in 2020, sets an estimated outlook of at least 60 GW of offshore wind by 2030 and at least 1 GW of ocean energy. By 2050, 300 GW and 40 GW of installed capacity, respectively shall be installed. The strategy mentioned the need for facilitated cross-border cooperation, adaptation of regulatory frameworks, a dedicated working group in the clean energy industrial forum and financial support for further research to name a few measures.

The European Hydrogen Strategy[5], published in 2020, promotes a share of hydrogen in EU energy mix of 13-14% by 2050, and <40 GW renewable hydrogen electrolysers by 2030 and a production of up to 10 mio tonnes of renewable hydrogen in EU. It announces the creation of a European Clean Hydrogen Alliance next to measures such as incentives for EU level quotas, clean hydrogen partnership or capacity and financial support.

Consequently, a European Geothermal Action Plan is more than justified given immense potential yet limited political coverage. The proposal should address barriers and opportunities in order to unlock mass deployment of geothermal.

Key elements that can be drawn from the above are an industrial alliance for geothermal (find further information in chapter 6), which brings together policy makers, industry stakeholders, civil society, research institutes etc. A clear target of 250 GW by 2040 should be set, which will provide orientation for politics and stakeholders. Further, public (and private) investments have to be unlocked as increased financial support for projects and research is necessary to boost close-to-market research projects, but also the most innovative ideas, able to revolutionize the geothermal sector. This can include dedicated Horizon Europe calls next to other funding schemes announced by the new Commission. Risk-mitigation schemes should be established.

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[2] EUR-Lex - 52022DC0221 - EN - EUR-Lex
[3] European Solar Photovoltaic Industry Alliance - European Commission
[4] EUR-Lex - 52020DC0741 - EN - EUR-Lex
[5] EUR-Lex - 52020DC0301 - EN - EUR-Lex

Additionally, accelerated permitting procedures have to be implemented, especially for geothermal heat pumps as outlined in the RED. Increasing political visibility and public awareness will be strengthened by the Geothermal Action Plan itself but should also benefit from additional campaigns. Direct support to Member States in increasing geothermal deployment via, e.g. peer-to-peer capacity building to establish additional national geothermal roadmaps should be included in the Plan. A dedicated European Geothermal Action Plan is required to represent the entire value chain from electricity, heating, cooling, storage and sustainable mineral extraction.

Sectoral Agreements are essential to addressing consumer needs for reliable supplies of cost-effective geothermal heating, cooling and power. This will boost local authorities' capacity while enabling the geothermal sector with the right means to grow.

5 How to scale up geothermal development

5.1 Policy and regulatory frameworks

Early 2024, the European Parliament's plenary voted with 96% in favour of a resolution to support a European geothermal energy strategy. The latter should facilitate a reduction in administrative burdens and investments in buildings, industry and agricultural sectors across the Union; for building a Geothermal Industrial Alliance; for setting up a harmonised financial risk mitigation insurance scheme, and to support regions in transition and coal regions to transition to geothermal.

The EU Committee of the Regions as well as the European Economic and Social Committee followed the Parliament's initiative and backed geothermal energy. In December 2024, the Council of the EU published its Council Conclusion on geothermal energy, promoting geothermal energy as a local, affordable and secure solution to decarbonise the energy system. Furthermore, the momentum to boost geothermal deployment in the EU evolves with the Energy and Housing Commissioner Dan Jorgenson committing to publishing a geothermal strategy during his mandate.

Geothermal energy is subject to various legislations on EU and national level, creating a highly complex framework to work with. Some policies provide needed guidance on installing geothermal plants. Nevertheless, a clear framework including appropriate targets, facilitated permitting rules and clarity to the industry and consumers is missing. The past mandate of the European Commission brought various new and updated policies to the table that are relevant to the geothermal sector. The overall climate and Energy targets to reduce carbon emissions by 55% in 2030 and achieving net-zero in 2050 mentions geothermal energy as one of many solutions.

