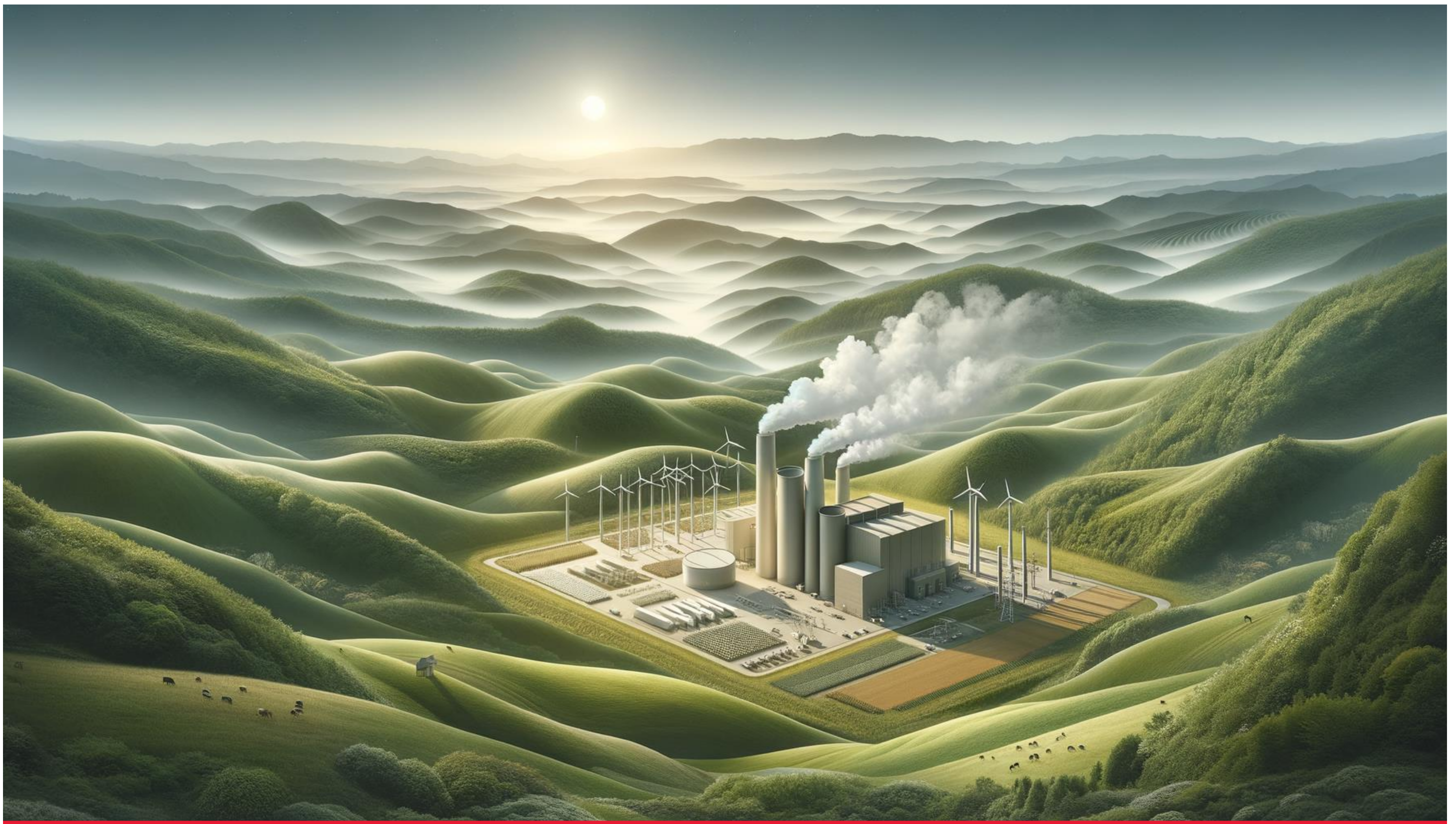

REPORT 2025

The Status-Quo of Geothermal Energy in Japan & Germany

Synergies and potentials for future cooperations

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This study was prepared by adelphi on behalf of the German Federal Ministry for Economic Affairs and Energy as part of the support of the Japanese-German Energy Partnership.

The contents reflect solely the findings and opinions of the authors and do not represent the position of the client or other members and stakeholders of the Germany's climate and energy partnerships.

Imprint

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Supported by:

Special thanks to Heiwa Hasegawa (AHK Japan) as well as Mervin Hummel and Merle Lya Stockmann (adelphi). Your feedback and additional information enriched and improved the study.

Layout:
adelphi

Photo credits:
Title: generated with AI

Status: 17.04.2025

Initiated by

Federal Ministry for Economic Affairs and Energy

Implemented by

adelphi

With contributions by

RENEWABLE ENERGY INSTITUTE

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Introduction

As the global energy transition accelerates, geothermal energy stands out as a reliable and sustainable solution to address pressing challenges such as climate change and energy security. This study, conducted within the framework of the "Energy Partnership with Japan and Korea," seeks to deepen cooperation between Germany and Japan in the field of geothermal energy. The partnership aims to strengthen energy collaboration, foster the exchange of technical expertise, and advance the adoption of renewable energy technologies in both countries. By uniting their respective strengths, Germany and Japan aspire to contribute to a sustainable and decarbonised future.

To lay the foundation for this comparative analysis, Chapter 1 provides an introduction to geothermal energy, outlining its potential as a renewable energy source and its diverse applications in electricity generation, heating, and industrial processes. It explains the key types of geothermal systems, such as hydrothermal and petrothermal, and introduces the technical and economic factors influencing their development.

Building on this groundwork, the study delivers a detailed analysis of the Status Quo of geothermal energy in both nations, structured around key topics explored in Chapter 2 for Germany and Chapter 3 for Japan. These include the geological characteristics and resource potentials of geothermal energy, with each country focusing on regions that align with their unique geological conditions. The policy frameworks governing geothermal energy are compared, highlighting differences in regulatory structures and strategies for balancing development with environmental and social considerations. Research and development efforts are also examined, showcasing each country's focus on technological innovation and modernisation. The chapters further explore the economic viability of geothermal energy, contrasting approaches to integrating geothermal energy into energy systems and local economies. Public acceptance and stakeholder engagement strategies are discussed, emphasising the importance of transparent communication and community involvement as critical factors for the success of geothermal projects. The economic potential and viability of geothermal energy are further analysed by focusing on three key aspects: a description of the geothermal industry, factors influencing economic viability, and the funding schemes available for geothermal energy. Lastly, specific geothermal projects in Germany and Japan are also highlighted to illustrate the opportunities and challenges faced in specific projects.

Chapter 4 builds on this comparative analysis by identifying potential synergies and opportunities for collaboration between Germany and Japan. The chapter highlights the mutual benefits of sharing technological advancements, such as innovative geothermal systems and next-generation technologies. It explores strategies to mitigate exploration risks, including geological surveys, exploration insurance, and enhanced data sharing, and addresses regulatory challenges by advocating for streamlined approval processes and unified legal frameworks. Public acceptance is presented as a critical factor, with recommendations for fostering trust through participatory approaches and transparent communication. The chapter also underscores the potential for joint research and development initiatives, such as collaborative pilot projects and knowledge exchange on seismic risk mitigation. Furthermore, the co-production of lithium from geothermal fluids is highlighted as a shared opportunity to boost the economic potential of geothermal energy while addressing global resource needs. These synergies are framed as a pathway for the two nations to jointly advance geothermal energy and strengthen their respective energy transitions.

The study concludes by synthesising these findings and offering actionable insights to deepen cooperation. It emphasises the importance of expanding geothermal exploration beyond traditional regions and addressing investment risks through financial instruments like exploration insurance. Recent advancements in regulatory frameworks are presented as models for unlocking geothermal potential, while community-driven approaches highlight the value of local engagement. Successful initiatives are showcased as examples of how participatory approaches can drive project success. By leveraging these insights, Germany and Japan are encouraged to set a global example of how geothermal energy can drive sustainable energy development.

1 Overview: Geothermal Energy

Geothermal energy is a renewable energy source derived from the natural heat of the Earth's interior. This energy is harnessed by tapping into geothermal reservoirs, which are areas of the Earth's crust that contain hot water and steam, to generate electricity and provide direct heating. It is considered a sustainable and environmentally friendly energy option due to its low emissions and consistent availability.

The potential of **geothermal heat supply** depends on five factors: 1) thermohydraulic properties of the subsoil, 2) thermal properties of the existing buildings, 3) properties of the building site, 4) technical heat source development and 5) the regulatory framework conditions (Bracke und Huenges 2022). Evaluation of the potentials and developing scenarios for the geothermal heat exploitation requires extensive technical and financial efforts to evaluate the potentials and to develop scenarios for the geothermal heat exploitation.

To produce **electricity** from a geothermal resource, reservoir temperatures typically need to be above 150°C for conventional geothermal power plants, such as dry steam and flash steam plants. However, for binary cycle power plants, which use a secondary fluid with a lower boiling point than water, temperatures can range from 85°C to 150°C (Ciucci 2023).

Geothermal energy is exploited by drilling wells into reservoirs to access steam and hot water, which drive turbines for electricity generation or are used directly for heating, such as in district heating and greenhouse warming. Enhanced Geothermal Systems (EGS) expand this potential by artificially stimulating reservoirs, enabling energy extraction in areas lacking natural reservoirs. An overview of the different geothermal systems is shown in **Figure 1**.

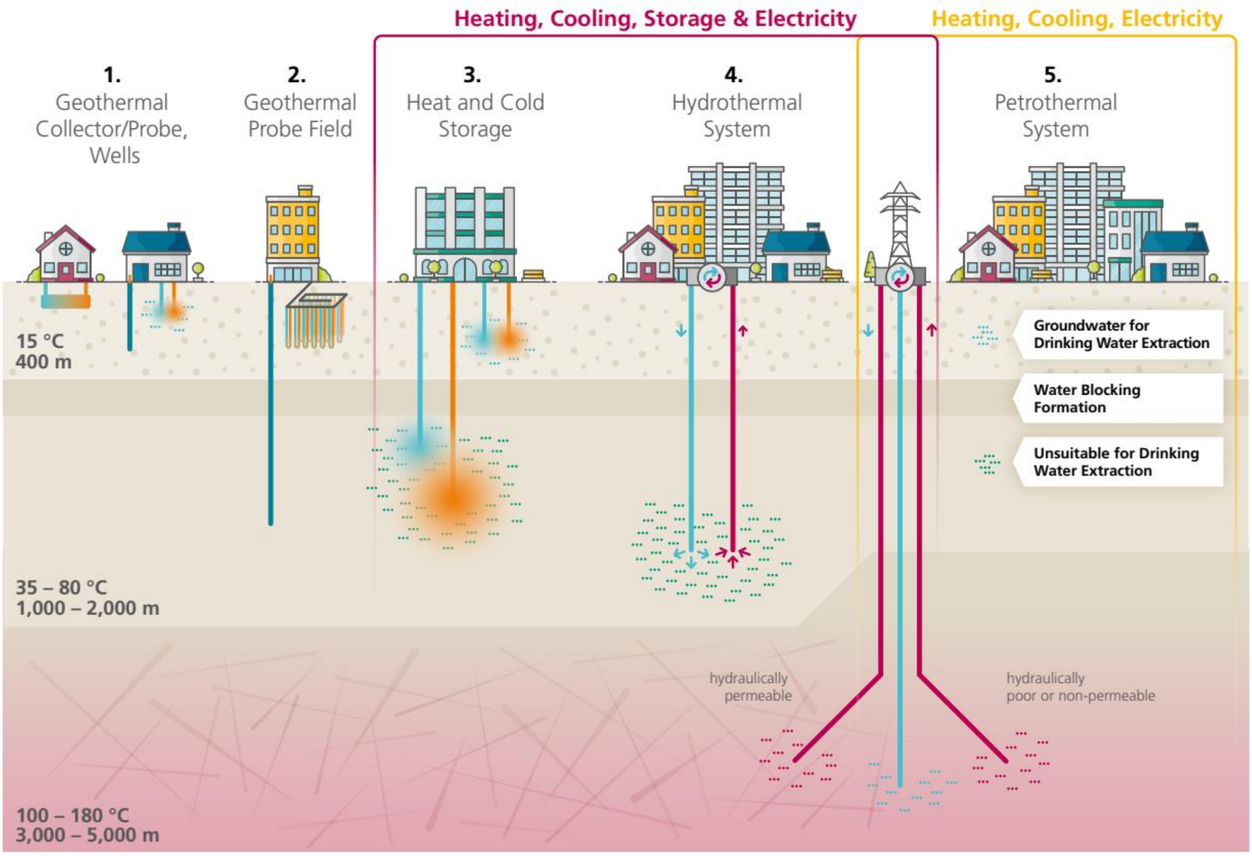

Figure 1: Overview about the various geothermal systems (Bracke und Huenges 2022).

2 Status Quo in Germany

2.1 Geothermal Systems, Regions and Potentials

In Germany, geothermal energy is classified based on geological settings and the depth of the geothermal resources. Deep geothermal energy is primarily harnessed in three major geological regions: the South German Molasse Basin, the Upper Rhine Graben, and the North German Basin. These areas are significant for geothermal energy production, particularly for district heating and, in some cases, power generation (Bracke et al., 2022). Almost all of Germany has shallow heat sources suitable for shallow geothermal energy. This involves the use of ground-source heat pumps to increase temperatures for heating homes and buildings. A comprehensive study about strategies to enhance shallow geothermal was published recently (Born et al. 2022b).

The main difference between shallow and deep geothermal energy is the depth and temperature of the resources. Shallow geothermal uses low-grade heat (10 to 25°C) from up to 400 meters deep for heating and cooling (Mahmoud et al. 2024). Deep geothermal, from several kilometres underground, involves higher temperatures suitable for electricity generation and large-scale heating (ETH Zürich 2025).

For deep geothermal applications, a distinction is usually made between hydrothermal and petrothermal geothermal energy. Hydrothermal geothermal energy is based on the use of hot thermal waters that move through natural pore, fissure and fracture systems, i.e. through cavities in the subsurface (Bracke et al., 2022). Generally, low-temperature reservoirs are in a single liquid phase, whereas high-temperature reservoirs can be liquid or vapor dominated (Colpan et al. 2021). Petrothermal geothermal energy is also referred to as enhanced geothermal systems (EGS) that require hydraulic stimulation in order to exploit geothermal energy. They are bound to hydraulically conductive fissure structures in the impermeable crystalline subsurface in deeper depth and are associated with higher temperatures (Born et al. 2022a). Technologies that are used to increase the permeability of fracture networks are commonly hydraulic stimulation or acid treatment.

2.1.1 Regions and Reservoirs

Germany has a high potential for both hydrothermal and petrothermal reservoirs. However, the seismic risks associated to the exploitation of petrothermal reservoirs lead to political decisions that favour hydrothermal reservoirs over petrothermal reservoirs, as for example in North-Rhine-Westphalia (NRW) (MWIKE 2024, S. 18).

Germany is commonly divided into three main geothermal regions for deep geothermal exploitation, due to their favourable geological conditions: (1) The North German Basin, (2) the Upper Rhine Graben and (3) the South German Molasse Basin (Figure 2). With implementing the obligatory municipal heat planning law (Wärmeplanungsgesetz - WPG), local and regional authorities also aim for the exploration of other regions and reservoirs.

Northern German Basin (NGB)

The geothermal resources of the North German Basin (NGB), estimated to yield 13.000 EJ of heat in place (Franz et al. 2018a), are bound to Palaeozoic petrothermal and Mesozoic hydrothermal reservoirs (Franz et al. 2018b). The most important hydrothermal potential can be found in the Middle Bundsandstein, Schilfsandstein, Rhaetian, in the Lower and Middle Jurassic as well as in the Lower Cretaceous (GTN 2025). Only a few projects were implemented to explore and produce geothermal energy, for example Groß Schönebeck (Blöcher et al. 2016), GeneSys Hanover (BGR 2018), where the low permeability sandstone, the complex chemistry of the pore waters limited the production. Recently, the geothermal project in Potsdam demonstrated, that geothermal capacity can exceed the expected potentials and will provide 4 MW which will supply heat to up to 6,900 households (see chapter 2.6).

