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Report progress on competitiveness of geothermal energy technologies

G Cittadini, P Dumas, L Kuhlmann

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1 Executive Summary

The competitiveness of geothermal energy technologies is shaped by a complex interplay of economic, technological, environmental, and policy factors. While historically evaluated primarily through the lens of the Levelized Cost of Electricity (LCoE), the sector is increasingly assessed using broader criteria that capture lifetime performance, load factors, socio-economic benefits, and supply chain resilience. This more holistic approach is essential to fairly position geothermal alongside other energy technologies in policy and market frameworks.

Geothermal offers unique strengths: exceptionally high load factors (often exceeding 80–90%), operational lifetimes surpassing 50 years, stable generation costs, and the capacity to provide baseload and flexible electricity as well as heating, cooling, and energy storage. These attributes make it a strategic renewable resource for the EU's decarbonisation, energy security, and industrial competitiveness goals. In 2024–2025, multiple independent studies confirmed geothermal's competitiveness while also highlighting the need for continued research and innovation to lower costs, improve efficiency, simplify installations, and expand "Made in Europe" manufacturing.

The report assesses the representative geothermal technologies developed in Europe over the past five years. Findings show that while initial capital costs for geothermal electricity remain higher than for utility-scale PV or onshore wind, they are comparable to offshore wind and significantly offset by long operational lifetimes, low running costs, and stable output. In heating applications, geothermal is already highly competitive, outperforming many renewable and fossil-based alternatives, especially in volatile energy markets.

Beyond price, non-cost advantages strengthen geothermal's case: minimal land use, near-zero emissions, low environmental impact, strong job creation potential, and synergies with existing oil and gas expertise. European manufacturing capacity covers much of the supply chain supporting resilience under the Net Zero Industry Act, which targets 40% EU manufacturing share for strategic net-zero technologies by 2030.

2 Introduction

Seeing the market development from 2019 (starting date) to 2024, the added value of monitoring cost developments for the different plants sizes has been limited. There is a need to consider a small-scale system with a geothermal heat pump to reflect the current scope of IWG and ETIP.
From the first set of key performance indicators with reference plants and assets defined in 2019, a new set of KPIs has been set in 2025. It reduces the number of reference plants to the main ones developed in Europe for 5 years. Therefore, this report is focusing on the following four references:

- 20 MWe high temperature plant (Flash turbine)
- 10 MWe medium temperature plant (Binary turbine)
- 20 MWth heating plant
- 50 kWth heating and cooling system assisted with heat pumps

The Report progress on competitiveness of geothermal energy technologies will review costs of these four plants. It reports costs review from recent publications and from a 2025 survey led by the European Geothermal Energy Council (EGEC).

3 Criteria for assessing the competitiveness of geothermal technologies

3.1. Economic metrics

3.1.1 Levelized cost of electricity (LCoE), LCoH, System costs and externalities

The levelized cost of electricity (LCoE) represents the ratio between the cost of generating an asset during its lifetime and the electricity produced. LCoE is a measure used to compare different technologies. The same breakdown of total investment costs applies to geothermal heating technologies. However, for these technologies, LCoH will usually be 30-50% lower than LCoE due to the absence of expensive electricity generation equipment [1].

Between 2015 and 2023, geothermal LCoE maintained a relatively stable trend. The costs of a 20 MWe high temperature plant (Flash turbine) and of a 10 MWe medium temperature plant (Binary turbine), depend upon the geological settings which influence the drilling costs. Considering that geothermal powerplants developed recently tapped known resources, their costs was rather stable.

While geothermal's costs are now higher than utility-scale PV and onshore wind in terms of LCoE, they are competitive with offshore wind. Geothermal LCoE stable range indicates geothermal's role in providing steady and predictable energy costs compared to more fluctuating trends of other technologies. But the development of plants in green fields areas will first render these plants more costly before being competitive with a learning curve.

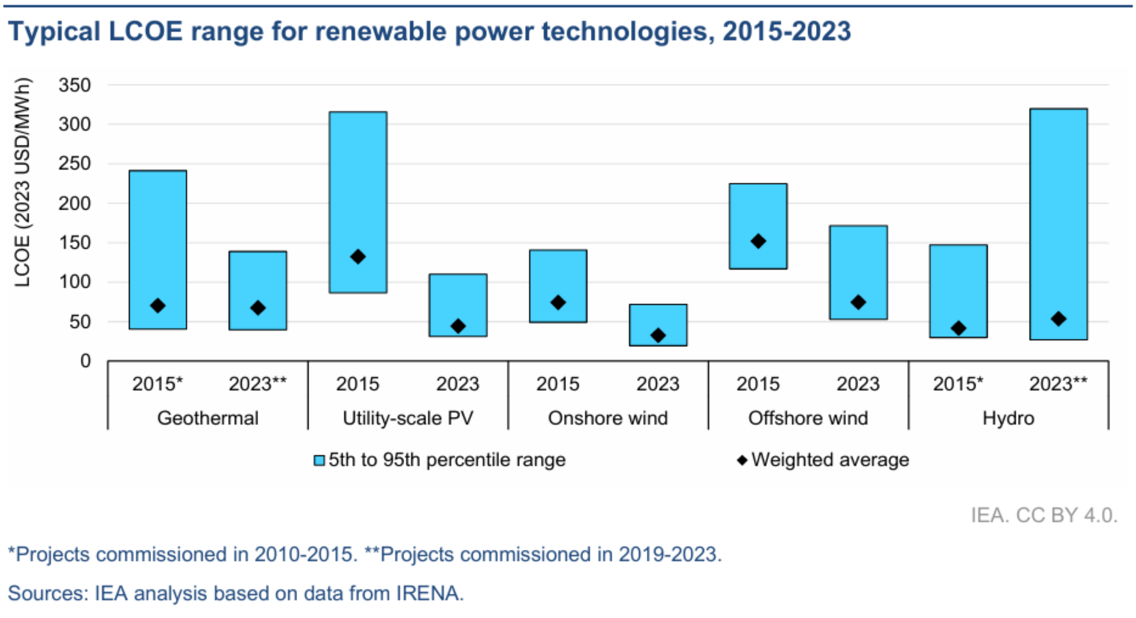

Figure 1: Typical LCOE range for renewable power technologies. Source: IEA 2025

In France, the evolution of support mechanisms and technological improvements have bolstered the sector's viability, particularly in heat production and district heating applications. While electricity generation from geothermal faces challenges related to resource availability and exploration risks, its long-term operational stability and low emissions make it an attractive option for decarbonization strategies.

[1] *The Future of Geothermal Energy*, n.d.