The **European Energy Union** set up by the EC in 2015 and updated in 2019 adding obligatory national energy and climate plans (NECPs) to the policy ensures a joint European approach to energy policy. Thus, there is common ground around energy security, integration of the internal energy market, energy efficiency, decarbonisation and research, innovation and competitiveness in the nationally organised energy mixes. Published on a yearly base, the state of the energy union report 2024 identified considerable progress when it comes to renewable energy expansion, resilience and lowering energy consumption.[6]

With the **European Green Deal** (EGD), approved in 2020, a set of policy initiatives by the EC have been published to achieve a climate-neutral Europe in 2050. This initiative has been translated into the Fit for 55 package, launched in 2021. It sets the goal of 55% emissions reduction by 2030 and updated legislations such as the Renewable Energy Directive (REDIII), the Energy Efficiency Directive (EED) and the Energy Performance of Buildings Directive (EPBD) among others.

The former aims to ensure a 42,5% renewable energy share of the gross energy consumption in 2030 at the least, aspiring 45%. Furthermore, national targets above 5% must be set for research and development of innovative renewable energy technologies. For heating and cooling, the Renewable Energy Directive (**REDIII)** demands an increase of 0.8% per year until 2026 and 1.1% from 2026 to 2030 (Article 23). Further, national assessments of the potential of different renewable energies shall identify targeted renewable solutions that will also increase the use of renewables for heating and

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[6] Ninth report on the state of the energy union - European Commission

cooling. Hence, at least 2 measures to promote the use of renewable energy in heating and cooling sector shall be set up by Member States.

Concerning permitting, the REDIII introduced "renewable go-to areas" identifying the domestic potential and the available land surface, subsurface, sea or inland water as necessary for the installation of plants for the production of energy from renewable sources, and their related infrastructure necessary for national contributions towards the 2030 renewable energy target. Different rules are identified for applications outside those areas. Furthermore, the directive specifies a considerable reduction in permitting for heat pumps below 50 MW, namely below 3 months for geothermal heat pumps.

The revised **EED** obliges municipalities above 45.000 inhabitants – via the implementation of this directive by the Member States - to establish local heating and cooling plans. However, the implementation of these plans remains free of obligation. It also obliges Member States to develop recommendations and strong technical and financial support for local authorities.

The revised **EPBD's** objective is to increase the rate of renovation in the EU which can have considerable impact given that 40% of energy consumed comes from buildings. The standard for 2030 shall be to have 'Zero-Emission Buildings'. Member States have to provide targets for their national renovation wave and Renovation Passports shall be set up with tailored roadmaps for renovation for specific buildings. Furthermore, the directive demands Member States to remove financial incentives to stand-along boilers and to provide phase-out plans.

The EGD also includes the **Net-Zero Industry Act** (**NZIA**) that addresses strategic approaches to renewable energy sources, including geothermal energy. With the objective is to meet at least 40% of the EU's annual deployment needs by 2030, to create a Union market for CO2 storage and the aim for an annual CO2 storage capacity to at least 50 million tonnes NZIA is highly ambitious. For geothermal, NZIA stresses simplifying regulation, channelling investment into strategic technologies, skills and fostering innovation.

In addition, the **Electricity Market Design** has been reformed to provide further flexibility and increase the share of renewable energy in the grid. This also results in green growth and job creation. The new design aims to strengthen the resilience of the EU energy market via long-term contracts, like power purchase agreements (EMD regulation, Article 19a) between an energy producer and a buyer, who agrees to purchase electricity at a fixed price. Structuring investment support with two-way contracts for difference is included as well.

The **Critical Raw Materials Act** addresses the need for secure and sustainable supply of critical raw materials. As geothermal lithium extraction expands, this act holds particular relevance, mentioning the need for reliable lithium specifically. Accordingly, permitting procedures for the extraction of CRMs shall be simplified.

Following the Russian war of aggression to Ukraine, the EC presented its **REPowerEU Plan** in May 2022 aiming at saving energy, cleaning the energy sector and diversifying EU energy supplies to reduce dependencies on Russia. As part of this plan, the European Solar Strategy has been published, including the first and to-date only geothermal target of increasing the energy demand covered by geothermal by at least three.

Next to the highly energy-focussed policies, environmental impact should be by all means avoided when using geothermal energy. Hence, key environmental policies are the **Water Framework**

Directive, the **Environmental Impact Assessment and the F-Gas regulation**. Additionally, environmental assessments evaluate implications of projects on their environment and are also set via EU policies (for individual projects based on Directive 2011/92/EU (EIA Directive, as revised by Directive 2014/52/EU) or for public plans or programmes based on Directive 2001/42/EC (SEA Directive)). The assessments cover water quality, air quality, waste, noise and vibration, landscape, soil quality, radioactivity, pressure equipment and liability.