Source: Leibniz Institute for Applied Geophysics, Hannover, Germany.

Figure 2: Overview about the common geothermal regions in Germany.

Upper Rhine Graben (URG)

The Upper Rhine Graben is located in the southeast of Germany and is a well-known geothermal region worldwide, shared by Germany and France. With the high thermal gradient of up to 100 K/km and the abundance of large fault zones, the technical potential for deep geothermal energy is estimated to up to 186 TWh/a, which equals about 5% of the primary energy demand of Germany (Frey et al. 2022a).

Since the 1980's the deep geothermal systems in crystalline rocks were investigated, especially on the French side (e.g. the EGS of Soultz-sous-Forêts). According to numerous studies, nine geological units were identified as suitable reservoirs: the Crystalline Basement, Permo-Carboniferous sandstones, Bundsandstein, Upper Muschelkalk, Hauptrogenstein, Upper Jurassic Limestones, as well as the Paleogenic Pechelbronn, Froidefontaine and Niederrödern Fm (Frey et al. 2022a).

Over time, six active deep geothermal heat and/or power plants became active in the region (e.g. Landau, Insheim, Bruchsal, Weinheim, Heubach/ Groß-Umstadt). The total installed thermal and electrical capacity of 50 MWth and 10 MWel is well below the technical potential, thus significant growth is still to be expected in this sector in the coming years (Frey et al. 2022b).

Hurdles for the exploitation of the geothermal potential arise from the complex geology and tectonic activity, as well as difficulties with the legal framework or lack of public acceptance (Frey et al. 2022a). In total, seven realized deep geothermal projects have not been successful in the URG so far due to a variety of technical and political reasons (Frey et al. 2022a). As drilling advances and understanding of geological complexities improves, the risks become more manageable, leading to increased public acceptance of geothermal energy.

Southern German Molasse Basin (SGM)

The Molasse Basin in Bavaria is the largest prospect for hydrothermal exploration in Germany, with a suggested geothermal potential of 7.655 MW_{th}, which is the equivalent of about 40% of Bavaria's heat demand.

According to the Bavarian Geothermal Atlas[1], two main regions in Bavaria are differentiated for geothermal exploration: the northern Bavarian "Fränkisches Becken" and the southern Bavarian "Molasse Basin". The geothermal temperatures and geological conditions vary strongly in the northern part of Bavaria depending on the respective target formation (Pre-Perm crystalline basement, Upper Carboniferous/ Rotliegend, Zechstein, Bundsandstein, Muschelkalk, Keuper), while there is no reliable proof for the geothermal potential yet.

The Molasse Basin offers a larger potential and is known for its high productivity and is therefore primarily targeted for geothermal exploitation in Bavaria. The Malm reservoir in the Bavarian Molasse Basin is a fractured karst aquifer with high water availability that reaches a thickness of up to 600 metres. Due to its depth, the groundwater south of Munich reaches temperatures of over 100°C.

The installed capacity currently amounts 404 MW_{th} for district heating and thermal spas (GeotIS 2024) and is therefore by far the largest contributor in Germany. The targeted reservoirs are hydrothermal, while petrothermal reservoir exploitation is not expected in the near future. However, the balneological (geothermal utilisation for thermal spas) usage of hydrothermal waters was assessed to

[1] Geothermal Atlas for Bavaria (in German): https://www.stmwi.bayern.de/fileadmin/user_upload/stmwi/publikationen/pdf/2024-02-19_Bayerischer_Geothermieatlas_akt24.pdf

be sufficient for all aquifers addressed in the Bavarian Atlas for geothermal energy.

The Geothermal Alliance Bavaria[2] is a platform commissioned in 2020 by the Bavarian State Ministry of Economic Affairs, Regional Development and Energy to transfer knowledge and data between science, business and politics, as well as to prepare an expert opinion on a geothermal master plan. The alliance developed a methodology for the techno-economic design that can be adapted to develop expansion strategies for deep geothermal energy in other similar regions worldwide (Molar-Cruz et al. 2022).

New regions and shallow geothermal energy

The government of North Rhine-Westphalia (NRW) has initiated two projects to explore the region's geothermal potential, also referred to the Rhein-Ruhr-Region (Bracke und Huenges 2021). These projects focus on the geothermal characterization of the Lower Rhineland and the northern margin of the Rhenish Mountains, as well as the greater Münster area, investigating intermediate to deep subsurface geological layers, particularly carbonate rocks (Esteban Lopez et al. 2022; MWIKE 2024). The projects involve the digitalization and harmonization of existing geodata, geophysical measurements, and the acquisition of 2D seismic data to promote a climate-friendly heat supply and support future geothermal project planning. Additionally, the Master Plan for Geothermal Energy in NRW aims to extensively utilize geothermal energy within the region, providing strategic expansion goals for shallow, medium-depth, and deep geothermal resources (MWIKE 2024).

The potential of shallow geothermal energy is assessed by analysing geological data such as thermal conductivity and groundwater flow, supported by detailed maps from state geological offices. This includes licensing restrictions and geothermal yields, integrated with building-specific needs and local heat demands to evaluate feasibility. Shallow geothermal energy is versatile, suitable for heating and cooling buildings from small homes to large urban areas and can be implemented in both urban and rural settings, though local conditions like building density and available space may impact feasibility (Born et al. 2022a).

2.1.2 Geothermal Potential

Up to 25% of Germany's total heating requirements could be covered by using geothermal energy (ITG 2024b). Therefore, Germany is aiming to accelerate the expansion of geothermal energy as a substitute for fossil fuels to achieve a rapid reduction in CO_2 emissions in the heat supply.

According to the "Bundesverband Geothermie" (BVG), as of 2025 42 deep geothermal plants are in operation, with further 16 plants in construction. The number of shallow geothermal installations (e.g., geothermal probes or collectors in combination with heat pumps) is more than 480.000 with ca 4.800 MW of installed heat output. The number of thermals spas is 170. Heat production is the main use for geothermal energy in Germany, but also electricity production contributes to the overall potential. An interactive map with all current projects can be accessed through the website of the BVG).[3] Most geothermal energy projects are operational sites are located in Bavaria (24) and North Rhine-Westphalia (3), but also in Baden-Württemberg, Mecklenburg-Western Pomerania, Rhineland Palatinate, Brandenburg and Hesse (GeoEnergy 2022; BVG 2023b).

This is reflected in recent numbers of installed geothermal capacity in Germany, which can be accessed via the Geothermal Information System (GeotIS).[4] According to these numbers, the installed capacity for district heating currently amounts 393.7 MW_{th}. Combined with the installed capacity for space heating (3.3 MW_{th}) and thermal spa (56.8 MW_{th}), the sum is about 454 MW_{th} with an annual production of 2.010 GWh/a.

Geothermal electricity generation in Germany takes place via binary systems (Kalina or ORC cycle), which can also generate electricity at temperatures of 100 °C (Weber et al. 2022). Eleven geothermal plants with a capacity of 55 MWel were feeding electricity into the German grid, according to BVG data.

In summary, no comprehensive market has yet developed for deep geothermal energy, despite its high potential (Bracke, 2022). Within the last few years, however, more and more projects are being developed to contribute to the targets and regulatory requirements set for the heat transition ("Wärmewende") in Germany. In the beginning of

[2] Geothermal Alliance Bavaria: https://geothermie-allianz.de/en/home/
[3] Interactive map of current geothermal projects: https://www.geothermie.de/aktuelles/geothermie-in-zahlen
[4] Geothermal Information System (GeotIS): https://www.geotis.de/homepage/GeotIS-Startpage

2023, about 12 sites were under construction and 82 sites were in the planning phase (BVG 2023b).

2.2 Policy Framework

2.2.1 Government Strategy

Germany took its first significant steps to expand geothermal energy in 2004 by setting a target to generate 1 GW of electricity within a decade. Despite these early efforts, the national exploitation of geothermal energy's potential, particularly for heat generation, remained limited in the following years (BMWK 2022). Although geothermal energy has been incorporated into the Renewable Energy Sources Act (EEG), which offered guaranteed compensation for electricity fed into the grid, the initial interest concentrated mainly in regions such as Upper Bavaria and the Upper Rhine (Bracke und Huenges 2022).

The German government was generally more cautious than countries like Turkey and Sweden in promoting geothermal projects, primarily due to the associated high costs and complexities (Clean Energy Wire 2020b). Geothermal energy was only mentioned parenthetically in the Climate Action Plan 2050 as a renewable heating source (BMUB 2016).

A significant policy shift occurred in 2020 when shallow geothermal energy received state support for the first time, including rebates of up to 45% for drilling, ground source heat pumps, and other costs related to replacing oil heating with renewable solutions. Currently, with the goal of producing 50% of heat in a climate-neutral manner by 2030 and achieving full climate neutrality by 2045, geothermal energy has regained significant attention in Germany's renewable energy strategy. To achieve these ambitious targets, the government plans to strategically enhance the utilization of geothermal energy (Bundesregierung 2023).

Central to this undertaking is the key issues paper, released in November 2022 by Germany's Federal Ministry for Economic Affairs and Climate Action (BMWK), that outlines strategies to catalyse the development of additional geothermal projects (BMWK 2022).

This plan primarily focuses on the expansion of medium-depth and deep geothermal energy, targeting thermal extraction from depths of 400 to 5,000 meters. It sets a target to develop as much of the 10 TWh of geothermal potential by 2030 as possible. This would translate to increasing the current contribution of geothermal energy to heat networks approximately tenfold compared to 2021.

Additionally, the government outlined the goal to initiate at least 100 new geothermal projects by 2030, integrate them into heating networks, and make geothermal energy accessible for residential buildings, neighbourhoods, and industrial processes. To facilitate these objectives, the strategy delineated eight key actions.

One of the measures stipulates initiating a dialogue process that will engage with federal states, associations, and companies to ensure acceptance and consistency in geothermal projects. This should be complemented by a data campaign, which aims to develop a comprehensive nationwide subsurface database to identify suitable geothermal sites and reduce information deficits.

In parallel, an exploration campaign should qualify over 100 sites for medium-depth and deep geothermal development, serving as demonstration projects. To streamline these efforts, legislative changes (as detailed in chapter 2.2.2.) shall be enacted to expedite planning and approval processes, backed by a state secretary-level steering group to ensure effective coordination.

Financially, the strategy includes targeted funding programs to support the development of geothermal systems and improve market readiness. This also includes federal funding for efficient heating networks that can cover up to 40% of investment costs for geothermal heating projects (Die Bundesförderung für effiziente Wärmenetze, BEW).

To mitigate financial risks, tools should be developed to address uncertainties during the discovery and development phases of these projects. In accordance with the coalition agreement, the government seeks to explore the development and implementation of risk hedging instruments to alleviate financial burdens on project developers in the initial phase.

Additional action has been planned in the area of workforce development and public acceptance. These include training initiatives aimed at equipping potential workers with the necessary skills for the geothermal sector and awareness and educational campaigns designed to foster public understanding and support, particularly in communities near potential geothermal sites (BMWK 2022).

The key issues paper was widely regarded as a positive signal for the geothermal industry.

Simultaneously, it spurred significant engagement from German stakeholders, who identified additional areas for improvement in their responses. For instance, the German Geothermal Association (BVG) emphasized the need not to overlook the potential of near-surface geothermal energy (BVG 2022). Together with the Energy Efficiency Association for Heating, Cooling and CHP (AGFW) and the Federal Association for Renewable Energies (BEE), the BVG expressed concerns about the lack of clarity regarding funding and timelines for introducing risk mitigation instruments. They advocated for mechanisms that not only cover discovery risks but also potential damage to existing buildings.

Moreover, these associations urged the government to expedite the review process for introducing operating cost subsidies for the direct use of deep geothermal energy within the BEW. They also recommended complementing the BEW with a KfW loan program to secure project financing on favourable terms, given the substantial financial resources required for successful project implementation (BVG, AGFW, BEE 2022).

2.2.2 Legal framework

Geothermal energy in Germany is subject to a complex regulatory framework involving various public law approval requirements. In an effort to accelerate the deployment of geothermal systems, the Federal Cabinet approved a series of legislative changes designed to streamline approval processes for geothermal systems in 2024, as previously stipulated in BMWK's key issues plan (BMWK 2022).

A notable legislative update concerns the Federal Mining Act (Bundesberggesetz, BBergG) and its relevance to near-surface geothermal energy. This legislation typically applies to mining activities at depths of 100 meters or more. However, the planned "Fourth Bureaucracy Relief Act" clarifies now that near-surface geothermal energy, up to a depth of 400 meters, is generally exempt from this law (BMJ 2023). This exemption means such projects will not require a mining license or an operating plan permit, thereby simplifying the approval process. In contrast, deep geothermal resources remain classified as free mineral resources, necessitating compliance with the mining law framework (§ 6 ff. BBergG). Depending on the project phase, different mining permits are required, such as a permit for exploration work (§ 7 BBergG) and another for extraction (§ 8 BBergG).

As the construction of geothermal plants often requires drilling that can affect the groundwater, the requirements of the Federal Water Act (Wasserhaushaltsgesetz, WHG) must also be considered. Geothermal projects thus frequently require a water law permit, which must be obtained from the local water and soil protection authority (§ 8 WHG). In Germany, water protection areas are generally divided into various zones. Typically, these areas are excluded from geothermal energy use. However, exceptions might be possible in specific instances within protection zone III, contingent upon the decision of the relevant authority. Additionally, in source protection areas for state-recognized medicinal springs, it is crucial to consider the quantitative protection zones and associated regulations during the assessment

The new legislative updates contain further changes to both the Federal Mining Act and the Federal Water Act, that should speed up, simplify and digitize the approval procedures for geothermal energy. This includes, for example, the introduction of maximum deadlines in mining law, that mandate authorities to make approval decisions within one year. Additionally, the legislation now also recognizes geothermal energy, heat pumps and heat storage systems as of overriding public interest, and will prioritize them in planning decisions (BMWK 2024b).

Building new geothermal power plants in Germany also requires obtaining a building permit according to state building regulations. Geothermal plants can, as an exception, be constructed in areas outside designated building zones under the Building Planning Law (Baugesetzbuch, BauGB). Previously, there was no explicit statutory regulation in the Building Code; however, administrative practice generally recognized the preferential status of geothermal plants (§ 35 BauGB) (Leidinger & Franken 2023). In September 2024, an amendment to the building law was approved by the cabinet, which will further facilitate the approval of geothermal projects in outdoor areas (BMWK 2024b).

In addition to building regulations, the construction and operation of a geothermal power plant in Germany must comply with environmental protection laws, particularly those concerning emission control. Facilities are required to prevent avoidable harmful environmental impacts using current technology and to minimize unavoidable impacts to the greatest extent possible, as stipulated in § 22 of the Federal Immission Control Act (BImSchG).

Moreover, nature conservation laws must also be observed, which fundamentally require the avoidance of significant impacts on nature and the landscape. Any unavoidable impacts must be compensated for, as outlined in § 13 of the Federal Nature Conservation Act (BNatSchG). Depending on site characteristics, further requirements from nature and species protection laws may also need to be considered.