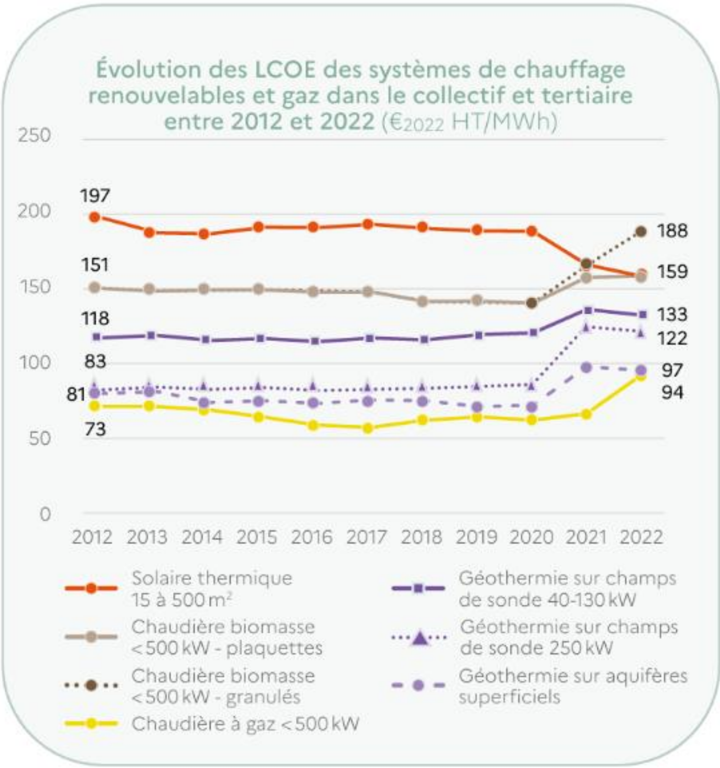

Figure 2: LCoE evolution of renewable heating systems between 2012 and 2022. Source: ADEME

A recently published report from ADEME highlights that geothermal heating systems maintain a competitive position compared to other technologies. Over the years, geothermal costs have remained relatively stable, with values ranging between approximately 81 €/MWh and 133 €/MWh in 2022, depending on the system type. In contrast, solar thermal systems and biomass boilers exhibit higher costs, with solar thermal reaching 188 €/MWh in 2022. Gas heating, while initially the cheapest option at 73 €/MWh in 2012, has seen an increase, reaching 94 €/MWh in 2022. The data suggests that geothermal remains a reliable and cost-effective renewable heating solution, particularly as fossil fuel prices fluctuate. Its relative stability in cost over the decade underscores its economic viability, especially in the context of increasing energy prices and the transition toward low-carbon heating solutions.

3.1.2 Capital expenditure (CAPEX) and operational expenditure (OPEX)

Initial investments for geothermal projects are quite high in total investment costs, accounting for around 80% of the whole project especially for geothermal power and heat plants. Usually, the construction of the plant accounts for 40-60% of the investment costs. These investments are, however, significantly influenced by geological conditions and reservoir quality, impacting indeed the number of wells required and the need to use a heat pump to reach a certain capacity. The quality of the geothermal resource also influences the type of plant that will meet the local conditions. Within the total installed costs are included the exploration and resource assessment phases [2]. As depicted in figure 2, well-drilling represents the second largest part of the investment costs of a geothermal electrical project, accounting for 30-45% of the total. The resource assessment, comprising the test-well drilling, and the permitting procedure take 10-15% of the total investment costs. Finally, engineering and management account for the remaining 5-10% [3]. For a heat plants, the first two phases have even a larger share as the plant construction is less expensive.

[2] *Renewable Power Generation Costs in 2023*, n.d.

[3] *The Future of Geothermal Energy*.

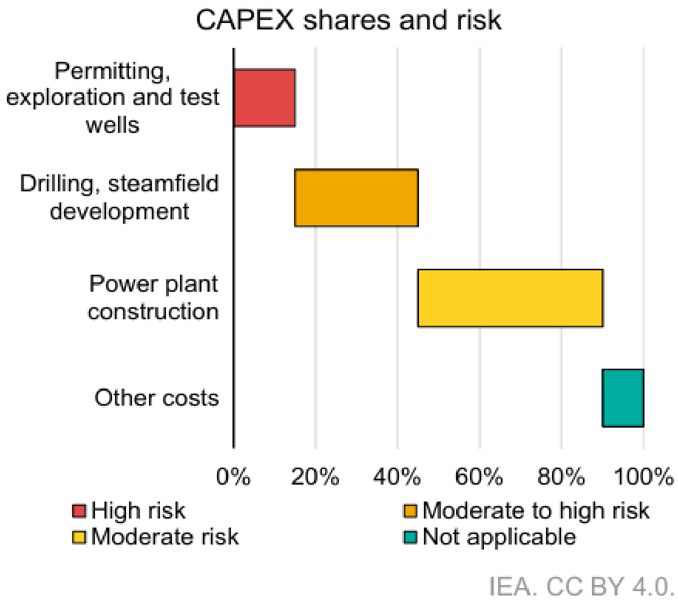

Figure 3: CAPEX shares and risk. Source: IEA 2025

3.1.3 Return on investment (ROI)

Return on Investment (ROI) is a key financial indicator in assessing the competitiveness and attractiveness of geothermal energy projects, especially for private investors. However, geothermal power development presents unique financial challenges that significantly influence ROI calculations. In most geothermal projects, debt financing covers the majority of capital requirement, typically 60% to 70%. However, lenders generally require a substantial equity contribution to ensure that the project sponsors have significant skin in the game. Equity investors, in turn, demand relatively high returns on their capital (often between 20% and 30% annually) to compensate for the perceived risks.
These risks include not only the technical and geological uncertainties but also financial risks related to debt structuring, such as interest rates, maturity and grace periods, and debt-equity ratios. Return on equity (ROE) is highly sensitive to such variables. Even minor changes in financing terms can significantly affect ROI, which underscores the importance of optimizing the financial structure of the project.
One way to meet the high ROI expectations of private investors without raising electricity tariffs or requiring long-term subsidies is for public entities to co-invest in high-risk, early-stage project components.

3.2 Technological factors

In current costs assessment based on LCoE and LCoH, the comparison with geothermal is not complete. Many parameters are fixed and doesn't fit for geothermal plants.
One example is the lifetime, geothermal plants have a duration larger than 50 years while models fix it at 20 years.
Load factor is another crucial parameter for competitiveness, but it is not considered in energy costs models based on LCoE. Geothermal achieved the best load factor of all energy sources, largely beyond 80%.
A third one is efficiency. Geothermal HP systems an efficiency higher than 4 for heating and Geothermal can provide free cooling (efficiency higher than 20). To calculate this efficiency, it is better to consider the Seasonal performance factor (SPF) and not the Coefficient of Performance (COP) which is realised in optimal conditions. As geothermal HP systems supply heating, cooling and domestic hot water, the efficiency must report the combined efficiency of these three supplies.
Efficiency of geothermal DH plants is also high, above 5.

For geothermal electrical plants there is often a confusion between the generation ration power/heat and the efficiency of the plant, geothermal being a renewable energy source. As for solar and wind, geothermal has a ration of 100%.