Research, development and innovation policies related to geothermal energy projects. The **Emission Trading System and Effort Sharing Decision** both contribute financially to the Modernisation Fund that increase financial flexibility of selected Member States for the energy transition and consequently can finance geothermal energy projects. The Innovation Fund is another of these kinds of beneficiaries of the ETS that can flow into geothermal.

With the new European Commission in place, new policy initiatives as well as upcoming legislations have been launched:
The **Clean Industrial Deal** adds an industrial and *Made in Europe* element to the European Green Deal. The latter together with the Affordable Energy Action Plan have been presented on February 26th by the European Commission. The **Affordable Energy Action Plan** is expected to drive many reforms and non-legislative initiatives for geothermal and other energy sources. The plan puts forward measures to lower energy costs and provides ways to save energy efficiently in the short term. These measures shall not only reduce burden on citizens but also for industries. It refers to investments into next-generation clean energy technologies, including geothermal.

The **Sustainable Agriculture Vision** will outline concrete steps to support farmers and rural communities to invest in sustainable practices, including reliable geothermal energy.
The **Affordable Housing Plan** is vital for geothermal. Many social and affordable housing providers have turned to collective geothermal systems such as networked geothermal or district heating systems with some notable examples across Europe.
The **Electrification Action Plan**, the **Heating and Cooling Strategy** update, and, ideally, the **Geothermal Action Plan,** which sits in between these two activities, will identify investment bottlenecks and remedial solutions.

5.2 Financing and de-risking

Scaling up geothermal development in Europe hinges on access to robust, predictable, and diversified financing mechanisms—paired with effective de-risking instruments. Despite geothermal energy's long-term benefits, including low operating costs, stable pricing, and high-capacity factors, the initial capital intensity and subsurface risk profile present substantial barriers to investors. Therefore, targeted financial strategies and risk mitigation frameworks are essential to unlock geothermal full potential.

Geothermal projects, particularly deep geothermal, are capital-intensive with long lead times and high upfront exploration risks. The drilling phase alone can consume 40–60% of the total investment, with limited visibility into subsurface viability before major capital is committed. These risks, combined with complex permitting processes and fragmented support schemes across Member States, continue to limit large-scale private sector investment.

In addition, smaller project developers often face high financing costs or lack access to suitable financial instruments. This limits innovation and local ownership in geothermal initiatives, particularly in rural or transitioning regions where geothermal could offer sustainable economic revitalisation.

The Central Role of Geothermal De-risking

Geothermal development is significantly hindered by geological resource risk, both in the short term (the risk of not discovering an economically viable resource after drilling) and in the long term (resource depletion reducing profitability). These uncertainties pose a challenge to project bankability and typically drive up the cost of capital, especially as 25–50% of total project investment must be committed before resource viability is confirmed. This makes geothermal energy more difficult to finance than other renewable technologies. Effective de-risking mechanisms are therefore critical for unlocking investment, enabling project development, and delivering affordable geothermal energy to consumers.

Risk mitigation schemes—including insurance, guarantees, and public-private funding models—reduce uncertainty and make geothermal projects more attractive to lenders. The French SAF Environment Fund is a notable example, combining short- and long-term risk coverage and operating on the principle that "successes pay for failures." In the Netherlands, a government-backed guarantee scheme offers partial protection for failed drilling, while Türkiye's Risk Sharing Mechanism covers exploration drilling costs through a performance-based insurance scheme. These models demonstrate how public support can unlock large-scale private investment.

The type of de-risking instrument depends on market maturity. In nascent markets, grants or convertible loans are vital to stimulate early investment and exploration. In more developed markets, insurance schemes—sometimes co-financed through public-private partnerships—can provide high leverage and long-term stability. Regardless of market maturity, public sector involvement remains essential in greenfield areas where geothermal potential is largely unexplored and exploration costs are higher. In such cases, large-scale exploration campaigns may be needed, supported by PPPs to spread cost and risk.

Ultimately, de-risking does not replace but complements operational support mechanisms such as feed-in tariffs or premiums. It ensures that high upfront costs do not deter investment, especially for municipalities and SMEs, and that geothermal development can expand beyond known reservoirs into new regions and applications. A harmonised **EU-level financial risk mitigation insurance scheme**, as called for by the European Parliament, would be essential to encourage exploration and reduce the financial exposure of project developers.