In Germany, geothermal energy projects are usually required to undergo an Environmental Impact Assessment (Umweltverträglichkeitsprüfung, UVP). For any drilling activities aimed at extracting or exploring mineral resources at depths greater than 1,000 meters, a preliminary UVP assessment must be conducted by the mining authority. This preliminary assessment evaluates whether the proposed project could have significant negative impacts on the environment, as outlined in Annex 2 of the Environmental Impact Assessment Act (Gesetz über die Umweltverträglichkeitsprüfung). If so, a full UVP, accompanied by a framework operating plan, is necessary for approval through a planning approval procedure. If no adverse effects are anticipated, the main operating plan procedure is sufficient. An important aspect of this process is the provision for public involvement. Under certain conditions, the local community is entitled to challenge the results of the preliminary assessment. Consequently, geothermal projects may often face extended approval timelines (BVG 2021).

An UVP is always necessary if "fracking" measures are to be used in the geothermal project, this project is located in earthquake zones 1-3 or substances hazardous to water are used (BVG 2021). Unlike unconventional fracking, which is forbidden since 2017 (with the exception of a maximum of four scientific test measures), the procedure of hydraulic stimulation for deep geothermal projects is generally not prohibited in Germany (BMUV 2022). The ban only affects petrothermal geothermal projects, which would have to resort to stimulation measures with water-polluting substances in order to create the necessary pathways (BVG 2021).

2.3 Research and Development

2.3.1 Research funding programmes

The current research and development topics in Germany are captured regularly within the "Energieforschungsprogramm". This catalogue provides an overview about funding objectives and was updated in 2024. Compared to the previous programme it is obvious, that no specific research topic was assigned to geothermal energy anymore.

Within the previous catalogue from 2018, the main research topics were demonstration projects, further development of the technology towards reducing costs, increase efficiency, system availability and digitalization, as well as further development in subsurface heat storage technologies, extension of geological data availability, safety aspects of technical utilization, material use of production fluids and simulation of geothermal systems to increase forecast reliability and risk reduction (BMWI 2018).

The new research missions within the 2024 catalogue rather aim to provide overarching goals with being the 1) upscaling of innovative technologies while increasing acceptance and participation, 2) decarbonization of heat production in industry and commerce, 3) shape a robust infrastructure for efficient distribution and storage of heat and 4) make use of the potential for flexibilization (diversify heat sources and increase sector coupling). Geothermal energy is mentioned among other technologies with an emphasize on coupling various technologies (BMWK 2023).

Germany also uses funds from its coal phase-out program to support geothermal energy R&D. For instance, €52 million has been allocated to establish a geothermal research laboratory in North Rhine-Westphalia. This project will be executed by the research institute Fraunhofer IEG and involves comprehensive mapping potential geothermal reservoirs and focusing on industrial applications of geothermal heat to support the region's decarbonization efforts (Clean Energy Wire 2025).

2.3.2 Current research topics

Another detailed catalogue for geothermal research topics was provided by the BVG (BVG 2023a). In this overview, the main topics were divided into deep and shallow geothermal energy, heat distribution, subsurface storage as well as environmental impact and sustainability. The demand for research is the largest for deep geothermal energy and is described based on the BVG publication on research and development topics.

One major research topic is the transregional exploration strategies to enhance subsurface data availability (geological and geomechanical data, temperature distribution, hydraulic and hydrochemical parameters). Sparsely distributed data of existing oil and gas boreholes was gathered with outdated exploration technologies. A main research demand is therefore the implementation of a publicly funded drilling programme for data generation including geophysical borehole measurements, hydraulic testing and large-scale seismic campaigns.

Further, the research demands for the specific geothermal regions (see chapter 2.1.1) were outlined. For the URG this includes the mapping and characterization of faults or risk mitigation strategies towards induced seismicity. For the NGB research towards pore space and permeability-related issues (clay layering, cementation processes), research on high-salinity thermal fluids and data compilation of Devonian and Carbonian reservoirs are required. For the SGM further research on seismic reservoir characterization, subsurface stress states of fault systems, thermal-hydraulic interaction of neighbouring geothermal systems and further development of stimulation technologies.

Other main topics are related to specific exploration methods for geophysical site investigation and hydrological conditions. For the specific geophysical methods this includes the implementation of a public data base and further development in specific methods, such as modern seismic acquisition technologies, increased seismic resolution and passive seismic methods, among others. Future research should focus on exploring hydrogeological conditions, with an emphasis on expanding and improving the data foundation for thermo-hydraulic properties in THMC modelling, enhancing datasets for hydrochemical analyses (including scaling and corrosion potentials), and developing strategies to minimise scaling during site operations.

Further research in the reservoir development is needed for drilling technologies to reduce drilling costs, lower the required personal and increase drilling velocity. This includes tools for borehole-risk-management and long-term stability of boreholes, as well as innovation in horizontal drilling techniques. Besides drilling, further research is required in hydraulic stimulation of reservoirs, such as multi-stage-fracturing and chemical stimulation techniques, as well as techniques to enhance continuous permeability patterns in fractured systems.

Production development and reservoir management is crucial during operation of geothermal power plants. Here, research to enhance the reliability, durability and efficiency of deep fluid pumps is important. Additionally, methods to manage scaling in fluid pumps and monitoring of production fluids are required.

During operation, enhanced seismic monitoring techniques are needed, especially in urban areas, including changes in stress-states, characterization, zoning and forecasting strategies for continuous seismic risk assessment, as well as traffic light systems.

Reservoir management needs research on enhancing coupled reservoir models (THMC), hydraulic permeability prediction, monitoring techniques on intersected aquifers, as well as changes in microbial, thermal or chemical variations during operation. The development of operation methods to manage heat supply and demand is also necessary.

Research topics on energy provision and material utilization of geofluids is divided into electricity and (process) heat production. For electricity production, further development of eco-friendly turbine and system efficiency during coupled electricity and heat production is needed, including seasonal heat-decoupling. For heat production, market-mature high-temperature heat pumps of several hundred MW, reduction of heat loss during transport are important research topics. Process heat, often required for industrial purposes, require field testing of high-temperature heat-pumps above 180°C. The utilization of geofluids becomes increasingly important and requires further research on geofluid analysis, economic (industrial) separation (extraction) of different minerals, as well as the profitability and long-term effects of geofluid utilization.

An alternative to the classic two-borehole systems is a closed loop system or the utilization of existing mining infrastructure. For geothermal probes, the verification of profitability for deeper systems or the utilization of dry geothermal or hydrocarbon-related boreholes is required. Closed loop systems generally require demonstration projects and economic feasibility studies, as well as studies on CO_2 as an alternative heat transfer medium.

2.4 Technical and Economic Challenges

To advance the heating transition, innovations and technologies must be rapidly transferred from research to industrial application. This requires a significant expansion of geothermal technologies, supported by structural and economic promotion measures, as well as strategies to mitigate possible risks associated with geothermal exploration.

2.4.1 Technology and Reservoir Operation

According to the Roadmap Deep Geothermal Energy (Bracke und Huenges 2022), numerous new drillings are necessary to achieve geothermal provision of space heating, hot water, industrial process heat, and process cooling with approximately 2,000 required by 2030 and around 7,000 to 10,000 by 2040. Currently, there is a shortage of drilling rigs and qualified personnel to meet these needs. The hydrocarbon industry, which is undergoing transformation, could contribute to capacity building. Meanwhile the machinery sector faces a demand for 3,500 to 14,000 new heating plants, needed in the 5 to 20 MW capacity range.

The transformation of local and district heating networks in Germany requires extensive technical adjustments, such as changes to feed-in points, volume flows and temperature levels. The operational management and technical equipment of most existing networks will have to be changed. Following the Roadmap, by 2030, large heat pumps for the geothermally supported generation of process heat up to 200 °C in the power class up to 50 MW should be available. The expansion of district heating from 112 TWh/a to 171 TWh/a will require over 10,000 km of new network capacity, which means that a total of 30,000 to 40,000 km of district heating networks will have to be built or converted, 25 to 30 % of which can be supplied geothermally (Bracke und Huenges 2022).

Induced seismicity can occur in deep geothermal reservoirs both during hydraulic stimulation and during the operating phase. As the pore pressure in the rock increases as a result of hydraulic measures, the resulting decrease of the effective normal stress and friction along existing weak zones can cause induced seismicity due to slippage along faults. One example for such an event in Germany is Landau (LGB-RLP 2010; Zang et al. 2014). Induced seismicity events outside Germany also contribute to the public discussion, especially those close to the German boarder in Soultz-sous-Forêts (Meller und Ledésert 2017). For the respective geothermal regions (Keil et al. 2022), induced seismicity can be mitigated by developing traffic light systems and innovative injection schemes, that allow for monitoring, early detection, as well as proper reaction to possible seismic events during operation (Hofmann et al. 2018).

Additionally, there are respective technical and operational demands and risks for the main respective geothermal regions in Germany (see chapter 2.1.1) are shown in Table 1.

Table 1: Technical and operational demands for the respective geothermal regions.

Region	Technological and Operational
South German Molasse Basin	project-related measures for long-term monitoring, operational optimisation, cost reduction, supra-regional networking to form larger composite heating systems and the investigation.
Upper Rhine Graben	avoidance of induced seismicity in urban areas and the control of the thermal water cycle in view of the high salinity, including mineral deposits, corrosion and the use of raw materials such as lithium.
North German Basin	special approaches and demonstrations at suitable plants are required for large-scale development to explore the known reservoir horizons.
Rhine-Ruhr Region	geological survey of the region, large-scale demonstration projects and economic development measures for the many manufacturing companies in the local mining and energy sector.

2.4.2 Exploration Risk

The exploration risk for geothermal projects is the risk that deep water may not be found at sufficient temperature or quantity, which is a major concern for geothermal energy exploitation. Exploration risk insurance can cover the financial losses associated with unsuccessful drilling, where millions of euros could be lost if deep water is not encountered.

The BMWK has tasked the public development bank KfW with creating a concept to address the high financial risk associated with geothermal exploration, specifically the risk of not finding sufficient geothermal resources (ITG 2024b). This initiative aims to provide insurance for expected thermal output, thereby reducing investment risks and encouraging the development of geothermal energy projects. Such insurance is crucial for municipal utilities to transition their district heating networks (ITG 2024a).

In a study by Seipp et al. (2016), several international examples of mechanisms to mitigate the exploration risk were listed and strategies for the implementation in Germany were suggested (Seipp et al. 2016) This study also suggests steps on how to assess the exploration risk (i.e. geological surveys, implementation of financial instruments and insurance solutions, encourage governmental support and standardized risk assessment methodologies, address public).

However, it is suggested, that to improve heat generation costs, it's essential to reduce the exploration risk in early project stages with around 40% investment support and ensure operating costs comparable to fossil and other renewable energy sources (Born et al. 2022a). No such standardized insurance is in place in Germany yet. As per the coalition agreement of 2021 and the "Eckpunkte für eine Geothermiekampagne", the BMWK has been assessing the development and implementation of risk mitigation instruments (BMWK 2022). In the coalition agreement of the new German government, the implementation of appropriate instruments to mitigate the risks of exploration failures ("Absicherung Fündigkeitsrisiko") is mentioned with high priority. Furthermore, the agreement mentions that all damages will be fully covered (CDU, CSU, SPD 2025).

2.5 Public Acceptance

2.5.1 Concerns and solutions

Despite the significant potential of geothermal energy to support Germany's energy transition, there are substantial public concerns that pose challenges to the advancement of domestic geothermal projects. A central issue hindering public acceptance is the perception of potential environmental risks associated with geothermal energy use, such as earthquakes (induced seismicity), groundwater contamination, and surface changes. Compared to other technologies, geothermal energy is also often perceived as relatively prone to failure due to the complexity and unpredictability of subsurface conditions (Renoth et al. 2023). A nationwide acceptance survey conducted in 2024 indicates that only about 50% of respondents would be currently willing to have a geothermal plant located near their homes (AEE 2024).[5]

Initially, the deployment of geothermal energy in Germany did not provoke significant social opposition. However, this changed after seismic incidents, notably following a 2006 earthquake of magnitude greater than 3.4 in Basel, Switzerland. Since then, media coverage has increasingly highlighted the drawbacks of geothermal technology, overshadowing its benefits. This shift in narrative has led to the formation of numerous local citizen initiatives ("Bürgerinitiativen"), often citing earthquake risks as their primary concern. Furthermore, a nationwide association aimed at opposing geothermal developments was established, reflecting growing public resistance (Kunze und Hertel 2017).

Citizen initiatives have also expressed doubts about the efficiency and sustainability of geothermal energy. Criticism is particularly focused on the energy return on investment and the high fixed costs involved in constructing geothermal facilities. In some regions, such as Puchheim and Waghäusel, these concerns have culminated in referendums opposing geothermal projects (Kunze und Pfeiffer 2017). In Puchheim, over 75% of 7,000 participating voters opposed a geothermal energy project in 2018. The local citizen initiative cited concerns about water protection, ground movements, and potential structural damage from deep drilling. These fears were partly fueled by previous incidents in Poing, east of Munich, where several micro-earthquakes occurred in 2016 and 2017. Subsequent investigations, however, revealed that geothermal energy was not responsible for reported house cracks (BR24 2018).

Similarly, in 2023, over 72% of Waghäusel's citizens voted against using municipal land for a deep geothermal power plant. The opposition was driven by fears of induced earthquakes and scepticism toward the private company, Deutsche Erdwärme, which was set to lease the land from the city for the project (SWR Aktuell 2023).

2.5.2 Stakeholder involvement and communication strategies

The before-mentioned incidents underscore the importance of involving local populations in planning processes and communicating in a comprehensive and transparent manner. However, strategies may need to be tailored to specific regional contexts. In the case of Waghäusel, for instance, the project developer has in fact sought to involve the

[5] The acceptance of geothermal energy plants is slightly higher than that of wind energy. In the same survey conducted by the YouGov opinion research institute, which polled over 1,000 participants, only 42% of respondents expressed a positive attitude toward having a wind energy plant near their home.

local community by inviting the citizens' initiative and an interest group to a public information event. However, these groups ultimately declined to participate in the event (ITG 2022). Research generally suggests that projects that are "locally anchored" and benefit from previous geothermal experience while fostering extensive local dialogue tend to be more successful. In contrast, projects selected based purely on political and economic considerations, without local integration, face a greater risk of failure due to their disconnection from community needs (Chavot et al. 2018).

Effective communication about geothermal energy also necessitates careful attention to language. Distinguishing between terms like "hydraulic stimulation" and "fracking" is particularly important in public discourse and media coverage. This distinction is vital because the term "fracking" is often associated with significant ideological and environmental concerns, which can disproportionately impact public perception and discourse (Umweltbundesamt 2014). Therefore, clear and accurate terminology is essential to prevent misunderstandings and to foster informed discussions.

Moreover, communication campaigns should give the benefits of geothermal technology more public spotlight, particularly its role in enhancing energy independence. This aspect appears to resonate strongly with the public. Recent survey data in Germany show that over 60 percent of respondents consider independence from global energy markets and fossil fuel-exporting countries as their primary motivation for supporting geothermal heating (AEE 2024).

To address concerns about potential damages caused by induced seismicity, it can also be helpful to communicate that robust financial security mechanisms are already in place in Germany. A recent report by the Universität Mannheim highlights the availability of liability insurance for geothermal projects, which has so far proven sufficient to cover all reported damages. Moreover, the liability framework under German mining law (BBergG) ensures a strong legal foundation for compensating affected parties, including the presumption of causation (Bergschadensvermutung) in relevant cases. (Universität Mannheim 2024). Proactively sharing this information can help alleviate fears and build public confidence in geothermal projects.

A notable example of a successful communication strategy is the geothermal project in Trebur, Hessen.[6] At the project's inception, developers initiated a proactive public information campaign and established a stakeholders' forum, known as a Bürgerbeirat. This approach allowed for ongoing dialogue and collaboration with the local community. The developers also undertook their own scientific and technical evaluation of the project, which was transparent and accompanied by a set of recommendations and requirements they pledged to adhere to. Moreover, the initiative included a comprehensive project website and organized six public workshops. These workshops featured regional and international experts who engaged with the community to discuss potential risks and benefits, thereby fostering trust and informed decision-making (Frey et al. 2022a).