3.3 Being more competitive with Research & Innovation

Research & Innovation can improve on several aspects:

- Costs decrease
- More efficiency
- Increase lifetime
- System easier to install

The annual European Commission report to the IEA Technical Cooperation Programme on Geothermal provides an overview of projects with Horizon 200 and Horizon Europe funding to 2023, and following simply gives an overview. The total amount of EU funding for geothermal energy projects from 2004 to 2023 is EUR 622 million, spread across 140 projects. Horizon 2020 provided the largest R&D funding for geothermal energy, with EUR 268 million allocated to 67 projects. Projects completed in 2023 include GECO, GEO4CIVHIC, Geo-Drill, REFLECT, and GeoHex, among others. These focused on various aspects of geothermal energy, such as emission gas control, drilling technology, and heat exchange performance. 20 ongoing HE projects include GeoSmart, EXCITE, HOCLOOP, and COMPASS, among others. These focus on topics such as geothermal energy storage, drilling technology, and enhanced geothermal systems. HE projects started in 2023 include PUSH-IT, SMILE, and EarthSafe, and focus on topics such as high temperature heat storage, coupled processes in geothermal systems, and deep geothermal power. The reports also mentions: The Innovation fund project EAVORLOOP, which received €91.6 million in EU funding, making it the largest individual funding for a geothermal energy project. Several projects funded under the LIFE program, including COOLING DOWN, REDI4HEAT, and GEOBOOST. These projects focus on topics such as renewable cooling, geothermal heat pumps, and district heating and cooling. Overall, the report highlights the EU's commitment to supporting research and innovation in geothermal energy, with a focus on reducing costs, increasing efficiency, and promoting the use of geothermal energy for heating and cooling [4].

[4] Nigel Taylor et al., 'Clean Energy Technology Observatory: Geothermal Energy in the European Union - 2024 Status Report on Technology Development, Trends, Value Chains and Markets', JRC Publications Repository, 2024, https://doi.org/10.2760/8898786.

4 Competitiveness of geothermal energy: quantitative analysis

4.1 Cost comparison

Geothermal power generation projects have, on average, relatively high capital costs compared to hydropower, solar PV and onshore wind, with installed costs more in line with offshore wind and CSP. Project development, field preparation, production and reinjection wells, the power plant, and associated civil engineering entail significant upfront costs. Geothermal projects are also subject to variations in drilling costs, the trends in which are often influenced by the business cycle in the oil and gas industry. These fluctuations have a direct impact on drilling costs and thus the costs of EPC. Geothermal power plant installed costs are highly site sensitive. Typically, costs for binary plants designed to exploit lower temperature resources tend to be higher than those for direct steam and flash plants. The total installed costs of geothermal power plants also include the cost of exploration and resource assessment. The other main additional cost driver for geothermal is the drilling cost of the production and injection wells.

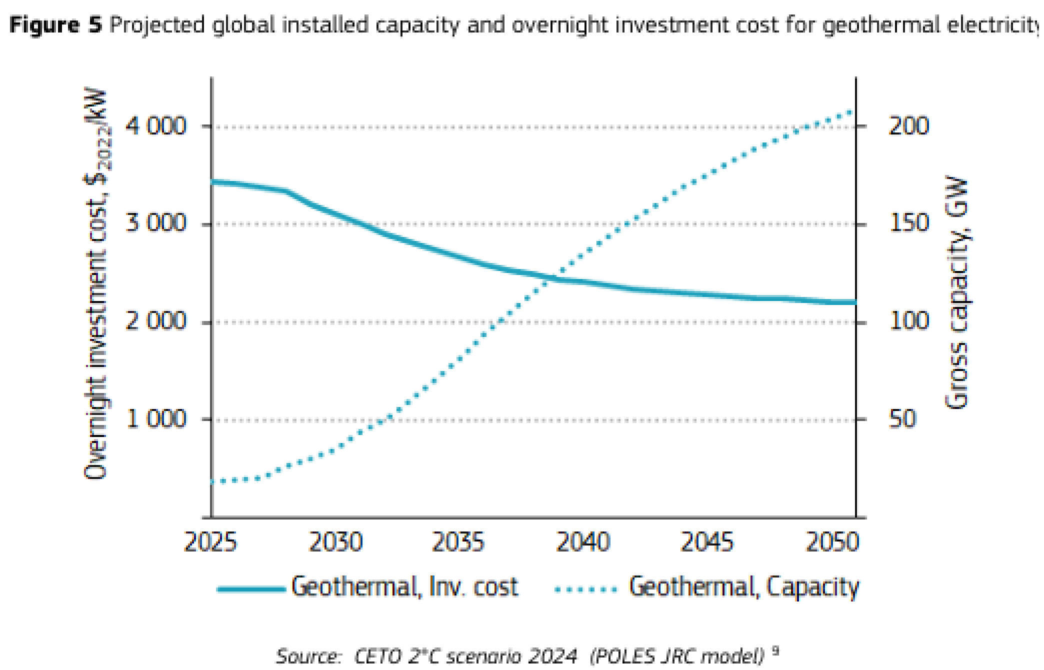

Figure 4: Projected global installed capacity and overnight investment cost for geothermal electricity. Source: JRC

As shown in the table below, a 20 MWe high-temperature flash turbine plant typically requires a CAPEX of €7.5–8.0 million per MW installed, with operating costs of €0.14–0.16 per MWh. A 10 MWe medium-temperature binary turbine plant shows a broader CAPEX range, from €5.8 million to €9.3 million per MW, and slightly higher OPEX at €0.15–0.18 per MWh, reflecting the increased complexity of extracting and converting lower-temperature resources. Meanwhile, first-generation zero-emissions geothermal plants in the 5–20 MWe range display the highest capital intensity, with costs of €10–12 million per MW, and an OPEX of around €0.20 per MWh, likely due to additional technology components aimed at eliminating emissions.