Support Schemes During Operation

To ensure the viability of geothermal electricity and heating projects after development, operational support schemes such as **feed-in tariffs (FiTs)**, **feed-in premiums (FiPs)**, and **contracts for difference (CfDs)** play a vital role. These mechanisms reduce the market risks tied to fluctuating electricity prices, which is particularly important for geothermal technologies with high upfront costs, low variable costs, and baseload production profiles. By securing stable revenue, these schemes lower the cost of capital, enabling broader project deployment.

FiTs are especially effective for emerging technologies by guaranteeing fixed payments per MWh produced, thus incentivising output without exposing producers to price volatility. FiPs, which top up market revenues, may be appropriate in more mature markets. However, geothermal development cycles are long (5–10 years), so abrupt or unpredictable changes to these support frameworks can seriously undermine investor confidence and halt project pipelines. Therefore, stable, predictable policy evolution is critical.

While FiTs have historically been used more for electricity, their application in the **heating and cooling (HC)** sector—particularly in countries like the Netherlands—has accelerated deployment of geothermal HC projects. When targeted at SMEs (e.g. greenhouse operators), they can encourage investment by aligning savings on energy costs with short payback periods. For households, however, high upfront costs remain a barrier, making additional support such as tax rebates, investment grants, or leasing/ESCO models necessary to unlock demand.

Overall, operation-phase incentives must be carefully designed to reflect the specific characteristics of geothermal energy while ensuring continuity and dialogue between governments and industry. Such coordination is key to maintaining investor confidence and driving geothermal market growth.

The Taxation and Financing Framework

Taxation and financing rules significantly influence the cost competitiveness of geothermal energy across EU Member States. The Energy Taxation Directive currently favours fossil fuels by applying lower minimum rates and exemptions to gas, while geothermal electricity and heating often face higher taxes, making them less competitive despite their low emissions. To correct this, taxation reform is essential—particularly reduced VAT and electricity taxes for geothermal heat pumps and district heating, as demonstrated by Finland's approved model, which offers lower rates for large-scale heat generation systems.

The EU's recent decision to introduce carbon pricing on fuels used in buildings and transport is a positive step toward internalising environmental costs and levelling the playing field for renewables. However, the **absence of carbon pricing for heating fuels has so far hampered geothermal HC uptake**, and more needs to be done to integrate such pricing into national frameworks.

Price regulation mechanisms also play a role in supporting geothermal, notably in Denmark, where political agreements allow for geothermal pricing caps negotiated between heat suppliers and producers. These contracts shield consumers from deep-drilling risk while maintaining transparency and affordability.

Moreover, a favourable **legal framework for Public-Private Partnerships (PPPs)** can facilitate geothermal development, particularly in the heating sector. EU directives on procurement and concession contracts guide such frameworks, with France's SAS-LTE model offering a strong example. In Vélizy-Villacoublay, a PPP between the municipality and Engie resulted in a jointly-owned company (Véligéo) operating a geothermal plant under a 28-year contract. This model fosters investment while ensuring long-term municipal benefit.

In summary, aligning energy taxation, pricing regulation, and legal PPP structures with clean energy goals is essential for accelerating geothermal deployment. These measures help reduce consumer prices, attract private capital, and create a fair market environment for geothermal energy.

5.3 Infrastructures

Part of the EU's path to a decarbonised and climate-neutral economy by 2050 includes infrastructure adaptation. With electrification being a major lever, the energy grid infrastructure needs to be improved. Following a lack of investment over the past decade, the EU focuses on hydrogen infrastructure, missing out on support for geothermal or other renewable heating and cooling grid infrastructure. In 2023, the European Commission adopted a European Grid Action Plan that promised to invest €584 billion in electricity grids across the EU. The funding announced by the European Commission includes amongst other €294 billion for electricity distribution and shall respond to the expected increase of 60% in electricity consumption. Cross-border investment will also play a key role. Moreover, it is vital to take a forward-looking approach, considering new technologies and innovations when building and renovating existing infrastructure. The latest and upcoming developments, especially in the field of geothermal energy have decreased costs significantly while increasing performance and efficiency. This can enable the adoption of innovative geothermal solutions to European infrastructure.