2.6 Economic Potential and Viability

Geothermal energy offers significant advantages for local value creation, as the energy comes from the region and therefore the added value remains in the region. This contributes to independence from external energy sources and supports the regional economy by creating jobs and supporting local businesses.

2.6.1 Geothermal Industry

The geothermal industry in Germany is young and relies partly on the know-how and experts from the oil and gas-industry. However, more and more companies offer specific services in the geothermal sector. Today, Germany's geothermal sector features a diverse range of companies specialising in exploration, drilling, technology development, and project operation. Daldrup & Söhne AG is a leading player in deep geothermal energy, known for its expertise in deep drilling and its ability to deliver comprehensive solutions, from project planning to operation. With numerous successful geothermal heating plants, Daldrup & Söhne has established itself as a key player in sustainable energy infrastructure. Erdwerk GmbH, based in Munich, focuses on feasibility studies and the development of geothermal power and heating plants, particularly in Bavaria's Molasse Basin, where it collaborates closely with municipalities and energy providers.

Geothermics Mainka Erdwärme & Brunnenbau GmbH is a major provider of geothermal drilling

[6] See Bürgerdialog Geothermie Groß-Gerau (DialoGGeo).

services, completing over 100,000 metres of boreholes annually and maintaining high industry standards. GeoDynamic GmbH (Oil Dynamics) specialises in advanced pump systems for geothermal projects, ensuring efficient resource extraction. The DMT Group offers comprehensive services for deep geothermal projects, including site exploration, geological modelling, and plant engineering, making it a crucial player in project success.

Stadtwerke München (SWM), Germany's largest geothermal operator, has implemented significant projects such as the Sauerlach plant and aims to make Munich's district heating system CO_2-neutral by 2040. Baker Hughes, a global leader in energy technology, provides high-temperature products and services for geothermal applications and collaborates with German institutions to advance the sector. Fraunhofer IEG, a research institution, plays a vital role in innovation, developing advanced geothermal technologies and integrating them into practical applications. Together, these organisations drive the development of Germany's geothermal sector.

However, the geothermal sector is facing typical challenges, such as costly deep drilling and seismic risks, which can lead to economic uncertainties. However, the investment environment for geothermal energy in Germany has improved, attracting both traditional and private investors due to increased significance of the heat transition and technological advancements that have enhanced the efficiency and profitability of geothermal projects, thereby reducing investment risks (NOERR 2024).

The BVG also offers a company register for geothermal services in Germany.7 Here, companies in Germany from more than 20 different categories are listed (i.e. facility technology, software, seismic monitoring, drilling equipment, etc.).

The value chain for shallow and deep geothermal energy can generally be described according to Figure 3 (Biernatzki und Stauss 2012).

The shallow geothermal sector is primarily shaped by craftsmen (plumbing, heating, air conditioning), planners, architects, drilling companies, and the heating industry (manufacturers of heat pumps/components). Deep geothermal projects require the collaboration of various disciplines such as geology, geophysics, power plant engineering, and drilling technology.

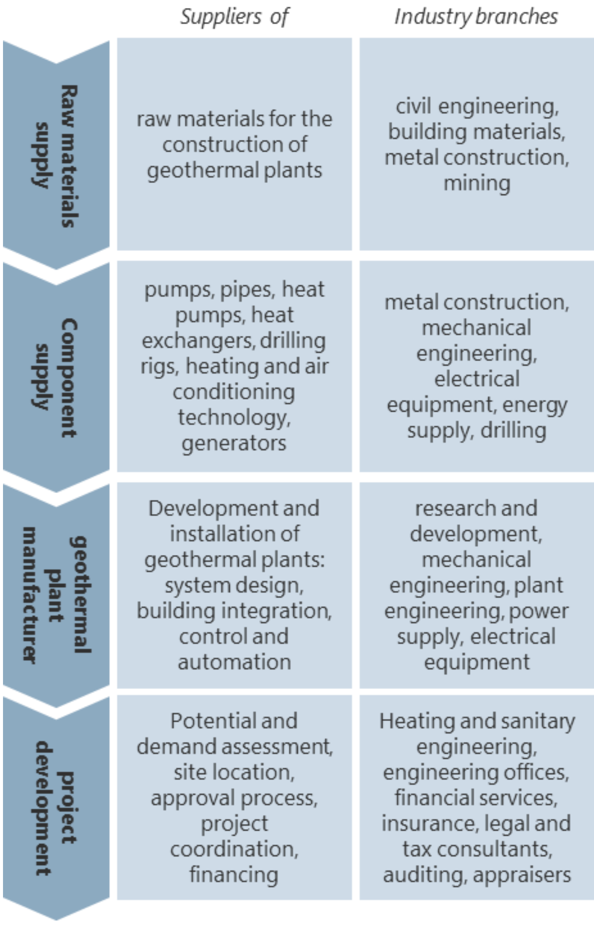

Figure 3: Value chain for geothermal energy (Biernatzki und Stauss 2012).

To achieve the proposed goals for geothermal energy in Germany, a significant increase in personnel across all areas is necessary. It was estimated, that for each megawatt of installed capacity, at least 5 to 10 people are required along the entire value chain, including R&D, education and training, administration, production, construction, and maintenance services (Born et al. 2022a). In the medium term, this translates to creating 50,000 new jobs in both academic and technical fields, with a long-term need for several hundred thousand jobs in the value chain.

2.6.2 Economic Viability

According to some studies, deep geothermal energy is competitive, assuming an output of approximately 20 to 22 MWth per doublet, resulting in a heat sales volume of 160,000 to 170,000 MWh annually. The production costs, depending on the required drilling

[7] Company register by the BVG: https://www.geothermie.de/firmen/firmenverzeichnis

depth, are currently around 1.8 to 2.2 million euros per MW of installed capacity. With a cost distribution of 60% capital costs, 10% demand-related costs, and 30% operational costs, the current heat generation costs are 25 to 30 euros per MWh (Bracke und Huenges 2022). Regarding the economic viability of geothermal energy, experiences with existing plants are quite optimistic, with production costs at 2.5-3 cents/kWh, comparable to fossil fuels. However, with plans for rapid expansion, significant investments of 50 to 60 billion euros are needed over the next decade (Born et al. 2022a).

To initiate further investments into geothermal energy, the economic viability can be increased when combining geothermal exploitation with lithium extraction, which is regarded to be a promising technology. Lithium-extraction during geothermal operation can also increase the economic viability (Weinand et al. 2023). According to some studies, geothermal plants could become cost-competitive in conjunction with lithium extraction (Alms et al. 2022; Weinand et al. 2023; BMWK 2024a). Further was shown, that the deployment of 33 deep geothermal plants in the URG, could provide enough lithium to produce about 1.2 million electric vehicle battery packs per year, equivalent to 70% of today‘s annual electric vehicle registrations in the European Union (Weinand et al. 2023). As of today, several research projects and start-ups try to further explore the possibilities of lithium extraction during geothermal operation, for example Vulcan Energy[8], EnBW[9] or the research projects UNLIMITED, Li-FLUIDS.

2.6.3 Funding Schemes

Germany provides a comprehensive range of funding opportunities to support the development of geothermal energy systems. Key programmes include the Federal Funding for Efficient Heat Networks (BEW), the Federal Funding for Energy-Efficient Buildings (BEG), and several targeted KfW loan and grant programmes, alongside additional funding options offered by individual German states.

The BEW[10] promotes the expansion and modernisation of heat networks, placing a strong emphasis on integrating renewable energy sources such as geothermal energy. It is structured into four main components: the first module supports feasibility studies and planning processes, while the second module provides funding for the construction or modernisation of heat networks that incorporate renewable energy systems, including deep geothermal solutions.

The BEG[11], on the other hand, focuses on energy-efficient buildings and retrofits, offering financial support for geothermal systems under several modules. The BEG EM (Individual Measures) provides subsidies for the installation of geothermal heat pumps, while the BEG WG (Residential Buildings) and BEG NWG (Non-Residential Buildings) support comprehensive energy-efficient renovations or new constructions that integrate geothermal technologies.

Complementing these programmes, the KfW Bank[12] provides financial incentives through specific schemes. KfW 270 focuses on renewable energy production, supporting the generation of heat and electricity through geothermal energy.

As mentioned in 2.4.2, the German government is also working with high priority on the development of a government-supported insurance solution to mitigate the exploration risk associated with deep geothermal drilling. This initiative is being pursued in collaboration with the development bank KfW (Solarserver 2024).

Beyond these national initiatives, individual German states offer tailored funding opportunities to promote geothermal projects, reflecting regional priorities and needs. These additional funding options can be explored in detail through the Federal Funding Database[13].

2.7 Geothermal Projects in Germany

In Germany, there are many geothermal projects that demonstrate the advantages of geothermal energy and the possibilities to overcome certain challenges associated with geothermal energy usage. In the following chapter, two different projects were chosen and described, which are remarkable towards the public acceptance of a geothermal project located in

[8] Vulcan Energy: https://v-er.eu/
[9] EnBW project on lithium extraction: https://www.enbw.com/press/research-project-lithium-production-in-geothermal-energy-plant.html
[10] „Bundesförderung effiziente Wärmenetze“ (BEW): https://www.bafa.de/DE/Energie/Energieeffizienz/Waermenetze/Effiziente_Waermenetze/effiziente_waermenetze_node.html
[11] Bundesförderung effiziente Gebäude (BEG): https://www.bafa.de/DE/Energie/Effiziente_Gebaeude/effiziente_gebaeude_node.html
[12] KfW bank: https://www.kfw.de/kfw.de.html
[13] Federal Funding Database: https://www.foerderdatenbank.de/FDB/DE/Home/home.html

an urban area (Potsdam) and the application of a new technology (Geritsried) that is related to innovations currently discussed in Japan.

2.7.1 Geothermal Project "Heinrich-Mann-Allee" Potsdam

The deep geothermal energy project of "Energy and Water Potsdam (EWP)" on Potsdam's Heinrich-Mann-Allee is a nationwide showcase project of the heating transition in Germany and a first major project of its kind in Potsdam. EWP has invested around 20 million euros in this project. The wells were drilled to a depth of approximately 2.000 meters to generate more than 4 MW of thermal power. Drilling for Potsdam's first geothermal plant began in mid-December 2022 (Tagesspiegel 2024). The deep drilling has been successfully completed in 2023, and the geothermal plant is completed in winter 2024. A test operation in Heinrich-Heine-Allee was already successful and the system is expected to go into regular operation in spring 2025 (Stadtspuren 2024).

In Germany, there is a legally required public display for every zoning plan, which allows for the exchange of objections and questions towards the land use of an area. The draft of the legal plan no. 104 "Heinrich-Mann-Allee/Kolonie Daheim" and concrete expert opinions have therefore been published on "Potsdam.de". In addition, the city council decided to hold a citizen meeting in 2018, which included a guided walk around the site and a subsequent discussion about the legal zoning plan.[14]

Based on a general preliminary assessment by the Brandenburg State Office for Mining, Geology and Raw Materials (LBGR), it was determined that there is no obligation to carry out an environmental impact assessment for the project (LBGR 2022). According to this assessment, the state-of-the-art construction and operation of a deep geothermal project, along with the operator's emission reduction measures, are unlikely to cause significant adverse environmental impacts based on the Environmental Impact Assessment Act (UVPG).

To enhance acceptance among the public and local policymakers, EWP leveraged the high public interest in deep geothermal energy, with notable guests like Olaf Scholz, Annalena Baerbock, and Jörg Steinbach (EWP 2024). Generally, there was no general obstruction against the project from local residents.

At the beginning of the well tests were performed, which indicated much higher output of the future geothermal plant than originally planned, due to a high potential of deep geothermal energy at the site. This will make it possible not only to supply the district with heat, but also to feed it into Potsdam's heating network. In the future, the plant will supply up to 6,900 households with geothermal energy from the depth. Part of the project is the creation of an inner-city, attractive residential location with a commercial and service component in the immediate vicinity of deep geothermal energy. ProPotsdam GmbH will build 700 –750 apartments in this area by 2025, which are to be supplied 100% by geothermal energy.

Project Manager Tristan Grüttner of EWP states that it is unprecedented in Germany to endeavour to generate heat directly within the neighbourhood where it is required. However, this also led to certain requirements during the drilling and construction work such as noise protection, which have nevertheless not led to any further problems or complaints. According to Eckard Veil, Technical Managing Director of EWP, one of the biggest challenges in the project was the enormous time pressure in the approval process, due to subsidies that are only valid for a certain time. Moreover, prior to the commencement of drilling a significant risk existed, as no geothermal drilling had previously been conducted in the vicinity, rendering the potential success of the project uncertain.

EWP wants to implement six deep geothermal energy projects as part of their heat targets by 2030 (EWP 2025). The project "Heinrich-Mann-Allee" was therefore only the beginning of several geothermal energy projects in Potsdam. According to Tristan Grüttner, geothermal energy could cover up to 40% of Potsdam's energy needs in the future.

2.7.2 Geothermal Project "Geretsried"

The geothermal power plant "Geretsried-Nord", located in Bavaria, is a project of significant importance for Germany, as it exemplifies both the potential and challenges of harnessing geothermal energy. Initially, the project encountered substantial setbacks, including two unsuccessful drilling campaigns. However, it is now poised to become the

[14] Citizen participation Potsdam: https://buergerbeteiligung.potsdam.de/content/beteiligung-zum-entwurf-des-b-plan-104-h-mann-allee-kolonie-daheim

first commercial geothermal power plant of its kind by utilizing highly innovative technology.

The planning for the original project began in early 2000, with plans to use a doublet system to extract thermal water from the Malm for electricity and heating. Initial seismic measurements indicated promising results, which led to the first deep geothermal well drilled in 2013 to a depth of 6,036 meters. At that time, it was one of the deepest boreholes in Europe. However, the drilling was found to be uneconomical, resulting in a temporary suspension of the project (Tiefe Geothermie 2025).

In 2017, a second attempt was made with a sidetrack drilled to 5,700 meters. Unfortunately, this attempt also was unsuccessful, eventually resulting in the dismantling of the drilling rig and the dissolution of Energie Geretsried GmbH, the company formed to execute the project (ThinkGeoEnergy 2017). Both drilling efforts, which cost over €30 million in total, did not yield sufficient hot hydrothermal water to achieve economic viability (Eavor Technologies 2020).

Despite these costly failures, the previous drilling efforts provided valuable data on geological conditions, including insights into the limestone and thermal conductivity. Notably, the data confirmed a temperature gradient suitable for the economic use of Eavor Loops, facilitating the generation of electricity and heat for district heating and industrial processes. This realization led to a strategic shift in 2020, with Enex Power Germany and the Canadian Eavor Technologies entering into a letter of intent to develop Eavor-Loop™ projects within Bavaria's existing geothermal concession area (Eavor Technologies 2020).

The Eavor-Loop™ technology represents a breakthrough in geothermal energy, utilizing closed-loop systems that harness geothermal heat without relying on thermal water. This method allows for energy extraction from deep rocks, overcoming the limitations faced by traditional geothermal systems. According to geoscientists' assessment, if the new Eavor-Loop™ technology performs as expected, deep heat could be extracted almost anywhere in Germany, with the exception of the Upper Rhine Graben and other earthquake-prone areas (Ludwig Knoll 2023).

As of 2024, the company reports that the Eavor-Loop™ project in Geretsried is progressing as planned. The initial drilling loops have been completed and sealed using Rockpipe technology. Leveraging previously obtained geological data, the project developers were able to accurately estimate the plant's production potential. The facility is expected to generate enough energy to meet the heating needs of 200,000 households (Eavor Technologies 2020).