	Capex/MWe (M€/MW)	Opex/MWh (M€/MWh)
20 MWe high temperature plant (Flash turbine)	7,5 - 8,0	0,14 – 0,16
10 MWe medium temperature plant (Binary turbine)	5.8 - 9,3	0.15 - 0.18
5 – 20 MWe Zero emissions geothermal plant - 1st generation	10,0 – 12,0	0,2

Figure 5: table costs for geothermal powerplants in Europe

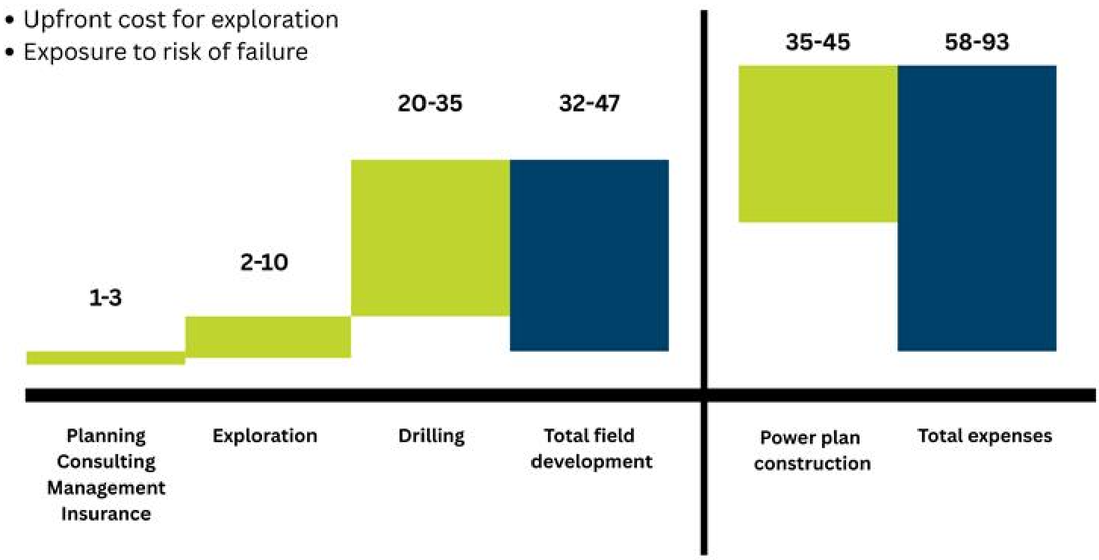

Figure 6: Cost range for the development of a plant with a binary turbine.

A 20 MWth geothermal heating plant has an estimated CAPEX of €1–2 million per MW installed, with relatively low OPEX of €0.02–0.04 per MWh, reflecting the cost-efficiency of large-scale direct-use geothermal heating. In comparison, a 50 kWth heating and cooling system assisted with heat pumps shows a CAPEX of €1.10–1.53 million per MW, with OPEX structured into fixed and variable components. The fixed O&M costs are around €0.0027 per MWh, while variable O&M costs, excluding electricity, are extremely low at €0.0000017 per MWh.

	Capex/MWth (M€/MW)	Opex/MWh (M€/MWh)
20 MWth heating plant	1 - 2	0.02 – 0.04
50 kWth heating and cooling system assisted with heat pumps	1.10 – 1.53	Fixed O&M = 0.0027
		Variable O&M excl. electricity costs: 0.0000017

Figure 7: table costs for geothermal heat plants in Europe

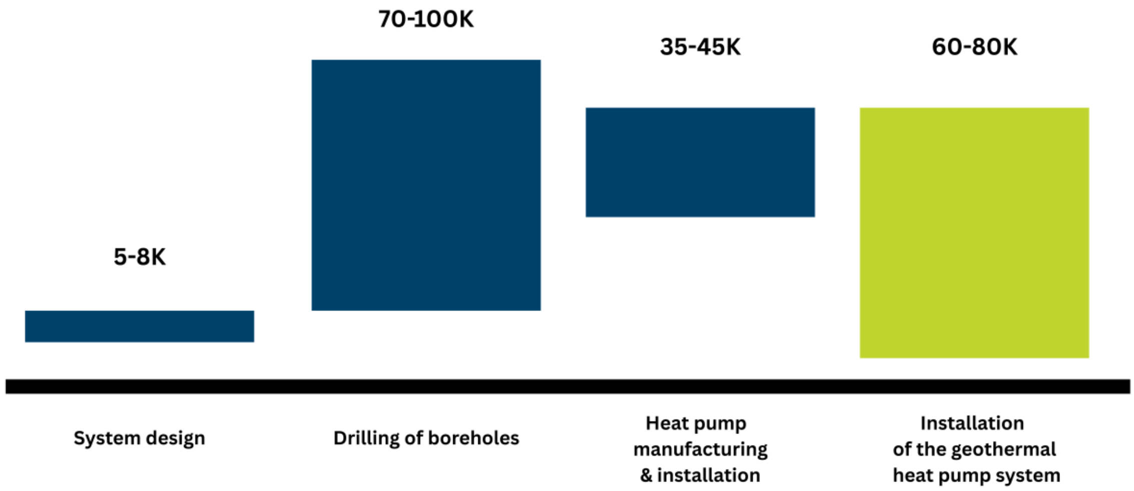

Figure 8: cost range for the development of a 50kWth geothermal heat pump installation

A large building of about 10 dwellings, would require a capacity of 50 kWth for heating and cooling. The system consists in a closed loop geothermal system, with 10-15 BHE at 100 m depth, assisted with an heat pump.

4.2 Manufacturing and supply chain

The European deep geothermal market is subdivided in as many national markets as there are countries. Historical markets in particular are especially linked to a national industry for project development and manufacturing of components such as in Italy. In recent decades however, the European geothermal industry gradually progressed towards a more unified market with competition at the European level.

The European market for geothermal electricity is dominated by historical industrial structures, as well as the legacy of the energy sector organisation. Current market trends also underline a diversification of the operators in the European market, with many companies looking to enter geothermal power production at scale. The construction of a geothermal power plants is done by three categories of actors: the project developers such as electrical utilities, turbine manufacturers with an EPC department, or EPC contractor.

European geothermal projects for heating and cooling, notably for district heating or agri-food uses, are for a large part undertaken by public authorities or in partnership with public authorities with municipality as crucial actors. Local energy companies are also important actors, operating nearly 30% of all deep projects in Europe. Geothermal heating and cooling projects require the availability of a guaranteed demand for the energy they supply, which municipalities or local energy companies operating a district heating network can provide. Moreover, the capacity of public authorities to adopt a longer-term perspective than many private businesses is more favourable for such long-term projects – both in terms of lead time and payback times. However, the private sector remains an important part of geothermal heating and cooling developments, representing 42% of projects operating in Europe as of 2018. Large private companies usually operate projects aimed at district heating and cooling on behalf of a public authorities that provide the guarantees required for the project to be viable. This model is particularly widespread in France, the largest user of deep geothermal heating and cooling within the European Union, where “délégations de service public” is a dominant model for deep geothermal projects. Geothermal projects for heating and cooling in the agri-food are mostly operated by smaller private actors.

With its limited needs of so-called critical raw materials, the geothermal industry is a key energy technology in reducing the vulnerability of EU industry and energy supply. Most materials that are essential for the geothermal sector are classified by the EU as non-critical. According to the Italian report "La geotermia a emissioni nulle per accelerare la decarbonizzazione e creare sviluppo in Italia", released in 2024 by The European House Ambrosetti[5], geothermal energy is the renewable energy technology least dependant on critical raw materials. So geothermal deployment reduces European dependence on third countries.

The two key raw materials of the geothermal energy supply chain are concrete and steel. Concrete is an essential component for the casing of geothermal boreholes. Steel makes up the pipes that carry the geothermal brine to the surface, and the geothermal energy to the district heating network. In geothermal power plants, steel is a key component of turbines as well. Another important material is aluminium which is increasingly being used in plant construction. Many materials (steel) and components especially electronics are imported from Asia, China.