To connect geothermal powerplants to the local grid, the costs of the individual components of a 1 MWe-transfer station include an envelope of the station, medium-voltage switchgear, transformer (1000 kVa), low voltage distribution and costs of incidentals. For instance, with an additional 50 geothermal powerplants for base load generation by 2030, the cost impact on the transmission grid will be minimal. They will ensure grid stability with a load factor higher than 80%, not requiring storage costs. The total costs forecasts for additional electricity distribution to connect geothermal power plants is about €120 million. Ongoing R&I developments can decrease this price even further.

Geothermal district heating and cooling (DHC) systems, individual geothermal heat pumps (GHPs) and collective GHPs systems (Networked Geothermal HP systems) provide a multitude of positive benefits to the cost of electricity grids, energy security and on the pace of the energy transition. Innovation trends indicate even further benefits, with materials improving longevity, technologies becoming more efficient and drilling costs decreasing.

There is a potential of 360 additional geothermal DHC projects by 2040, which would require investment of over €3,6 billion. For geothermal heat pump installation, the grid cost for the consumer is minimum with only the adaptation of the voltage in the building for the electricity system to cope with the heat pump. Geothermal heat pumps are the most efficient heat pumps systems, supplying heat, cold and hot water with efficiency higher than 4 for heat and higher than 50 for free cooling of buildings. This higher efficiency requires less electricity consumption and additional grid to install.

Lastly, thermal underground storage (UTES) allows to store excess thermal energy from various power and heat sources in the underground during times of low energy demand and retrieving it, after weeks or months, when there is a need for heating or cooling. Compared to other storage techniques, UTES is economically competitive and it is especially interesting when synergy is possible of heat and electricity sources with low marginal cost are available. In particular in the field of geothermal energy storage, considerable research projects are ongoing, developing further storage options and making access easier. For instance, former coal mines are being investigated to be repurposed to UTES.

The transmission grid is needed for all electricity sources, including geothermal powerplants, to supply electricity to all consumers all over Europe. The distribution grid is different to integrate base load or variable generation, and for the energy system integration of DH and HP. It is composed of the medium voltage (MV) – mainly connected to industry - and low voltage (LV) levels – connected to the residential sector and some tertiary buildings. Geothermal technologies are able to reduce costs for the distribution grid.

Notably, geothermal technologies bring electricity baseload and flexible generation given 24/7 availability and the possibility of ramping up and down from 30 to 100% in 15 seconds. Thus, the more geothermal plants are installed, the lower investment in grids are required. Furthermore, geothermal plants can also have a combined heat and power production and so contribute to grid stability and additional grid infrastructures. Additionally, geothermal DH systems require heat and cold grids but can compensate for electricity grid congestion and costs with power to heat.

Geothermal operators can offer ancillary services to system operators and provide valuable short and long-term flexibility at a regional level, a step between centralised and decentralised systems. A stable electricity system needs to be based on a variety of sources and technologies, producing power close to demand centres. This approach can alleviate the need for additional transmission and distribution infrastructure as well as costly storage. The development of geothermal will result in reduced system costs, particularly when comparing geothermal to other electricity technologies. There is an urgent need to develop mechanisms which reward the flexibility geothermal can provide.

5.4 Supply chain

Geothermal energy systems, whether for heating, cooling, power generation, underground thermal storage, or raw material extraction, follow a multi-stage development pathway:

- Site Investigation
- Exploration and Resource Assessment
- Drilling and Subsurface Engineering
- Resource Utilisation and Management
- Operation and Maintenance (O&M)
- Decommissioning

Each stage relies on a specific set of tools, materials, technologies, and expertise, many of which are produced within Europe. However, certain components are still vulnerable to global supply chain fluctuations and competitive pressures from non-European manufacturers. One of geothermal energy's major advantages is its minimal reliance on critical raw materials, reducing Europe's strategic vulnerability [7].

The Net Zero Industry Act (NZIA) identifies geothermal as one of the EU's strategic clean technologies. This recognition underscores the importance of scaling up domestic manufacturing to meet 40% of deployment needs by 2030. The act provides a clear framework to channel investment into European supply chains, improve permitting procedures, and encourage cross-border industrial partnerships.