Eavor's total investment is expected to reach €350 million, with more than one third already secured from EU funding. This includes a EUR 45 million loan from the European Investment Bank and a EUR 91.6-million grant from the EU Innovation Fund (ThinkGeoEnergy 2024b).

3 Status Quo in Japan

Japan is one of the most geologically active countries in the world, situated along the Pacific Ring of Fire. This region is characterised by intense tectonic activity, including frequent earthquakes, volcanic eruptions, and high heat flow from the Earth's interior. As a result, Japan sits on some of the world's most abundant geothermal resources, which is the world's third-largest potential supply of the energy resource, behind only the United States and Indonesia, according to the Japan Organization for Metals and Energy Security (JOGMEC). These estimated reserves are equivalent to roughly 23 nuclear reactors (Johnston 2024).

3.1 Geothermal Systems, Regions and Potentials

The country is home to over 110 active volcanoes, which contribute significantly to geothermal heat near the surface, spanning from Hokkaido in the north to Kyushu and Okinawa in the south. Japan's unique geological setting, at the convergence of four major tectonic plates—the Pacific, Philippine Sea, Eurasian, and North American plates—further enhances its suitability for geothermal activity. This geological activity has also resulted in the formation of numerous naturally occurring hot springs (*onsen*), which are surface manifestations of the country's rich geothermal resources.

Hot springs have played a central role in Japanese culture for centuries, serving purposes of bathing, health, and recreation. With approximately 28,000 hot springs, Japan is one of the richest nations in terms of hydrothermal surface activity (Yousefi und Mortazav 2018). *Onsen* culture remains deeply embedded in the lives of local residents and continues to thrive as a cultural and recreational tradition.

Beyond the cultural significance of hot springs, Japan has been at the forefront of geothermal energy development. The country's first experimental geothermal power plant began operation in 1925, and commercial-scale exploitation followed in 1966 with the Matsukawa geothermal power plant (GRSJ 2020). A significant expansion of geothermal energy capacity occurred after the 1973 oil crisis, as Japan sought to diversify its energy sources.

In Japan, geothermal systems are classified based on geological conditions, which reflect the diverse geological settings in the country. According to different studies (Sumi 1978; Tamanyu und Sakaguchi 2003; Tamanyu und Wood 2003; Jalilinasrabady und Itoi 2013; Stelling et al. 2016; Xu et al. 2006; JOGMEC 2025a), the following geothermal systems can be described for Japan:

Volcanic Geothermal Systems are predominantly found in Japan due to its position along the Pacific Ring of Fire. They are associated with active or recently active volcanoes and are characterized by high temperatures (for example Kyushu and Tohoku region). The heat source for these systems is

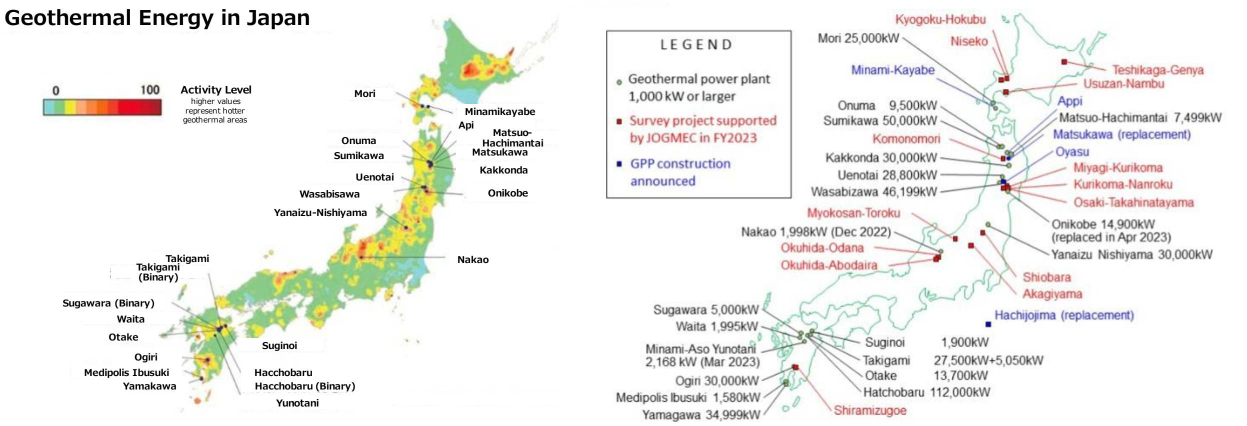

Figure 4: Geothermal Potential in Japan (left), power plants and ongoing projects in Japan as of December 2023 (right).

typically magma or hot rocks beneath the earth's surface, and they often feature surface manifestations like fumaroles, hot springs, and geysers.

Non-Volcanic Geothermal Systems occur in regions without recent volcanic activity (for example specific locations in the Tohoku region). They are often linked to deep-seated faults or fractures that facilitate the movement of heat from the earth's interior. These systems can vary in temperature and are used for both direct heating use and power generation depending on their thermal characteristics.

Sedimentary Basin Geothermal Systems are found in sedimentary basins where heat is trapped beneath layers of sedimentary rocks (for example Onikobe caldera). The geothermal gradient in these systems can be relatively high, making them suitable for direct use applications. They are generally lower in temperature compared to volcanic systems.

In Fractured Rock Geothermal Systems, the geothermal reservoir is located in fractured rock formations. The fractures allow for the circulation of water, which is heated by the earth's internal heat. These systems can be found both in volcanic and non-volcanic regions and are often tapped using enhanced geothermal systems (EGS) technology.

3.1.1 Regions and reservoirs

The major geothermal regions in Japan include Hokkaido, Tohoku, Chubu, and Kyushu (Figure 4). The areas in Japan are characterised by volcanoes and frequent seismic activity, making them rich in geothermal resources. Among these, the Tohoku region (northern Honshu) and Kyushu (in the south-west of Japan) possess the most favourable geological conditions for geothermal energy development.

Kyushu

With its abundant volcanoes, hot springs, and geothermal reservoirs, Kyushu leads Japan in geothermal power generation. Geothermal energy in the region is utilised for various purposes, including electricity production, tourism, and direct heating applications.

Kyushu's geological activity is driven by its location, where the Philippine Sea Plate subducts beneath the Eurasian Plate. This tectonic interaction results in high underground heat flow, creating extensive geothermal reservoirs. Prominent volcanoes associated with this geothermal activity include Mt. Aso (Kumamoto Prefecture), Mt. Unzen (Nagasaki Prefecture), Mt. Kirishima (spanning Kagoshima and Miyazaki Prefectures), and Sakurajima (Kagoshima Prefecture).

Kyushu is home to several large-scale geothermal power plants. The Hachobaru Geothermal Power Plant, located in Oita Prefecture, is the largest in Japan, with a capacity of 110 MW. Beyond electricity generation, Kyushu's geothermal energy is also harnessed for innovative applications, such as heating greenhouses for cultivating vegetables and flowers.

Tohoku

The Tohoku Region, located in northeastern Honshu and renowned for its abundant geothermal resources, active volcanoes, and high heat flow, is another prime location for geothermal energy development. The region hosts some of Japan's largest geothermal power plants and numerous hot springs, which contribute to tourism and support local industries.

Tohoku lies at the tectonic boundary where the Pacific Plate subducts beneath the Eurasian Plate. This tectonic activity generates significant underground heat, creating geothermal reservoirs. Areas such as Akita, Iwate, and Fukushima are particularly rich in geothermal potential, with several operational geothermal power plants. The region also boasts a high geothermal gradient, where underground temperatures rise rapidly with depth, facilitating efficient access to geothermal energy for electricity generation and direct heating.

Tohoku is home to several prominent volcanoes associated with geothermal activity, including Mt. Hakkoda and Mt. Osorezan (Aomori Prefecture), Mt. Akita-Komagatake (Akita Prefecture), Mt. Bandai (Fukushima Prefecture), and Mt. Zao (spanning Miyagi and Yamagata Prefectures). Hydrothermal reservoirs in these areas naturally trap hot water and steam, making them ideal for energy development.

The history of geothermal energy in Tohoku is long-standing. The Matsukawa Geothermal Power Plant in Iwate Prefecture, operational since 1966, was Japan's first geothermal power plant. Most geothermal resources in Tohoku are concentrated in the mountain range that runs north to south through the region's interior, where the majority of its geothermal power plants are located.

Hokkaido

While less developed in geothermal power generation compared to Kyushu and Tohoku, Hokkaido, Japan's northernmost prefecture, holds significant untapped potential for geothermal energy.

The region is home to several active volcanoes that contribute to geothermal heat near the surface. Notable volcanoes associated with geothermal activity include Mt. Tokachidake (Daisetsuzan National Park), Mt. Asahidake (Hokkaido's highest peak), Mt. Meakan (Akan volcanic region), and Mt. Usu and Mt. Tarumae (near Lake Toya). These volcanic systems support multiple hydrothermal reservoirs containing underground hot water and steam, which can be utilised for power generation or direct heating applications. Key areas with geothermal potential include Daisetsuzan National Park, the Akan volcanic region, and Noboribetsu near Lake Toya.

Despite its geothermal potential, Hokkaido has seen limited development, with only a few small-scale geothermal power plants currently in operation. Progress has been slow due to environmental concerns, particularly the impact on national parks, and regulatory restrictions.

Chubu

The Chubu Region, located in central Honshu, Japan, is home to numerous hot springs, geothermal reservoirs, and has significant potential for geothermal power generation. Although Chubu's geothermal energy development is less advanced compared to Kyushu and Tohoku, it has several promising geothermal fields, particularly in Nagano and Gifu Prefectures.

Geologically, the Chubu Region is highly active, as it lies at the intersection of the Eurasian, Pacific, and Philippine Sea Plates. This tectonic interaction results in high underground heat flow, creating ideal conditions for geothermal activity. Prominent volcanic features in the region include Mt. Ontake (spanning Nagano and Gifu Prefectures), Mt. Norikura (Gifu and Nagano Prefectures), and Mt. Asama (Nagano Prefecture), all located along the Northern Alps Mountain range. These volcanoes contribute to the region's high geothermal gradient, where temperatures increase rapidly with depth.

Chubu is rich in hydrothermal reservoirs, where underground hot water and steam can be harnessed for energy production. However, geothermal energy development in the region has been limited. Restrictions on development in national parks and tourist areas have hindered progress, and as a result, no large-scale geothermal power plants currently operate in Chubu.

3.1.2 Geothermal Potential

Despite its significant potential and long-standing history, geothermal energy contributed only 0.3% to Japan's total energy mix in the fiscal year ending April 2023, according to a recent report by the Ministry for Economy, Trade and Industry. In comparison, solar accounted for 9.8%, hydropower for 7.6%, and onshore and offshore wind combined for 1.1% (Johnston 2024).

However, there is a large gap between Japan's resource potential and its actual exploitation. As of December 2024, Japan's geothermal power generation capacity accounted to only 0.6 GW, representing just 2% of its estimated potential (ThinkGeoEnergy 2025). This places Japan 10th globally in terms of installed geothermal capacity, with its relative ranking declining as other countries put a stronger focus on geothermal energy development.

A survey conducted by the Ministry of the Environment further breaks down Japan's geothermal potential. It estimates a capacity of 23 GW for reservoirs with temperatures exceeding 150°C, 1.1 GW for reservoirs between 120°C and 150°C, and 8.5 GW for lower-temperature resources ranging from 53°C to 120°C (FY2010 Renewable Energy Introduction Potential Survey Report) (MoE 2011).

In 2023, the total installed capacity electricity amounts 499.4 MWe and 2,086.6 MWth for direct use of geothermal energy, according to the country report by the IEA (Yasukawa 2024).

The Hokkaido region stands out with enormous geothermal potential compared to other regions in Japan. Similarly, the Tohoku, Hokuriku, Chubu, and Kyushu regions also possess significant geothermal resources. The Tokyo region, while showing comparable potential, primarily reflects the volcanic islands located far to the south within Tokyo Prefecture, which lie on the Philippine Sea Plate.

3.2 Policy Framework

3.2.1 Government Strategy

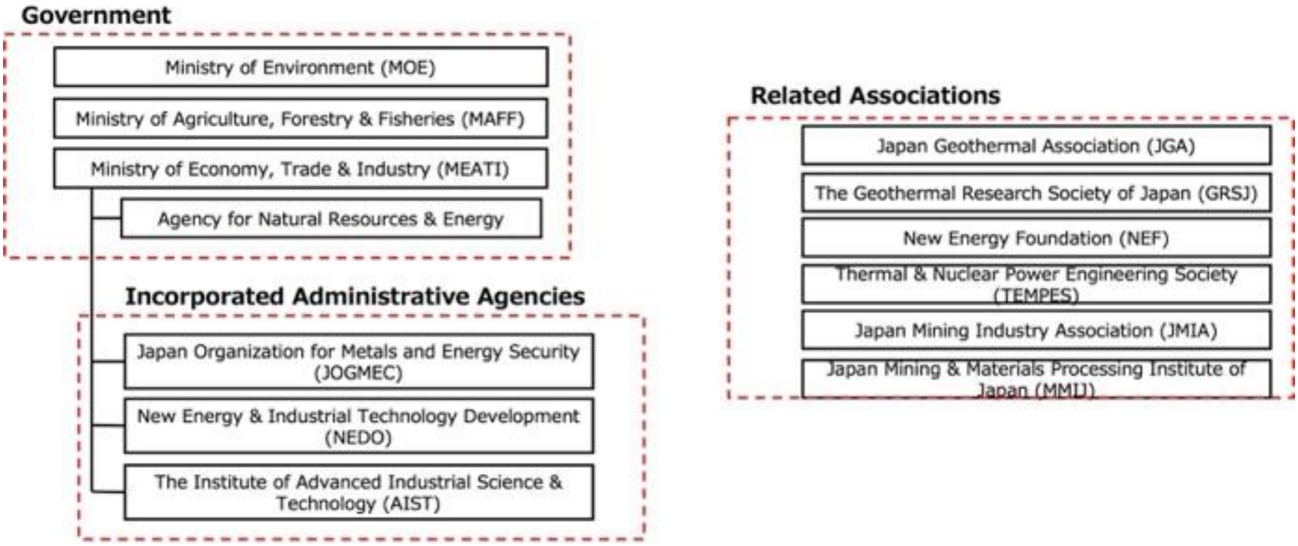

Figure 5: Ministries and organizations involved in geothermal policy (JOGMEC 2025d).

The Japanese government's 6th Energy Basic Plan sets a target of achieving 1.5 GW of geothermal power generation capacity by 2030 (ANRE 2021). However, based on the current progress, achieving this target seems unlikely. The subsequent 7th Energy Basic Plan, introduced in February 2024, sets a more ambitious goal of generating up to 25 TWh of geothermal power annually by 2040 (ANRE 2025).

As written in Chapter 3.1., Japan's geothermal development initially accelerated during the oil crisis of 1973 and continued until 1997. During this period, a nationwide survey of potential geothermal sites led to the operation of seven new geothermal power plants in the 1990s. However, interest in geothermal power declined as thermal and nuclear power plants became more prominent.

Following the 2011 earthquake, geothermal energy regained attention as a reliable base power source. This revival was supported by the introduction of the Feed-in Tariff system, the transfer of promotional responsibilities from NEDO (New Energy and Industrial Technology Development Organization) to JOGMEC (Japan Organization for Metals and Energy Security), and the deregulation of the Natural Parks Law.

The Ministry of the Environment is now advancing a geothermal development acceleration package (MoE 2024). Leveraging data from NEDO's geothermal surveys (up to 2009) and JOGMEC's Leading Resource Studies (since 2009), METI and JOGMEC have launched several "geothermal frontier projects" in undeveloped areas, including natural parks with high geothermal potential.