The specificities of the operating environmental of deep geothermal installations introduces some specific requirement for materials in terms of strength and corrosion resistance that may expose the deep geothermal sector to some degree of vulnerability. For instance, chromium, as key component of stainless steel is by some measures considered a critical raw material. For concrete, although there seem to not be major vulnerability of supply thus far, emerging tension in the availability of sand may be a source of vulnerability in the long term.

The specificities of the operating environmental of deep geothermal installations introduces some specific requirement for materials in terms of strength and corrosion resistance that may expose the deep geothermal sector to some degree of vulnerability. For instance, chromium, as key component of stainless steel is by some measures considered a critical raw material (although not in the EU 2018 list). For concrete, although there seem to not be major vulnerability of supply thus far, emerging tension in the availability of sand may be a source of vulnerability in the long term. The only key material of the geothermal value chain identified as "critical" by the EU is coking coal, which is used in the steel industry to transform iron into steel [6].

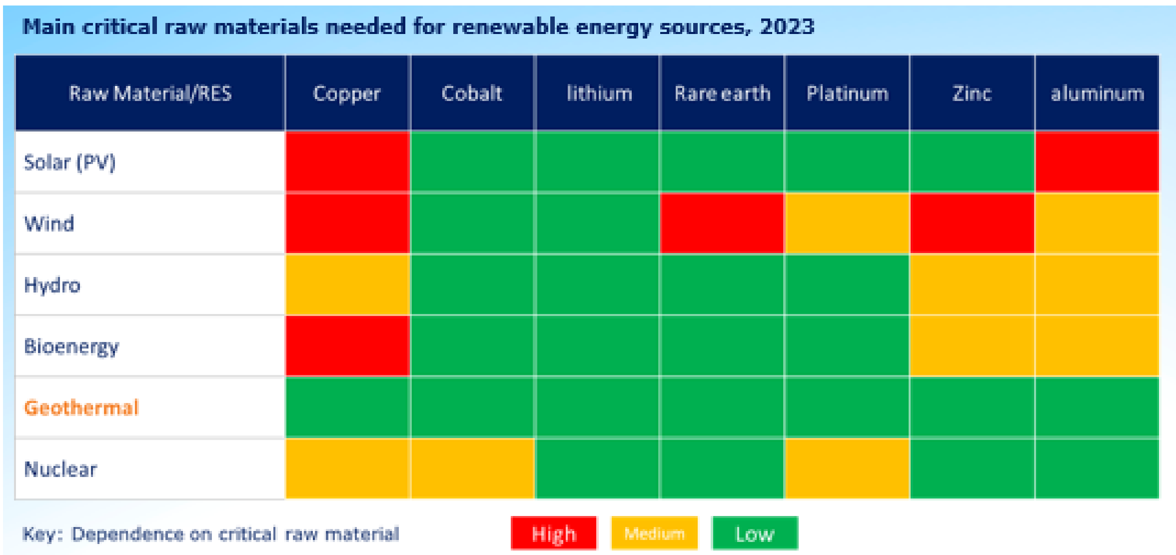

Figure 9: Main critical raw material needed for renewable energy sources (source: The European House – Ambrosetti)

[5] The European House – Ambrosetti on International Environment Agency data, 2024

[6] 'EGEC Geothermal Market Report 2022', *EGEC - European Geothermal Energy Council*, n.d., accessed 23 May 2024, https://www.egec.org/media-publications/egec-geothermal-market-report-2022/.

5 Competitiveness of geothermal energy: qualitative analysis

Next to costs and efficiency, non-price criteria considerably impact the competitiveness of geothermal energy. These include factors such as local production, meaning "made in Europe" manufacturing, reduced socio-economic and environmental impact, resulting in higher benefits for society and better engagement with the public. The following parts will elaborate more on the latter.

5.1 Environmental benefits

Geothermal energy is a renewable source of energy that relies on the inexhaustible heat – from a human perspective - below the earth. Geothermal is climate neutral as it does not emit CO2 or other greenhouse gas emissions. In the rare circumstances that CO2 is released with hot water, it can be collected and re-dissolved in the brine.[7] Furthermore, geothermal energy technologies provide environmental benefits compared to other renewable energy sources. Geothermal power production is indeed recognised among the cleanest energy generation technologies, releasing a low quantity of sulfur dioxide, nitrogen oxides and fine particulate matter. However, through complete injection, binary geothermal power systems eliminate any kind of emissions. Compared to conventional coal plants, on a per MWhe, flash geothermal power plants produce less than 4% of sulfur dioxide and none of nitrogen oxides or particulate matter [8].

Furthermore, geothermal energy necessitates 404 m² per GWhe of land footprint. This value is considerably lower than other energy technologies, such as coal with 3,642 m², wind with 1,335 m², and solar photovoltaic with 3,237 m² [9].

Geothermal energy projects barely have any impact on biodiversity and wildlife as the installations are mainly underground and do not require a lot of space on land. On top, this land can easily be used for other purposes. Environmental impact of drilling and reservoir/well stimulation is close to zero, with very limited effects on wildlife, air quality and ground water. Also, heat production is completely noiseless and electricity generation only has minor noise. Additionally, investment in geothermal energy provide long-lasting opportunities, with lifetime of geothermal heat pumps or other technologies exceeding 50 years. Thermal storage is not only of economic interest but also contributes to thermal sustainability, giving heat back to the earth.

Other non-price criteria include system costs and externalities. This includes security of supply, balancing the grid with baseload and flexible generation with dispatchability, the electricity and/or heat produced, and the use of underground thermal storage. Geothermal has the best load factor (higher than 90%) and can generate flexible electricity (ramp up and down in 15 seconds). It is a local source of renewable energy, producing also heating, cooling and minerals such as geothermal lithium. Geothermal contributes to local economic development, especially when supplying energy to the agro-food industry and tourism (hotels & spas etc.).

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[7] 'Why Geothermal Energy? | VITO', accessed 11 August 2025, https://vito.be/en/geothermal-energy/why-geothermal-energy.

[8] *GeoVision: Harnessing the Heat Beneath Our Feet*, n.d.

[9] *GeoVision: Harnessing the Heat Beneath Our Feet*.