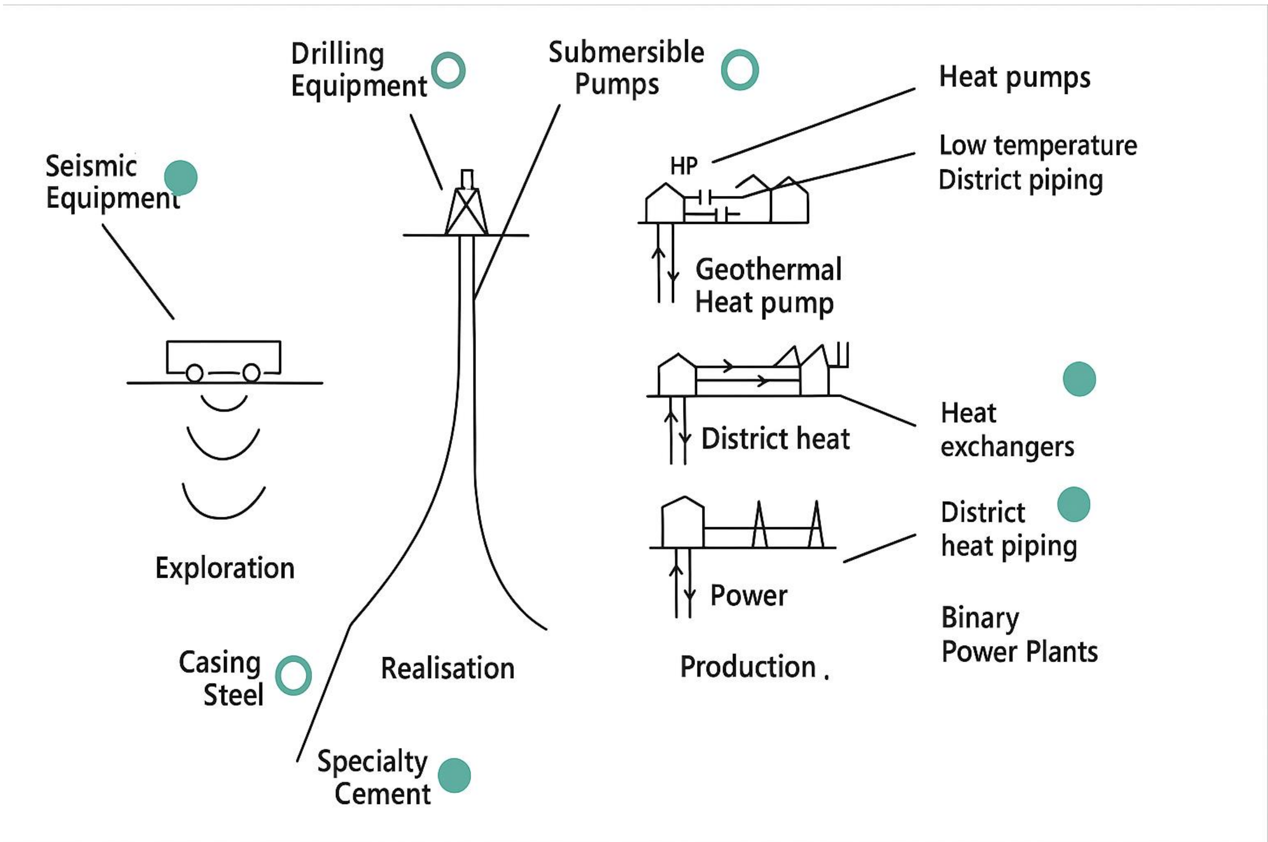

Figure 1: Geothermal schematic value chain

[7] EGEC, Market Report 2023

5.5 Workforce development and capacity building

One of the major barriers to scale of geothermal energy is the lack of workforce and capacity building. Exploration campaigns via seismic surveys and other technologies are key to ensure accurate planning for geothermal installations. However, compared to the potential geothermal energy could have, little exploration campaigns have been and are being conducted. Yet, one can observe an increase in seismic surveys over the last years, with over 17 campaigns done in 2024[8] and even more are expected to be done over 2025.

When it comes to drilling, workforce development by transitioning from the oil and gas sector is of particular interest. Technological and geological skills overlap considerably and the European green transition will require that sector to somehow transition in any way. Additionally, universities and other higher education should offer opportunities to specialize in geothermal drilling.