Moreover, in April 2025, METI launched its first public-private council on next-generation geothermal technologies. This initiative marks a significant step toward the early commercialisation of advanced geothermal systems, with a target timeline set for the 2030s. The council focuses on fostering innovation in closed-loop systems, EGS, and supercritical geothermal technologies, supported by METI's alignment of funding strategies through the Green Innovation Fund and JOGMEC investments (Denki Shimbun 2025).

Recently, the development of geothermal energy in Japan enjoys strong political backing. Ahead of the October 27 election for the 435-seat Lower House, nearly 100 parliamentary members joined a group advocating for expanded geothermal energy use (Johnston 2024). This group includes significant representation from both the ruling Liberal Democratic Party and Komeito, which account for over half its members, as well as broad support from major opposition parties such as the Constitutional Democratic Party of Japan, the Democratic Party for the People, and Nippon Ishin no Kai. With their endeavors they are recognizing the potential of geothermal energy to drive regional revitalization, which is particularly significant as geothermal resources are predominantly found in rural areas, offering these communities opportunities for economic growth and development.

In order to achieve the 2030 target, Agency for Natural Resources and Energy, which plays an important role for Japan's geothermal policy, insists on the necessity to significantly strengthen the current initiatives as follows (ANRE 2024).

It is important to establish a system for managing the progress of individual projects and following up on them, involving the relevant government ministries and agencies as figure shows.

Given that the projects that have been successfully developed to date have been ones in which the operators have made use of the results of NEDO's drilling surveys (potential surveys), in order to further reduce development risks and development costs, JOGMEC should promote initiatives in which it itself carries out exploration and drilling (including fumarole testing) in new development areas and provides the results to the operators.

In terms of specific development, the Ministry of Economy, Trade and Industry, the Ministry of the Environment, and JOGMEC should work together to ensure that the relevant licensing and approval processes, including regulations related to national and quasi-national parks, and the process of gaining the understanding of local residents, progress smoothly, leading to the early commencement of operations in harmony with the local community.

At the same time as forming projects for conventional geothermal power generation, in order to make the most of geothermal power generation potential, it is also necessary to promote discontinuous innovation and develop next-generation geothermal power generation technology.

The committee on Resources and Fuels, which is in charge of geothermal policy, proceeded the discussion as the above points. The strategy for geothermal policy in Japan is an initiative that responds to these four issues.

JOGMEC, which operates under Japan's Ministry of Economy, Trade and Industry (METI), is a government organisation that aims to ensure a stable and sustainable energy supply, including geothermal resources. It provides financial support to mitigate the high risks and costs associated with geothermal exploration and feasibility studies. JOGMEC is actively involved in scientific research and technological innovation, working with research institutions to improve geothermal exploration techniques and provide resource assessment reports relevant to private investment. The organisation promotes environmentally responsible geothermal development by promoting small-scale (1-5 MW) plants near hot springs and efficient binary cycle power plants suitable for lower temperature resources. As Japan seeks to increase its energy security and reduce carbon emissions, JOGMEC's efforts will be essential in unlocking the country's vast geothermal potential (JOGMEC 2025b).

The Agency for Natural Resources and Energy (ANRE), which belongs the Ministry of Economy Trade and Industry (METI) is proposing several measures to promote geothermal energy in Japan and accelerate installed capacity. Key actions include reducing development risks and costs by expanding direct exploration and drilling by JOGMEC, as well as increasing subsidies and debt guarantees. To speed up project implementation, ANRE could promote coordination with local communities and authorities to simplify licensing, particularly in national parks. ANRE also proposes to support the development of innovative technologies to expand the potential areas for geothermal energy. Finally, further actions could include the training of geothermal engineers, the establishment of model districts, and the promotion of public participation through local outreach. (cit)

3.2.2 Legal framework

Japan's geothermal policy is governed by a framework of laws, regulations, and policies that aim to balance energy development, environmental protection, and local interests. Figure 7 shows the ministries and organizations involved in geothermal policy making. The key regulations are listed in the following:

The Hot Spring Act[15], overseen by the Ministry of the Environment, regulates the extraction and use of geothermal hot water (typically less than 500 m) to protect hot spring resources. It requires permits from local governments and the Hot Springs Council, which is composed of representatives from the hot spring industry, for drilling activities near hot springs.

This act is a major barrier to geothermal development, as *onsen* owners often fear that

[15] Hot Spring Act (in English), https://www.japaneselawtranslation.go.jp/ja/laws/view/4791

geothermal power plants may affect hot spring temperatures and water flow. Regulatory requirements vary by prefecture. For example, in Nagasaki Prefecture, developers must obtain consent from all hot spring source owners within a 1 km radius before proceeding. Additionally, the influence of the Hot Springs Council, which includes members from the hot spring industry, adds another layer of complexity to the approval process.

Approximately 80% of Japan's geothermal resources are located within national parks or protected areas. The Natural Park Act[16], also led by the Ministry of the Environment, imposes strict regulations that limit large-scale geothermal development in Special Protection Zones.

In 2012, the government relaxed some restrictions, allowing limited geothermal development in Class 2 and Class 3 Special Zones of National Parks. However, these changes have not fully addressed the barriers to development, as large-scale projects remain prohibited in Special Protection Zones, leaving developers with limited options.

The Electricity Business Act[17], administered by the Ministry of Economy, Trade and Industry (METI), regulates geothermal power plants as part of the broader electricity industry. It requires government approval for large-scale geothermal projects exceeding 2 MW and sets stringent safety and operational standards for geothermal facilities.

The Environmental Impact Assessment Law[18] mandates developers to conduct surveys, predictions, and assessments of the environmental impact of projects that may significantly affect the natural environment. Developers must disclose the results and seek public and local government feedback to improve project plans from an environmental conservation perspective. For geothermal power generation, an environmental assessment is mandatory for facilities with an output of 10,000 kW or more. For facilities with outputs between 7,500 kW and 10,000 kW, assessments are determined on a case-by-case basis. In some areas, local regulations require assessments for facilities with outputs as low as 5,000 kW. These assessments are often time-consuming, significantly lengthening the lead time for geothermal development.

Japan's geothermal energy sector faces several significant challenges due to the lack of a dedicated geothermal energy law and the complexity of its existing regulatory framework.

One of the primary issues is the lack of clarity around ownership rights for geothermal resources. Currently, it is possible to drill wells freely on private land, which can lead to conflicts. For example, if a new geothermal well is drilled near an existing power plant, it could reduce the steam pressure at the operating plant, making power generation impossible. Without clear regulations addressing ownership and resource management, unregulated development poses a risk to the sustainable use of geothermal resources.

Another challenge is the overlap and complexity of existing regulations. Developers must navigate multiple laws, such as the Hot Spring Act, Natural Park Act, and Environmental Impact Assessment Law, each overseen by different ministries. These regulations partly hinder each other, creating inefficiencies and delays. For instance, while the Hot Spring Act aims to protect *onsen* resources, it lacks provisions specific to geothermal energy development. Meanwhile, the Natural Park Act imposes strict restrictions on development in national parks, where the majority of Japan's geothermal resources are located.

These challenges, combined with the lengthy timelines required for environmental impact assessments and local resistance from *onsen* owners, have hindered the growth of Japan's geothermal energy sector.

However, Japan has taken steps to boost geothermal development by addressing regulatory barriers. While 80% of the country's geothermal potential lies within national or quasi-national parks, strict environmental regulations had long made drilling in these areas nearly impossible. Following increased calls for renewable energy use after the 2011 Fukushima disaster, the government introduced new directives in 2015, easing restrictions on drilling in national parks and paving the way for greater geothermal energy utilization (Johnston 2024).

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16 Natural Park Act (in English), https://www.japaneselawtranslation.go.jp/ja/laws/view/3060

17 Electricity Business Act (in English), https://www.japaneselawtranslation.go.jp/ja/laws/view/3355

18 Environmental Impact Assessment Act (in English), https://www.japaneselawtranslation.go.jp/ja/laws/view/3375

3.3 Research and Development

3.3.1 Research funding programmes

Japan's government is actively funding next-generation geothermal power technologies through the New Energy and Industrial Technology Development Organization (NEDO). NEDO is a public management organisation that promotes research, development, and the deployment of industrial, energy, and environmental technologies.

As part of its efforts, NEDO has launched the funding programme *"Research and Development for the Expansion of Geothermal Power Generation"*.[19] This programme aims to accelerate the expansion of geothermal power generation by focusing on innovative technologies, particularly supercritical geothermal resources, which are gaining attention as a next-generation energy solution. The programme is structured around three key objectives:

– Expanding Geothermal Resource Potential
– Reducing Power Generation Costs
– Coexistence with Local Communities and Environmental Conservation

In addition to NEDO's initiatives, JOGMEC is also supporting geothermal research and development programmes. To help achieve the government's target of 1% geothermal power generation in Japan's energy mix by FY2030, JOGMEC is providing financial and technical support for projects aimed at discovering and developing geothermal resources with a total capacity of 1 GW. This support includes assistance for high-risk exploration and feasibility studies, ensuring that promising projects receive the resources needed to advance.

3.3.2 Current research topics

The research and development programs for geothermal energy in Japan are primarily led by NEDO and JOGMEC. NEDO focuses on three key research topics to expand and enhance geothermal power generation:

Supercritical geothermal resource technology development: Research on the resource assessment in model fields and development of deep geothermal exploration methods.

Technology development for advanced utilization of geothermal power generation: Development of a power generation facility management method and development of reservoir management techniques.

Development of technology for environmental conservation measures: Development of alternative methods for meteorological surveys / atmospheric diffusion prediction methods and development of an IoT hydrogen sulfide monitoring system.

JOGMEC complements NEDO's efforts by focusing on technology development in the following research topics.[20] The latest developments in each field are briefly described:

Geothermal Reservoir Exploration Technology: JOGMEC developed compact and lightweight magnetotelluric (MT) survey equipment using Magneto Impedance (MI) sensors, reducing the total weight from ~30 kg to ~12 kg. A new C3 prototype, built in 2023, aims to improve performance in higher frequency ranges and undergoes field testing since 2024.

Geothermal Reservoir Drilling Technology: JOGMEC is developing Enhanced Geothermal Systems using supercritical CO_2 as a heat transfer fluid in non-hydrothermal areas. Lab tests confirmed the potential of a CO_2-water hybrid fracturing method, with field demonstrations planned for 2025 and eventual pilot-scale deployment after 2035.

Geothermal Reservoir Evaluation and Management Technology: At the Yanaizu-Nishiyama geothermal power plant, a river water injection project helped stabilize steam output and prevent acidification. The test was conducted without inducing major seismicity, using a "Traffic Light System" to manage micro-seismic risk. It is Japan's first successful implementation of this approach.

3.4 Technical and Economic Challenges

3.4.1 Technology and Reservoir Operation

The Japanese government considers next-generation geothermal energy critical for accelerating the expansion of geothermal power generation. Key

[19] NEDO R&D for Innovative Technologies Applied to Geothermal Exploration and Exploitation: https://www.nedo.go.jp/english/activities/activities_ZZJP_100198.html

[20] JOGMEC R&D website: https://www.jogmec.go.jp/geothermal/technology_001.html

focus areas include supercritical geothermal power generation and emerging technologies like the closed-loop method.

Between 2018 and 2020, NEDO conducted surveys to identify areas with estimated supercritical geothermal resources. Since 2021, research at four selected locations has focused on resource volume assessments using simulations, as well as the development of technologies, business models, and other components necessary for commercialisation.

These research and development efforts aim not only to improve production and facility utilisation rates for next-generation geothermal technologies but also to deliver broader benefits. Innovations in exploration, drilling, and reservoir evaluation techniques are expected to enhance conventional geothermal resource development, creating a ripple effect across the entire geothermal energy sector.

Looking ahead, NEDO plans to prioritize verifying supercritical geothermal technologies and advancing support for emerging methods like the closed-loop system. Meanwhile, JOGMEC plans to focus on applying these technologies to next-generation geothermal development while continuing to drive improvements in conventional resource development.

The Japanese government classifies geothermal energy into two categories and provides tailored programs for each:

Conventional Geothermal: The government aims to further promote geothermal development currently at the survey stage. JOGMEC will conduct initial surveys in target areas and support private-sector entry into the geothermal market. To facilitate project promotion, a project follow-up system involving government ministries, businesses, and local governments will be established. This system will address challenges such as rising drilling costs, environmental impact assessments, construction expenses, and regulatory and permit-related issues.

Next-Generation Geothermal: To advance next-generation geothermal technologies, the government will strengthen feasibility and economic assessments and promote domestic demonstrations. A public-private council will be established to encourage private-sector participation and accelerate commercialisation efforts for innovative geothermal systems.

3.4.2 Exploration Risk

Large- and medium-scale geothermal power generation projects face significant development risks and costs due to the inherent uncertainties of geothermal resource exploration. A major risk is that commercially viable reservoirs may not be discovered even after extensive exploration and drilling. Additionally, gaining local support for such activities can be challenging, further increasing the risks and costs associated with new development projects.

To mitigate these risks, JOGMEC provides subsidies and debt guarantees to operators. Since fiscal year 2020, JOGMEC has also undertaken "prospecting surveys," where it conducts exploration and drilling activities directly. The results of these surveys are shared with operators, reducing the financial burden on private companies and encouraging investment in geothermal projects.

However, several issues persist. Exploration and drilling during new development projects remain costly and risky, leading to delays in the development of new sites. While JOGMEC's "Leading Resource Survey" has been instrumental, it primarily focuses on surface surveys rather than drilling, which limits its effectiveness in reducing development risks.

To address these issues, the Japanese government is implementing a new initiative to enhance resource exploration. JOGMEC will expand its efforts to conduct exploration and drilling activities in new development areas. By providing detailed survey results to business operators, this initiative aims to reduce the risks and costs associated with geothermal development.

3.4.3 Public Acceptance

Despite Japan's significant potential for geothermal power generation, development has often been hindered by local resistance, particularly from hot spring owners near proposed projects. This resistance is largely driven by a lack of understanding of geothermal energy and its impacts. To accelerate the adoption of geothermal power, addressing public acceptance and fostering trust among local communities is crucial.

3.4.4 Barriers and solutions

Seismic concerns, which are often a significant issue in other countries considering geothermal power, are notably less of a concern in Japan. This is perhaps because Japan, as an earthquake-prone nation, has long adapted to seismic activity as part of its natural environment.

Still, Japan's geothermal energy development faces unique challenges regarding seismicity due to the country's position along the Pacific Ring of Fire, where natural seismic activity is frequent. This high baseline of natural earthquakes often makes it difficult to distinguish induced seismic events (for example caused by geothermal operation) from natural ones, potentially complicating public perception of geothermal projects (H. Asanuma et al. 2012). However, Japan's advanced seismic monitoring networks and robust building codes, developed to withstand frequent natural earthquakes, provide a strong foundation for mitigating the impacts of induced seismicity (Buijze et al. 2019). Additionally, initiatives such as the Japan Beyond-Brittle Project (JBBP) aim to minimise seismic risks by developing geothermal reservoirs in ductile zones, supported by project-specific mitigation plans and monitoring protocols (Buijze et al. 2019; Muraoka et al. 2014). These measures highlight Japan's proactive approach to managing induced seismicity while leveraging its expertise in seismic risk management.

One of the primary reasons geothermal development in Japan has been slow to progress is that over 80% of the estimated 23,400 MW of geothermal resources are located within national parks, semi-national parks, and other protected natural areas. Strict legal restrictions on development in these parks historically made it impossible to conduct surveys, let alone construct power plants.

However, regulations governing national parks have gradually been relaxed. A significant milestone was the 2012 revision of the National Park Regulations, which permitted geothermal development in Class 2 and Class 3 Special Zones of National Parks. These zones account for 38% of Japan's geothermal power generation potential. Therefore, one of the major barriers to geothermal development—restrictions in national parks—is slowly being addressed.