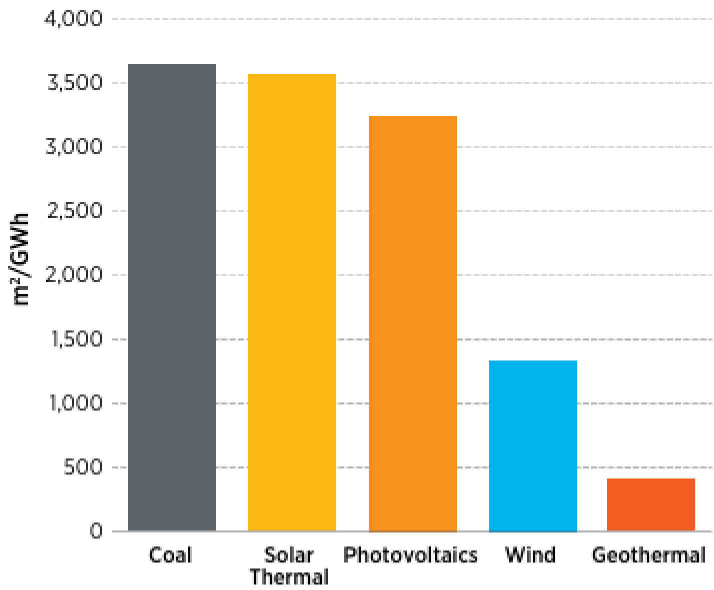

Figure 10: Land footprint by GWhe for various electricity-generation technologies. Source: Geovision

It is key to recognize the above-mentioned environmental benefits of geothermal energy. The European Net Zero Industry Act (NZIA)[10] introduced recognition of the latter via mandatory non-price criteria that consider non-measurable benefits. Thus, investment in strategic technologies shall increase with public procurement procedures and auctions (Articles 19-22). Public authorities are obliged to consider at least one of the following criteria such as sustainability, resilience, cybersecurity and other qualitative factors. Concretely, sustainability is the minimum criteria for public procurement. Auctions to deploy new renewable sources must prioritize investment in technologies that provide multiple services such as dispatchable or baseload renewable electricity, heating and cooling or sustainable critical raw material extraction and seasonal storage. Additionally, public buyers are required to diversify supply sources in case of high dependencies and households and businesses should be incentivized to purchase net-zero technologies via public intervention forms, covered by the act. Geothermal is able to provide all these services.
A connected initiative is the Industrial Decarbonisation Accelerator Act[11], planned for Q4 2025. It shall trigger increased demand for EU-made clean products, motivated by public and private procurement criteria around sustainability, resilience and 'made in Europe'. The public procurement framework will be reviewed in 2026 to adapt accordingly.

5.2 Social and community impact

The successful integration of a geothermal project within the local energy supply strongly depends on public and community acceptance. Geothermal development provides benefits to local economies, bringing financial benefits and positively impacting the labour market. Geothermal technologies require a wide variety of labour categories and skills. Additionally, due to the similarities with other sectors, geothermal development allows for the mobility of workers across industries [12].
Currently, 145,000 jobs are directly related to the geothermal industry which could rise to 1 million by the end of the decade. However, this increase requires significant increase in needed skills.[13] Mainly the oil and gas sector possess those: On the one side, knowledge, research and development expertise can be transferred to geothermal. On the other side, substantial financial resources can be shifted

[10] The Net-Zero Industry Act
[11] Industrial Decarbonisation Accelerator Act - speeding up decarbonisation
[12] *GeoVision: Harnessing the Heat Beneath Our Feet*.
[13] The Future of Geothermal Energy, IEA

towards the RES. Transferring skills, resources or material does not only have direct positive implications on society such as job creation, circularity and greener energy supply but also increases productivity. [14]

However, these skills significantly lack on technical (seismic surveys, work force) and administrative level (permitting, financial support). Only 15% of geothermal operators are part of the oil and gas sector.[15] Based on political and societal trends, it will be crucial to transition fossil fuel workplaces to alternative sectors. Geothermal is ideal. Already today, one can observe especially mid-career workers transitioning from the oil and gas sector to geothermal. This can be traced back to either ethical motivation to support clean energy or to the unsure future of fossil fuels.

Furthermore, studies highlight how geothermal suffers from lower public acceptance compared to other renewable energy sources. The reasons behind this result also depend on the limited governmental support provided to geothermal technologies in general [16]. To address this challenge, community engagement is key to avoid any delays or even cancellation of projects due to public opposition. Involving communities can start at the early planning stage and include general information campaigns, teaching about geothermal, conversation around values and worries. To ensure adequate community preparation, frequent public meetings, feedback mechanisms and joint decision making when possible can be considered.[17]

Furthermore, geothermal energy brings particular positive impacts on consumers. With stable prices and long-lasting products such as geothermal heat pumps, end-users become independent of economic or political developments. It is crucial to ensure, that all groups of society benefit from these advantages. Consequently, marginalised communities have to be included to ensure environmental justice. Hence, geothermal energy for social housing represents a significant part of the positive impact of geothermal on society. Additionally, geothermal energy does not impact habits of consumers neither it is very visible, with the majority of the technology being underground. Thus, barriers of path dependency that various other RES face, can be overcome. Moreover, it increased the value of a property, brings end-users closer to net-zero.

In short, geothermal energy brings various positive aspects to society, creating jobs, enhancing economic development and creating energy independence.

5.3 Geopolitical and energy security factors

The EU is one of the most attractive destinations for global companies and for investment. Our economies thrive on open and rules-based trade and investment, on secure cross-border connectivity and collaboration on research and innovation.

However, with geopolitical tensions rising and global economic integration deeper than ever before, certain economic flows and activities can present a risk to our security.

The recent European Economic Security Strategy sets out a framework for a robust assessment and management of risks to economic security at EU, national and business level while preserving and increasing our economic dynamism.

Achieving this will depend on

1. promoting our own competitiveness
2. protecting ourselves from economic security risks
3. partnering with the broadest possible range of countries who share our concerns or interests on economic security.

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[14] The Future of Geothermal Energy, IEA

[15] The Future of Geothermal Energy, IEA

[16] 'CROWDTHERMAL-D1.1_IZES.Pdf', n.d., accessed 12 June 2025, https://www.crowdthermalproject.eu/wp-content/uploads/2020/04/CROWDTHERMAL-D1.1_IZES.pdf.

[17] 'What Are the Social Implications of Geothermal Projects? → Question', *Energy → Sustainability Directory*, n.d., accessed 11 August 2025, https://energy.sustainability-directory.com/question/what-are-the-social-implications-of-geothermal-projects/.

The Economic Security Strategy recognises that the openness of our system is the 'bedrock for our innovative economies', but that the EU needs a comprehensive strategic approach to economic security, de-risking and promoting its technological edge in critical sectors. It identifies 'risks related to technology security and technology leakage' as one of four main categories of risks.
In January 2024 the European Commission adopted an 'Economic Security Package', which includes two initiatives related to Research and Innovation: a White Paper on Enhancing R&D Support Involving Technologies with Dual-Use Potential, and a Proposal for a Council Recommendation on Research Security.
Over the last two decades, Europe's potential has remained strong, even as other major economies have grown at a faster pace.
The EU has everything it takes to unlock its full potential and drive faster, more sustainable growth: we boast a talented and educated workforce, capital, savings, the single market, and a unique social model. To restore our competitiveness and unleash growth, we need to tackle the barriers and weaknesses that are holding us back.
In January 2025, the Commission presented the competitiveness compass, a new roadmap to restore Europe's dynamism and boost our economic growth.
The compass builds on the analysis of Mario Draghi's report on the future of European competitiveness.
The Draghi report originally identified **three necessities** for the EU to boost its competitiveness:

1. Closing the innovation gap
2. Decarbonising our economy
3. Reducing dependencies

The compass sets out an approach to translate these necessities into reality.