When it comes to manufacturing, capacity building is key. With most of the manufacturing already located in Europe, the possibility of scaling up the latter is crucial. Hence, demand should be possible to tackle via European manufacturing only, allowing local supply of components and materials for geothermal technologies with European steel, cement, and chemicals.

Geothermal industrial valleys represent a transformative concept ready to reshape Europe's economic landscapes. These systems aim to support the transition of regions from conventional energy sources to sustainable, self-reliant hubs for geothermal renewable energy to supply local energy generation, distribution, and consumption.

5.6 International cooperation

Europe is not only a global leader in geothermal heating and electricity but also a major exporter of expertise, equipment, and services. Capacity building is central to successful international geothermal cooperation, particularly in countries with high resource potential but limited technical or institutional readiness. Europe is not only a global leader in geothermal heating and electricity but also a major exporter of expertise, equipment, and services.

- Creating local, long-term jobs in drilling, construction, and O&M
- Offering sustainable energy access to underserved populations
- Repurposing skills and technologies from the oil and gas sector
- Supporting climate resilience through reliable, low-carbon heat and power

International cooperation ensures that geothermal contributes not only to climate mitigation, but also to inclusive economic development in partner countries. For Europe, this aligns with both external energy policy goals and internal industrial policy objectives, particularly in promoting supply chain resilience and global leadership in net-zero technologies.

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[8] EGEC Market Report.

6 Towards a Geothermal Alliance

Next to legislative texts, the European Commission publishes strategies, action plans and other guiding material for member states, industries and other stakeholders. In the field of renewable energy, wind, solar and hydrogen strategies have already been published as outlined in chapter 4.3. The latter for instance set up a European Clean Hydrogen Alliance[9] as well, bringing together stakeholders from industry, public authorities, civil society, financial institutions and more to address the renewable and low-carbon hydrogen production, demand in industry, mobility and other sectors and hydrogen transmission and distribution.

Based on the latest update in February 2024, the hydrogen alliance features 424 projects in its project pipeline. Moreover, the alliance publishes reports, presentations and organizes fora – to name a few activities – that advance the sector.

The European Solar Photovoltaic Industry Alliance[10] was launched to develop an EU solar PV industrial ecosystem. Scaling up EU manufacturing, diversifying value chain components and raw materials as well as overcoming bottlenecks and facilitating access to finance are elements covered by the alliance. A European Geothermal Action Plan has been announced by the European Commission. To be published in Q1 2026, the Commission plans on publishing the plan together with the renewable heating and cooling strategy update and the electrification action plan. The Geothermal Action Plan is of particular importance to set clear ambitions for the sector, send an encouraging signal to the industry and ensure investments. As part of the Action Plan, a Geothermal Alliance shall be established, as recommended by the Transport, Telecommunications and Energy Council Conclusions in December 2024 and the European Parliament.

The alliance will bring together stakeholders of the sector such as the industry, policy makers, civil society, research institutions and more. The European Geothermal Energy Council (EGEC) is envisioned to manage the Alliance and a board should be established, including an elected chair, Member States representatives, the European Commissions and chairs of each workstream. The later comprise national and industry experts, non-industry experts and a chair. Thus, national roadmaps, permitting and data collection, financing, value chain, sectoral agreements on cities and social housing and industry and agriculture as well as on electricity and grids shall be established.
Strategic goals of the alliance must be clearly identified with key actions and a timeline to ensure effective work. Next to capacity targets, R&I targets and dedicated funding schemes should be addressed by the alliance to boost the geothermal energy sector.

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[9] European Clean Hydrogen Alliance - European Commission
[10] European Solar Photovoltaic Industry Alliance - European Commission

7 Conclusions

This report focuses on the development of a European Geothermal Industrial Strategy as a way to support the tripling of geothermal energy in Europe.

To set out a vision for the future of geothermal technology, the report provides an overview of the geothermal market.

The first part indeed addresses the current technological and market status, considering as well the EU policy framework and the climate target set for 2030, 2040, and 2050.

The analysis also considers the strategies developed for other renewable energy sources in Europe. To achieve the geothermal energy expansion, the strategy set some strategic objectives and areas of intervention: development of a skilled workforce; increase of R&I initiatives; institution of positive financial and de-risking schemes; and the establishment of a geothermal alliance.