The primary challenge to advancing geothermal power generation remains the lack of acceptance of hot spring owners. Many local stakeholders express concerns about the potential impact of geothermal development on hot spring resources, which are vital to tourism and local economies. Gaining the support and understanding of these communities is therefore a critical hurdle to overcome in promoting geothermal energy.

The Japan Onsen Association, representing 1,300 hot spring operators, opposes geothermal development due to concerns about drying up water sources, changes in water quality, and reduced availability, particularly from large-scale drilling (Johnston 2024).

While not against geothermal energy entirely, they criticize binary-cycle plants, which use shallow heat sources and looser regulations, causing issues for hot spring operators. The association calls for stricter rules and safeguards to protect hot springs.

Japan's government has implemented several programs aimed at easing these concerns. The initiatives focus on educating local authorities and residents, addressing specific fears, and promoting successful examples of geothermal utilisation:

Educational activities on geothermal energy for local authorities: These programs aim to support local governments interested in geothermal energy by sharing best practices and successful case studies from model areas. It facilitates opinion exchanges and study sessions between local governments to address challenges and questions surrounding geothermal development. By fostering networks and collaboration between municipalities, the program seeks to create opportunities for future geothermal promotion.

Educational activities on geothermal energy for local residents: Recognizing the importance of gaining the support of residents, including hot spring business owners, this program focuses on education and awareness. It supports local study groups and demonstration projects to provide accurate information about geothermal power generation and its regional benefits. By deepening understanding, the program aims to alleviate concerns and build trust within communities.

Hot Spring Impact Survey Program: For hot spring owners, the greatest fear is that geothermal development might lead to a decline or depletion of their hot spring resources, impacting their livelihoods. This program addresses such concerns by offering support for alternative drilling of hot spring wells if excessive reductions in hot spring water occur near geothermal development sites. This reassurance helps mitigate the perceived risks associated with geothermal projects.

Geothermal Model Areas: JOGMEC has designated three municipalities—Mori-cho in Hokkaido, Hachimantai City in Iwate Prefecture, and Yuzawa City in Akita Prefecture—as "geothermal model areas." These areas serve as examples of sustainable geothermal development that coexist with local communities. The program promotes geothermal use in industries, supports local dialogue forums, and facilitates tourism branding and hot spring promotion. Successful practices from these model areas are disseminated nationwide to encourage similar initiatives in other regions.

These programs are designed to create opportunities for local residents and authorities to learn about geothermal energy and envision its potential in their communities. By providing information on managing risks and showcasing successful examples from other regions, the initiatives foster dialogue and connections.

3.4.5 Stakeholder Involvement

The gaps in existing laws regarding geothermal development in Japan has sparked significant concerns about unregulated activities, particularly among stakeholders in the hot spring industry.

A major issue is that under current legislation, such as the Hot Spring Act, anyone can drill a geothermal well as long as they secure land rights. However, these laws were designed for smaller-scale activities and do not adequately consider the broader implications of large-scale projects that often extend across wide geographic areas. This regulatory blind spot leaves critical gaps in stakeholder involvement.

While some local ordinances require consent from hot spring source owners, this authority is limited to specific zones, leaving hot spring operators outside these areas without a voice in the process. This lack of transparency and consultation has fostered distrust among hot spring operators, who are particularly sensitive to any perceived risks to their resources. Even when geothermal projects are located far from their hot spring sources, the "invisible" nature of the development process fuels ongoing apprehension.

In response to these challenges, the Japan Hot Spring Association has called for the establishment of clear rules and collaborative processes to ensure responsible geothermal development. They proposed five key principles to guide future projects (ThinkGeoEnergy 2022):

- Agreement from the local community (government, hot spring operators, etc.)
- Mutual information disclosure, with guaranteed objectivity and the establishment of a third-party organization
- Regulations to prevent excessive extraction
- Thorough, continuous, and wide-ranging environmental monitoring
- Formalization of recovery work for damaged hot springs and hot spring areas

Encouragingly, there are already positive examples in Japan of how clear rules and transparent processes can foster cooperation among stakeholders. One notable case is that of Obama Town in Nagasaki, where a structured approach to geothermal development has successfully improved collaboration and trust between developers and the local hot spring industry.

In the early 2000s, Obama Town faced significant opposition to a geothermal development project. At the time, the town was quietly advancing the project without informing key stakeholders, including the well-known Unzen Onsen and Obama Onsen hot spring resorts. Although Nagasaki Prefecture regulations required consent from all hot spring owners within a 1 km radius of the drilling site, the proposed site for this project was just outside the mandated boundary. As a result, the local residents and hot spring operators were not consulted during the initial stages of development.

By the time the project reached the drilling phase, the lack of communication had created mistrust within the community. When an explanatory meeting was finally held, it sparked an opposition movement among residents. Although written consent for the drilling was not legally required, the Nagasaki Prefecture Hot Spring Council made the unusual decision to deny permission for the project, citing the confusion and dissatisfaction it had caused among the local community. The project was ultimately abandoned.

In 2011, the residents of Obama Onsen took a proactive approach to geothermal development. Dissatisfied with the opaque processes of the earlier project but supportive of decarbonisation efforts, they began holding study sessions with Nagasaki University to learn more about geothermal power generation. These discussions led the community to take control of the development process themselves.

The residents established a local company, Obama Onsen Energy, to lead the geothermal development. This company prioritised dialogue between local residents and partner companies, fostering transparency and trust. It also spearheaded demonstration experiments for small-scale geothermal power generation and eventually launched electricity sales. Today, the Obama Onsen Binary Power Plant remains in operation, serving as a successful example of community-led geothermal development.

The case of Obama Town demonstrates that public engagement is just as important as public acceptance in geothermal development. This can take various forms, including financial participation and active involvement in discussions and decision-making. By giving local residents meaningful opportunities to participate, developers can build trust, foster cooperation, and create sustainable projects that align with community interests.

3.5 Economic Potential and Viability

3.5.1 Geothermal Industry

Japan, with its abundant geothermal resources, has significant potential to expand its geothermal energy sector. While the country has developed a strong industrial base in specific areas, there remain untapped opportunities to further enhance its economic potential. Most geothermal related companies joined the Japan Geothermal Association (JGA) which consists of 87 companies and 11 organizations[21].

Japan's geothermal sector benefits from the presence of globally renowned manufacturers of geothermal turbines. Companies such as Toshiba, Fuji Electric, and Mitsubishi Heavy Industries (MHI) collectively hold over 60% of the global market share in geothermal turbine production. These heavy-industry conglomerates have leveraged their expertise in power generation technologies, including nuclear and coal-fired power plants, to establish themselves as leaders in geothermal energy (JOGMEC 2025c; JGA 2024). In addition to these major players, other companies such as Taiyo Electric Co.[22], Shin Nippon Machinery Co.[23] and Sumitomo Heavy Industries[24] contribute to the production of geothermal turbines, often as original equipment manufacturers (OEMs).

On the development and operational side, electricity companies like Hokkaido Electric Power Co., Tohoku Electric Power Co., and J-POWER, as well as specialised project companies such as Iwate Geothermal Co. and Machiokoshi Energy Co., play a crucial role in geothermal project implementation. These entities are supported by engineering firms like INPEX and JFE Engineering and renewable energy developers such as RENOVA and GDI (Geothermal Development & Investment Inc.).

INPEX is a Japanese oil and gas exploration company expanding into the renewable energy sector. It is involved in domestic geothermal projects. RENOVA, for example, is a shareholder in the Minami-Aso Yunotani geothermal power plant, which has been in operation since 2023 (RENOVA n.d.). JFE Engineering has been designing and building geothermal power plants using binary generation technologies since 2010. GDI is an investor and developer of small and medium-sized geothermal projects in the Asia-Pacific region,

Baseload Power Japan, a subsidiary of Sweden's Baseload Capital, is developing small-scale geothermal plants in cooperation with local communities. International companies have also entered the Japanese geothermal market. Baseload Power Japan, a subsidiary of Sweden's Baseload Capital, is developing small-scale geothermal plants in cooperation with local communities. US-based Ormat Technologies has been supplying equipment for binary geothermal plants in Japan, working with Japanese companies such as the above-mentioned JFE Engineering. As part of the New Zealand-Japan geothermal coalition, a number of agreements have been signed in 2024 between companies in the two countries, such as GEO40 and Mitsubishi Gas Chemical (Think GeoEnergy 2024a).

3.5.2 Economic Viability

Despite these strengths, Japan's geothermal sector has limitations that hinder its full potential. Currently, the primary service offered by geothermal operators is electricity generation, often sold through feed-in tariff (FIT) schemes. Diversifying services and exploring innovative applications of geothermal energy, such as direct-use heating or industrial processes, could unlock new economic opportunities. Moreover, the sector faces challenges in scaling up operations due to regulatory barriers, community opposition, and limited exploration of untapped geothermal resources. Expanding the range of services and improving stakeholder

[21] https://www.chinetsukyokai.com/about/index.html#kaiin
[22] https://www.taiyo-electric.co.jp/english/
[23] http://www.snm.co.jp/index.html
[24] https://www.shi.co.jp/english/index.html

engagement are critical steps to address these gaps (ANRE 2024).

One of the most pressing challenges for Japan's geothermal sector is the shortage of skilled professionals. The "winter period" for geothermal energy development prior to the FIT system led to a significant decline in mid-level expertise. Organisations like JOGMEC (Japan Oil, Gas and Metals National Corporation) have been working to address this issue through training programmes and educational initiatives. These efforts aim to develop talent for resource exploration and project management, but sustained investment in workforce development is needed. Collaboration with international research institutions and the promotion of geothermal careers to younger generations could further alleviate the labour shortage (ANRE 2024).

The extraction of lithium as a by-product of geothermal energy production has been discussed as a potential avenue to enhance the economic viability of geothermal projects in Japan. Lithium, a critical component for batteries used in electric vehicles and renewable energy storage, has seen surging global demand. However, Japan has made limited progress in capitalising on this opportunity. While companies like Itochu Corporation (Nikkei 2010) and startups such as elleThermo (PRTimes 2024) have explored lithium extraction technologies, these efforts remain small-scale and largely experimental. Significant technical and economic challenges persist, making it uncertain whether this approach can meaningfully boost the profitability of Japan's geothermal sector in the near future.

3.5.3 Funding Schemes

The Japanese government is providing financial support for geothermal power, mainly led by JOGMEC. JOGMEC provides financial assistance through four key programs:

Geothermal Resource Potential Survey: This program supports basic surveys, including leading resource volume surveys, airborne geophysical surveys, surface surveys, and drilling surveys conducted by JOGMEC. Many promising areas with geothermal potential remain unexplored. To address this, JOGMEC conducts initial surveys and provides critical data to help companies decide whether to enter the geothermal market.

Geothermal Resource Survey Grant: This grant program reduces the costs of initial surveys, such as surface and excavation surveys. The grant rate varies depending on the size and location of the planned power station. For instance, projects exceeding 25 MW located within semi-national parks are eligible for a 75% grant rate. The program also supports well drilling and post-drilling monitoring to assess environmental impacts.

Exploration investment: JOGMEC provides up to 50% of the funding required for geothermal exploration, helping to reduce the financial burden on developers during the high-risk exploration phase.

Development Debt Guarantee: For projects requiring loans from private financial institutions, JOGMEC offers debt guarantees of up to 80%. This applies to costs associated with well drilling, pipeline installation, power generation equipment, and accompanying infrastructure development, significantly reducing financial risks for developers.

The grant program was first introduced in 2012 and later revised. To date, 99 projects have utilised these subsidies and grants. Starting in 2023, the program has begun to show visible results, with new projects totalling 60 MW of capacity expected to be installed by 2028. This initiative plays a crucial role in accelerating the early stages of geothermal development in Japan.

3.6 Geothermal Projects in Japan

There are several successful examples of regional development and sustainable energy development using geothermal power in Japan. In the following the geothermal power initiatives in Yuzawa city, Akita Prefecture and the Waita Onsen in Kumamoto Prefecture are introduced.

Yuzawa city, Akita

Yuzawa City in Akita Prefecture is one of the local governments that is actively working to create a sustainable community and generate geothermal power by making use of Japan's leading geothermal resources. The area has several geothermal power plants, including the Wasabisawa Geothermal Power Plant (started in 2019), and is contributing to the expansion of geothermal power generation and the revitalization of the local economy.

The capacity of the Wasabisawa Geothermal Power Plant is 46 MW, and it is a project that was developed jointly by Tohoku Electric Power and Mitsubishi Materials and carried out in cooperation with the local government. The Akita Prefectural Government and the Yuzawa City Office have actively held discussions with local residents and built good relationships with the power generation company, which is thought to be a factor in the success of the project. In addition to the Uenotai Geothermal Power Plant (28 MW), which began operating in 1994, the Katatsumuriyama Geothermal Power Plant (15 MW) in 2028, and the Kijiyama Geothermal Power Plant (15 MW) in 2029, is also expected to begin operating.

In the city of Yuzawa, the Yuzawa City Office has established a geothermal resource utilization council, and opportunities for dialogue between developers, experts and local residents are being actively created.

Also, Yuzawa is well known for geothermal resources utilization. Resources are used for purposes other than power generation, such as agricultural greenhouses, agricultural product drying facilities, and the production of pasteurized milk, leading to a close relationship between the local residents and the geothermal resources.

Waita Area, Kumamoto

The Waita Onsen Hot Spring Village in Kumamoto Prefecture is a small hot spring resort with only about 30 households, but it is known as a town that has succeeded in a geothermal power generation project in which local residents also participated. In 2015, a 2MW geothermal power plant began operating in Waita Onsen. What is characteristic about this power generation business is that it is owned by a local capital company, and the entire power plant operation is outsourced to a company outside the region. The local capital company is funded by all 30 households living in the Waita area, and 50% of the profits generated by the power generation business are distributed to the 30 households. The remaining 50% of the profits are used for the town, such as for the maintenance of the hot spring piping.

The Waita residents of 30 families agreed to welcome the geothermal power plant nearby and they participated in the plant business. This is another good example of public engagement.

4 Comparison and Potential Synergies

This chapter aims to provide an understanding of the potential synergies and collaborations between Germany and Japan to push geothermal further. Therefore, the previously described characteristics and frameworks for geothermal energy in both countries was compared to identify these synergies.

4.1 Geothermal Potential

Japan as country with plenty tectonic activity and 110 active volcanoes is said to have one of the largest geothermal potentials worldwide (JOGMEC 2025d), but Germany as well has vast untapped potential which could provide 25% of the country's heat demand. Currently, in Germany only 1.3% and in Japan only 0.3% of the heat demand is covered by geothermal energy (Clean Energy Wire 2020a). The morphology and geographic shape of both countries indicate that the actual exploitation of potentials faces different chances and challenges. Japan's morphology is dominated by mountainous, volcanic, and tectonically active terrain and around 80% of its geothermal resources are located in national parks. Germany on the other hand features a stable landscape of flat plains, rolling hills, and river valleys shaped by glacial and fluvial processes.

Nonetheless, geothermal energy offers a large opportunity to reach their respective targets in terms of climate neutrality and the expansion of renewable energy. This is especially desirable, due to its ability to provide reliable baseload power, offering a consistent and stable energy supply compared to other renewable technologies.

Looking at both countries, the geothermal resources are linked to partially very different geological settings. Germany aims for mainly deep hydrothermal geothermal reservoirs at depth of several kilometres in very specific regions, tapping reservoirs in both sedimentary and crystalline reservoirs. The heat sources in Japan are linked to volcanic activity and are usually located in more shallow depth, due to the higher temperature gradient.

Generally, the classification of geothermal energy systems is comparable: the terminology of hydrothermal and petrothermal reservoirs and enhanced geothermal reservoirs (EGS) is accepted and commonly used in both countries (see chapter 2.1 and 3.1). However, the larger complexity of the geologic conditions in Japan needs to be considered when comparing and describing the respective geothermal systems. Generally, the exchange of knowledge, experience and technical expertise between both countries for any cooperation should be no issue.