4. Closing the innovation gap

The compass spells out how the European Union will boost innovation by:

- **creating a friendly environment for young companies** to start and expand, with a dedicated EU start-up and scale-up strategy
- **helping big companies adopt new technologies** such as artificial intelligence (AI) and robotics, thanks to an **"Apply AI" initiative**
- making it easier for companies to operate across the EU by **simplifying rules and laws**, with a proposal for a **28th legal regime** that will guarantee one set of rules across the EU
- supporting the development of new technologies, with **action plans for advanced materials, quantum, biotech, robotics and space technologies**

5. Decarbonising our economy

The compass sets out how we can shift to clean and affordable energy by:

- putting forward the Clean Industrial Deal, to help reduce carbon emissions, especially for energy intensive companies, and facilitate their **transition to low carbon technologies**
- presenting tailor-made **action plans for energy intensive sectors**, such as chemicals, steel and metals, which are the most vulnerable at this phase of the transition
- developing an affordable energy action plan to help bring down energy prices and costs

6. Reducing dependencies

The EU already has the largest and fastest growing network of trade agreements in the world, covering 76 countries.
The compass identifies how we can further diversify and strengthen our supply chains by:

- developing a new range of **clean trade and investment partnerships** to help secure supply of raw materials, clean energy, sustainable transport fuels, and clean tech from across the world
- reviewing the **public procurement rules** to allow for the introduction of a European preference in public procurement for critical sectors and technologies

Critical raw materials are of great economic importance for Europe while being also highly vulnerable to supply disruptions. Critical raw materials are confronted with a growing global demand, driven by the decarbonisation of economies. For instance, EU demand for rare earth metals is expected to increase six-fold by 2030 and seven-fold by 2050, for lithium, EU demand is expected to increase twelve-fold by 2030 and twenty-one-fold by 2050. Today, Europe relies heavily on imports, often from a single third country, and recent crises have underlined EU strategic dependencies. Without joint and timely action, a well-functioning single market, resiliency and competitiveness, European industries and

EU efforts to meet its climate and digital objectives are at risk.

The European Critical Raw Materials Act is a comprehensive response to these challenges. Building on the strength of the single market, the Act will ensure that the EU can rely on strong, resilient, and sustainable value chains for critical raw materials. The Regulation will strengthen all stages of the European critical raw materials value chain, diversify the EU's imports to reduce strategic dependencies, improve EU capacity to monitor and mitigate risks of disruptions to the supply of critical raw materials, and improve circularity and sustainability.

A communication accompanying the Regulation outlines how the EU intends to strengthen its global engagement to develop and diversify investment, production, and trade with reliable partners. The EU will pursue these objectives in cooperation with third countries through mutually beneficial partnerships, with a view to promoting their own economic development in a sustainable manner while also creating secure, resilient, affordable and sufficiently diversified value chains for the EU.

In line with the Green Deal Industrial Plan, the Critical Raw Materials Act comes out alongside the Commission's Net Zero Industry Act, which aims to scale up the manufacture of key carbon-neutral technologies for clean energy supply chains.

6 Global perspective on the competitiveness of geothermal energy

With its core characteristics, including locality, low-carbon, stability and independence, geothermal energy attracts increased attention. Global crises disrupting supply chains and questioning once reliable partner demand alternative energy supplies, which geothermal energy can deliver. Despite underuse of the renewable energy source, increasing political attention is put on geothermal as well as investment frameworks. The EU, the birthplace and once a leader in geothermal is falling behind global players such as the US or China that heavily invest in geothermal power and heat respectively.
To ensure a fair competition, the Carbon Border Adjustment Mechanism (CBAM) from the EU puts a fair price on carbon entering the EU.[18] It aims at creating fair condition for products entering the EU compared to locally produced products. Consequently, the temporary increase in costs when installing a geothermal plant shall be mitigated as imported goods increase in price if not produced to sustainability standards of the EU.
For global competitiveness access to critical raw materials is crucial for the EU. The EU's Critical Raw Materials Act[19] is of strategic importance for geothermal expansion. Lithium demand in the EU is expected to increase by a ratio of seven by 2050. Consequently, geothermal lithium extraction has the potential to increase European resilience and independence in terms of critical raw materials significantly. As the act mitigates risks of supply chain disruption and to improve EU capacity a stronger focus should be placed on geothermal lithium.
From 2023 to 2024, geothermal electricity generation capacity grew to 16,873 MW, an increase of 389 MW globally. New power plants have been registered all around the world (Austria, Indonesia, Japan, New Zealand, the Philippines, Türkiye, and the United States). However, 93% of geothermal power is produced in only 10 countries, with the US leading with 3,937 MW installed capacity. The remaining 7% is shared among 25 countries.

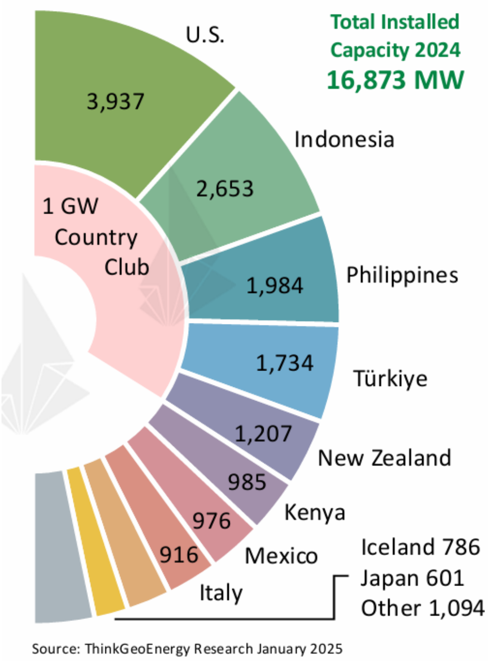

Figure 11: Total installed capacity 2024 at global level. Source: ThinkGeoenergy

Grouping those countries into regions, the Asia-Pacific region is leading in terms of geothermal electricity production with 6,559 MW installed capacity. In particular Indonesia continues to expand in the sector and also China identified tremendous opportunities for geothermal energy production. Additionally, new plants have recently been built in the Philippines, Japan and New Zealand.
In North America, nearly all installations are located in the US and a minimal of 5 MW is generated in Canada. Remarkable is the political support for geothermal energy installations in the US. In January 2024, the USA's Department of Energy's Geothermal Technology Office

[18] 'Carbon Border Adjustment Mechanism - European Commission', accessed 11 August 2025, https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.
[19] 'Critical Raw Materials Act - European Commission', accessed 11 August 2025, https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en.

announced a $31 million investment in six projects.[20] Furthermore, two bipartisan bills have been approved to accelerate geothermal energy development.[21] Despite backlash from the US government to renewable energy sources, geothermal is the only one receiving continuous support. “Geothermal heat” has even been included in the National Energy Emergency Declaration.