It is further to note, that specific geothermal areas are usually aimed to develop geothermal resources (see chapter 2.1.1 and 3.1.1). These areas developed over many years due to scientific activity and are not necessarily linked to regions with a high heat demand. In both countries, the exploration and drilling activity could be extended to other regions, where geothermal resources are less known, but the heat demand is large.

4.2 Strategy and Outlook

Both countries emphasize the importance of technological innovation and development to enhance geothermal energy utilization. Germany plans to expand medium-depth and deep geothermal energy, while Japan is focusing on next-generation technologies like supercritical geothermal power generation.

Germany has set specific targets, such as developing 10 TWh of geothermal power annually by 2030. In order to achieve that, at least 100 new projects should be initiated by 2030. Japan, on the other hand, aims to introduce 1.5 GW of power generation capacity by 2030, and 25 TWh of geothermal power annually by 2040. Considering their respective potentials, both targets remain rather conservative.

In Germany, this strategy includes legislative changes to streamline approval processes and financial support for geothermal projects. Japan's strategy involves JOGMEC conducting initial surveys and supporting private sector entry, focusing on resource volume assessments and technological development.

Germany's strategy is more regionally focused, with specific goals for integrating geothermal energy into heating networks and leveraging it for residential and industrial processes. Japan's approach is broader, aiming to exploit its abundant volcanic geothermal resources across various regions for both electricity generation and heating and other applications like greenhouses.

4.3 Exploration Risk

An important issue, that both countries are dealing with, is the exploitation risk associated with geothermal exploration. Drillings are costly and require larger investments, but dry wells are a big risk for companies and stakeholders to invest in geothermal energy. The response of both countries is different. Germany is aiming to implement an exploration insurance for operators (see chapter 2.4.2).

Japan mitigates these risks with large geological and drilling surveys conducted by the state-owned agency JOGMEG sharing results with operators after completion, the provision of subsidies and debt guarantees to operators, as well as the development of next-generation geothermal power generation technologies, such as closed loop systems (see chapter 3.4.2).

Since the demand for large geological surveys is also discussed among the geothermal community in Germany, Japan could provide their knowledge and experience in conducting large surveys by state institutions that are shared with private operators. Conversely, Germany has already developed concepts in cooperation with the KfW to implement an insurance program to mitigate the financial risk associated with geothermal exploration. This knowledge could be shared with Japan, since no concepts are known to be developed currently.

4.4 Policy and Legal Framework

The legal frameworks for geothermal energy in Germany and Japan have both similarities and differences, reflecting each country's unique geological and regulatory landscapes (see chapter 2.2 and 3.2).

Both countries face a complex regulatory environment that involves multiple laws and regulations impacting geothermal development and there is no specific law like New Zealand's Geothermal-Act[25]. In Germany, relevant laws are the Federal Mining Act; the Federal Water Act; the Building Planning Law; the Federal Immission Control Act and the Federal Nature Conservation Act, while in Japan, the Hot Spring Act; the Natural Park Act; and the Electricity Business Act govern geothermal policy.

Both countries address public and environmental concerns in their legal frameworks and projects under certain conditions need to undergo an environmental impact assessment under the respective Environmental Impact Assessment Laws. While in Japan, environmental impact assessment is principally mandatory for geothermal projects over a certain size, in Germany the obligation is connected to the method used, the seismicity of the respective region and the use of substances hazardous to water.

This complex legal framework can cause barriers in the development of geothermal energy. From the operators and science point of view, a single act would be more efficient, that regulates all legal requirements associated to project planning, environmental protection and public acceptance.

Differences between the legal framework of both countries are associated with the ownership and rights for geothermal resources, some specific legal instruments regarding the prioritization of geothermal projects in planning decisions, as well as the local involvement and acceptance.

In Japan, there is no clear legal definition of who owns the rights to geothermal resources, leading to potential unregulated development. This contrasts with Germany, where geothermal resources are classified as free mineral resources, necessitating compliance with mining laws.

Germany has further introduced legislative updates to expedite approval processes and prioritize geothermal projects in planning decisions. This includes exemptions for near-surface geothermal projects from certain mining laws, which is not mirrored in Japan's legal framework. In 2015, Japan eased regulations to allow geothermal development in national parks, addressing a major barrier to utilising its vast geothermal resources. This change enabled drilling in specific zones within the parks, unlocking access to approximately 80% of the country's geothermal potential.

Japan also faces unique challenges with local acceptance due to the cultural significance of hot springs, which are often impacted by geothermal

[25] Geothermal Act New Zealand: https://www.legislation.govt.nz/regulation/public/1961/0124/latest/DLM15785.html

development. This has led to specific local regulations requiring consent from nearby hot spring owners, an issue less prevalent in Germany. However, in Germany the public acceptance is strongly linked to potential induced seismicity events. This topic is further discussed in chapter 4.6.

4.5 Research and Development

Both Germany and Japan have identified several specific research topics in geothermal energy that reflect their shared goals and challenges in advancing this renewable energy source (see chapter 2.3 and 3.3). Some of the common research topics are:

Subsurface Data and Exploration: Both countries emphasize the importance of improving subsurface data availability and exploration techniques. This includes geological and geomechanical data collection, as well as the use of advanced exploration methods to better understand geothermal reservoirs.

Seismic Risk Mitigation: Addressing seismic risks associated with geothermal energy development is a priority for both countries. Research is focused on developing strategies and technologies to mitigate induced seismicity, which is a concern for geothermal projects.

Reservoir Management and Enhancement: Both Germany and Japan are investing in research to improve reservoir management techniques. This includes developing methods to enhance reservoir permeability and manage thermal-hydraulic interactions within geothermal systems.

Technological Innovation: Innovation in geothermal technology is a shared focus, with both countries researching ways to improve the efficiency and sustainability of geothermal power generation. This includes developing new technologies and business models to support the commercialization of advanced geothermal systems.

These specific research demands could be addressed as cooperations between the two countries to strengthen the knowledge exchange and experiences both countries could contribute.

Germany and Japan are actively pursuing advancements in next-generation geothermal technologies with the potential to transform the sector. By collaborating, the two nations could accelerate the commercialization of innovative solutions. Japan’s progress in supercritical geothermal technologies, which operate under higher temperatures and pressures, offers valuable insights for adapting these advancements to European geothermal systems. Meanwhile, Germany’s focus on closed-loop geothermal systems, designed to extract heat without dependence on water reservoirs, could greatly benefit from Japan’s technical expertise and experience in field testing. This partnership highlights the opportunity for mutual exchange to drive forward geothermal innovation.

Collaborative demonstration projects could serve as testbeds for new technologies and methodologies. Jointly funded pilot projects could focus on testing advanced drilling techniques, seismic monitoring systems, or innovative heating applications in real-world settings. Demonstration projects could also facilitate the exchange of best practices, such as Germany’s district heating integration or Japan’s resource exploration strategies.

4.6 Public Acceptance

The public acceptance of geothermal energy in Germany and Japan varies due to different cultural, environmental, and historical contexts (see chapter 2.5 and 3.4.3).

Both countries recognize the importance of involving stakeholders and the public in geothermal projects to improve acceptance. This includes educational campaigns and stakeholder forums to address concerns and provide information about the benefits of geothermal energy.

In Japan, public acceptance is significantly influenced by concerns over hot springs, a cultural and economic asset. The lack of clear rules for geothermal development near hot springs often leads to public opposition. In contrast, Germany faces challenges primarily related to induced seismicity, which has led to public resistance following seismic events associated with geothermal projects.

According to critics, Japan's regulatory framework lacks specific guidelines for geothermal development, leading to a lack of transparency and concerns about unregulated development and its impact on local hot springs. Germany, on the other hand, has a more structured regulatory environment, which includes measures to address seismic risks and involves public input in planning decisions.

Especially the public discussion about induced seismicity is driven by the fear of damages to public properties and can become quite emotional in Germany. Since Japan is regularly faced with seismic events and earthquakes due to Japan's location near the pacific Ring of Fire, there is almost no public debate about possible seismic events triggered by geothermal operation.

Japan also operates the Hi-net system[26], a highly sensitive seismic monitoring network with over 800 stations designed to detect microseismic activity. This system is also well-suited for geothermal applications, such as monitoring induced seismicity in Enhanced Geothermal Systems (EGS), enabling effective risk management and operational adjustments. Therefore, an exchange of knowledge in dealing with small scale seismicity between Japan and Germany could contribute to factualize the discussion in Germany.

4.7 Economic cooperation

Germany and Japan, as two nations with significant but underutilised geothermal potential, have complementary strengths that present opportunities for economic cooperation in the geothermal energy sector. Each country brings unique technological and industrial expertise to the geothermal sector, creating a solid foundation for technical and business partnerships.

The visit of a Japanese delegation to geothermal site in Bavaria in 2024 highlights the growing interest in cross-border collaboration between the two nations[27]. Formalising cooperation between a high-potential region like Bavaria and a Japanese prefecture could unlock new business opportunities and accelerate the adoption of geothermal energy in both countries. Leveraging the strong existing ties between Japan and Germany, including Bavaria's active presence in Japan through its representative office, provides a solid foundation for deepening this collaboration. Regional partnerships of this kind have already demonstrated success, as seen in the cooperation between Fukushima and Hamburg in renewable energy.[28] Building on such examples, a regional partnership focused on geothermal energy could foster joint innovation, technology exchange, and co-investment in projects.

Looking at the respective industries, Japan is a leader in geothermal turbine manufacturing, with companies such as Toshiba, Fuji Electric, and Mitsubishi Heavy Industries holding over 60% of the global market share. Their turbines are known for efficiency, reliability, and adaptability to diverse geothermal conditions. Exploring business partnerships with these Japanese manufacturers could offer Germany an opportunity to optimise operations in high-potential regions, while creating business opportunities for Japanese manufacturers in Europe.

Germany has extensive experience in integrating geothermal energy into municipal heating networks, particularly in Bavaria (for example München-Sendling, Unterföhring, Grünwald, Unterhaching, Holzkirchen), where it supplies heat to residential, industrial, and municipal facilities. This experience could inform Japan's efforts to diversify its geothermal applications beyond electricity generation to include district and industrial heating. This aligns with Japan's efforts to expand geothermal usage in regions like Hokkaido and Kyushu. Facilitating expert knowledge exchanges between German and Japanese stakeholders could provide valuable insights into designing and implementing efficient heating networks tailored to Japan's unique regional needs.

Germany is also pioneering geothermal lithium extraction, a sustainable method to meet rising global demand for lithium, critical for electric vehicle batteries and renewable energy storage. It could be beneficial for Japanese companies, with expertise in battery technology and materials science, to partner with German firms to develop and scale geothermal lithium extraction technologies. Collaboration could be particularly relevant for regions like the Upper Rhine Graben, where geothermal brines are rich in lithium. It could create new revenue streams for geothermal projects in both countries while reducing reliance on environmentally harmful mining practices.

Japan has a self-sufficient geothermal service industry, relying on domestic companies for project development and operational needs. In contrast, Germany remains dependent on international service companies, particularly from the oil and gas sector, for drilling expertise and equipment. Germany could learn from Japan's approach to developing a robust domestic geothermal service

[26] Hi-net system in Japan: https://www.hinet.bosai.go.jp/
[27] Geothermie: Besuch aus Fernost auf dem Bohrplatz und im Rathaus
[28] https://hamburg-business.com/de/news/hamburg-und-fukushima-vertiefen-energiepolitische-zusammenarbeit

industry. Joint training programs or knowledge exchanges with Japan could reduce Germany's reliance on external service providers, reduce costs, and improve project timelines.

Both Germany and Japan are exploring next-generation geothermal technologies that could revolutionise the sector. Collaboration in these areas could fast-track the commercialisation of innovative geothermal solutions.

4.8 Project cooperation

Comparing the geothermal projects that were described in detail in chapter 2.7 and 3.6, both countries could learn from the different project characteristics.

Both Germany and Japan emphasise public engagement and transparency to ensure the success of geothermal projects. In Potsdam, Germany public meetings, citizen participation, and guided site visits were integral to gaining local acceptance. Similarly, in Yuzawa City, Akita, Japan, dialogue between developers, experts, and local residents through a geothermal resource utilisation council played a crucial role. The Waita Onsen project in Kumamoto also highlights the importance of local involvement, where residents directly participated in the business model.

Geothermal projects in both nations are tied to broader goals of regional and urban development. In Potsdam, the Heinrich-Mann-Allee project integrates geothermal energy into a residential and commercial area, supplying heat to thousands of households. In Japan, geothermal energy in Yuzawa supports agricultural applications and economic revitalisation, while the Waita Onsen project directly benefits local residents through profit-sharing.

A notable distinction lies in the ownership structures of geothermal projects. Japan's Waita Onsen project stands out for its community ownership model, where local residents invest in and benefit directly from the geothermal power plant. In contrast, German geothermal projects are typically led by companies or municipal utilities, with less direct financial involvement from local communities.

Both countries are leveraging innovative technologies. In Germany, the Geretsried project employs the Eavor-Loop™ technology, a closed-loop system that avoids reliance on thermal water. In Japan, modern geothermal power plants like Wasabisawa integrate advanced engineering and partnerships with local governments to optimise efficiency and sustainability.

Germany could benefit from Japan's expertise in managing mature geothermal systems and scaling projects efficiently. Conversely, Japan could explore Germany's innovative closed-loop technologies, such as the Eavor-Loop™, to expand geothermal applications in areas with less accessible hydrothermal resources.

Furthermore, both nations could exchange best practices in public engagement and community acceptance. Germany could draw inspiration from Japan's diverse utilisation of geothermal energy in agricultural and industrial applications to maximise socio-economic benefits. Similarly, Japan could adopt Germany's advanced technological innovations to optimise geothermal energy use in challenging environments.

4.9 Summary of Potential Synergies and Cooperations

This study, conducted within the framework of the Energy Partnership with Japan, examines the current status and potential synergies between Japan and Germany in advancing geothermal energy as a key component of the regional energy transition. By promoting knowledge exchange and fostering technological innovation, the study aims to strengthen the role of geothermal energy in achieving sustainable energy systems in both countries.

The following key aspects have been identified as particularly promising for fostering future synergies and cooperation between Japan and Germany. These aspects highlight opportunities to learn from each country's unique challenges, solutions, and approaches, with the ultimate goal of accelerating the development of geothermal energy:

1. Discuss methods to accelerate geothermal exploration and development beyond traditional geothermal regions, aiming to enhance the regional energy transition through initiatives such as strategic heat planning.
2. Explore strategies and instruments to minimise and manage exploration and drilling risks for investors, including geothermal operators and other stakeholders, through measures like exploration insurance and improved geological surveys and data enhancement.

3. Facilitate an exchange on overcoming regulatory challenges in geothermal exploration and operation, with a focus on creating a unified legal framework and establishing prioritisation principles in municipal planning processes.
4. Discuss the legal definitions concerning the ownership of geothermal resources to ensure clarity and consistency in exploration and utilisation.
5. Identify potential collaborative opportunities in research and development related to subsurface data and exploration, such as public authority-led geological survey campaigns and open-source data initiatives, as well as seismic risk mitigation through traffic light systems and AI-supported operational strategies, and technological innovations like closed-loop systems and supercritical reservoirs.
6. Share strategies to enhance public acceptance and stakeholder involvement, particularly in addressing concerns about induced seismicity, safeguarding groundwater and hot springs.
7. Discuss strategies for developing an economically viable value and supply chain in Germany and Japan, recognising the need for the geothermal sector to expand its expertise, services, and technologies to meet future demands.
8. Share insights on extracting lithium as a co-product from geothermal fluids, enhancing the economic viability of geothermal energy while exploring a valuable resource.

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