In the Latin American region, Mexico is the leading country with 976 MW, followed by Costa Rica with 259 MW and El Salvador with 204 MW. Further, in Chile the use of shallow geothermal resources should become easier following a modification of existing law.[22] The Colombian government opened a public consultation to support geothermal energy development, amending Decree 1073 of 2015.[23]

The African continent has an installed capacity of around 992 MWe, which could expand by a factor of four to 3,974 MWe in the following years. In Kenya, the largest market, 10% of the national electricity supply originates from geothermal.[24]

When it comes to geothermal heating and cooling, 1% of the global heat demand in buildings has been provided by geothermal, focusing on the residential and commercial sector. GHPs account for roughly half of all geothermal heat used worldwide, particularly in China, the United States of America, Sweden, Switzerland, Germany, France, Canada, and Norway. However, despite their effectiveness and the widespread availability of low-temperature geothermal resources, the potential for GHPs remains underutilised in many parts of the world.

China is leading the geothermal district heating sector with about 2/3 of the global use. Geothermal sources account for about 4% of China’s overall district heating supply supported by the government policies to reduce carbon emissions from heating. Still, the remainder is met by coal-based systems.

Beyond residential and commercial heating and cooling, Türkiye stands out in this area, particularly for its extensive use of geothermal energy in greenhouse farming, which supports both crop production and energy efficiency. In total, geothermal heat provides 4% of global agricultural and aquaculture sectors. Additionally, Geothermal provides 1% of global industrial energy consumption. This usage is largely concentrated in China and New Zealand, accounting for 96% of the geothermal heat applied in

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[20] ‘U.S. Department of Energy Announces $31 Million to Improve Enhanced Geothermal Systems and Advance Thermal Energy Storage | Department of Energy’, accessed 11 August 2025, https://www.energy.gov/eere/geothermal/articles/us-department-energy-announces-31-million-improve-enhanced-geothermal.

[21] Saul Elbein, ‘House Passes CLEAN and HEATS Acts, Meant to Spur Geothermal Energy’, Text, *The Hill*, 20 November 2024, https://thehill.com/policy/energy-environment/5000000-house-bills-ease-geothermal-drilling/.

[22] Biblioteca del Congreso Nacional, ‘Biblioteca del Congreso Nacional | Ley Chile’, www.bcn.cl/leychile, 4 November 2024, https://www.bcn.cl/leychile.

[23]‘Colombia Abre Consulta Pública Para Modificar La Regulación de Energía Geotérmica y Avanza Hacia La Primera Subasta de Energía Geotérmica - Energía Estratégica’, accessed 11 August 2025, https://www.energiaestrategica.com/colombia-abre-consulta-publica-para-modificar-la-regulacion-de-energia-geotermica-y-avanza-hacia-la-primera-subasta-de-energia-geotermica/.

[24] ADDIN ZOTERO_ITEM CSL_CITATION {"citationID":"TJ55Vg4S","properties":{"formattedCitation":"\\uc0\\u8216{}The Future of Geothermal Energy \\uc0\\u8211{} Analysis\\uc0\\u8217{}, IEA, 13 December 2024, https://www.iea.org/reports/the-future-of-geothermal-energy.","plainCitation":"‘The Future of Geothermal Energy – Analysis’, IEA, 13 December 2024, https://www.iea.org/reports/the-future-of-geothermal-energy.","noteIndex":20},"citationItems":[{"id":1079,"uris":["http://zotero.org/users/14306962/items/DAMFSGXY"],"itemData":{"id":1079,"type":"webpage","abstract":"The Future of Geothermal Energy - Analysis and key findings. A report by the International Energy Agency.","container-title":"IEA","language":"en-GB","title":"The Future of Geothermal Energy – Analysis","URL":"https://www.iea.org/reports/the-future-of-geothermal-energy","accessed":{"date-parts":[["2025",8,11]]},"issued":{"date-parts":[["2024",12,13]]}}}],"schema":"https://github.com/citation-style-language/schema/raw/master/csl-citation.json"} ‘The Future of Geothermal Energy – Analysis’, IEA, 13 December 2024, https://www.iea.org/reports/the-future-of-geothermal-energy.

industrial processes. In these countries, geothermal energy is used for a variety of industrial purposes, such as drying, processing, and heating in manufacturing.[25]

Central to the global energy transition are critical raw materials. Since 2023, a 75% price decline for lithium and 30-45% decline for cobalt, nickel and graphite have been noted.26 Nonetheless, the demand for critical raw materials remains very high, keeping the extraction of those from geothermal brine crucial. The US government department of Energy has allocated over $15 million for direct lithium extraction research.27 Additionally, the EU has awarded Vulcan Energy and Eramet under the Strategic Projects under the Critical Raw Materials Act.[28] Some of the planned projects a foreseen to have an on-site battery manufacturing facility to fully integrate the extracted lithium into battery manufacturing. If all planned geothermal lithium projects are realised, they could supply about 47,000 tonnes of lithium annually by 2035, covering roughly 5% of global demand under the Announced Pledges Scenario (APS).

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[25] 'The Future of Geothermal Energy – Analysis', IEA, 13 December 2024, https://www.iea.org/reports/the-future-of-geothermal-energy.

[26] IEA, 'The Future of Geothermal Energy – Analysis'.

[27] 'DOE Invests Millions in America's Massive Lithium-Production Potential | Department of Energy', accessed 11 August 2025, https://www.energy.gov/articles/doe-invests-millions-americas-massive-lithium-production-potential.

[28] 'Selected Strategic Projects under CRMA', accessed 11 August 2025, https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/strategic-projects-under-crma/selected-projects_en.

7 Conclusion

This report analyses the status of geothermal technology from a competitiveness perspective. Both qualitative and quantitative aspects are here considered to elaborate a comprehensive overview of geothermal energy competitiveness at the European but also global levels.

The complexity of this work is due to the fact that it considers different technologies to get a general analysis, but takes into account the differences within the different applications. Hence, from a cost perspective, 4 representative plants are addressed:

- 20 MWe high temperature plant (Flash turbine)
- 10 MWe medium temperature plant (Binary turbine)
- 20 MWth heating plant
- 50 kWth heating and cooling system assisted with heat pumps

The analysis conducted tries to go further the traditional approach focused exclusively on LCoE research, considering other significant and representative elements. Indeed, the inclusion of other criteria, such as lifetime performance, load factors, socio-economic benefits, and supply chain resilience, allows for the development of a more comprehensive picture of geothermal technology in relation to other energy sources.

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