SAPHEA

INTEGRATING GEOTHERMAL HEATING AND COOLING NETWORKS IN EUROPE

Roadmaps towards better integration of geoHC networks in Europe

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1. Introduction

This report on “Roadmaps towards better integration of geoHC networks in Europe” presents a comprehensive analysis of roadmaps for deep geothermal energy projects across seven European countries: Austria, Denmark, France, Germany, Italy, Poland, and the UK. With the aim of supporting the sustainable and widespread adoption of geothermal energy in Europe, this study investigates both the enabling conditions and existing barriers in diverse regional contexts for each of the countries considered. Two areas are indeed examined: one representing a relatively developed geothermal ecosystem, and another situated in a less advanced or emerging context within the same national framework. Through this approach, it is then possible to get a balanced understanding of both successful practices and the persistent challenges that can hinder project development.

Country	Developed area	Underdeveloped area
Austria	Vienna	Bad Waltersdorf
Denmark	Aarhus	Greater Copenhagen
France	Île-de-France	Provence-Alpes-Côte d'Azur
Germany	Munich	Brandenburg
Italy	Toscany	Piemonte
Poland	Podhale	Krakow
The UK	Cornwall	Central Britain

Figure 1: List of developed and underdeveloped regions examined in the report

The analysis goes with inputs collected from key stakeholders and geothermal national experts to shape realistic, context-sensitive roadmaps that reflect not only national trends but also project-level operational realities. Each roadmap reports on different thematic layers: policy and regulatory framework, technical, financial, social and environmental. The result is the elaboration of comprehensive roadmaps allowing for the realisation of a broader picture of deep geothermal development, considering all the relevant aspects that are involved at different stages. Two types of roadmaps have been developed: a roadmap adopting a broader approach and offering a national perspective on the specific country in question, and a project-focused roadmap, as for the Aspern project in Austria and the Aarhus project in Denmark. Together, these roadmaps form a practical and actionable framework to guide policymakers, developers, and investors in navigating the geothermal landscape in Europe.

The findings and analysis presented in this report were validated through a dedicated session during the 3rd Cross Thematic Workshop, which brought together professionals from the energy sector across multiple European countries. During the workshop, participants had the opportunity to review and comment on the country-specific assessments, share national experiences, and reflect collectively on the key differences, challenges, and enabling conditions across selected countries. The analysis of the roadmaps has been carried out together with the results of the Political Readiness Evaluation Scheme developed for the same countries considered here within the SAPHEA report „Status quo report on regulatory and policy framework in the context of geoHC networks in Europe“. This exchange produced valuable insights and supported the strengthening of the comparative dimension of the study. Clearly, one key aspect emerges from the analysis carried out throughout the project and the discussions that have been held: de-risking measures appear as a central aspect throughout all countries. Regardless of national context, the absence of adequate mechanisms to reduce risks—particularly in the early phases of geothermal development—was consistently identified as a major obstacle to project deployment. Addressing this issue appears fundamental to unlocking the potential of geothermal district heating and cooling across the EU.

2. Country roadmaps

2.1. Austria

2.1.1. Developed areas: the case of Vienna

The city of Vienna is characterised by the "Aderklaaer Konglomerat", a natural hot water reservoir at 3000 meters. Located in a water-bearing rock layer, this reservoir has a temperature of about 100°c. This water formation brings particular benefits to the city of Vienna, and after years of research and planning, the city is able to make use of it. [1]

To decarbonise the city, while meeting its heating requirements, Vienna chose to integrate deep geothermal energy technologies into both existing and new district heating networks [2]. Several installations are therefore planned in the following years.

The adoption of deep geothermal energy technologies promises numerous environmental, social, and economic benefits, ranging from reductions in greenhouse gas emissions to improved economic efficiency.

However, alongside these advantages come significant challenges, such as induced seismicity and drilling hazards, which must be carefully managed. In addition, implementation hinges on regional studies, deployment strategies aligned with policies, and lobbying efforts for improved permitting and financial incentives. Nevertheless, financial risks, legal uncertainties, and environmental concerns remain consistent obstacles, as uncertainties regarding geothermal capacities and the risks associated with induced seismicity could complicate the transition process.

[1] 'Climate-Neutral District Heating Beginning in 2028: Drilling Starts for First Deep Geothermal Plant in Vienna', accessed 7 February 2025, https://www.omv.com/en/media/press-releases/2024/241216-climate-neutral-district-heating-beginning-in-2028-drilling-starts-for-first-deep-geothermal-plant-in-vienna.

[2] City of Vienna, 'Energy Framework Strategy 2030 for Vienna', September 2017.

2.1.2. The Aspern project in Vienna and its roadmap

OMV and Wien Energy, Vienna's largest regional energy provider, set up the Deeep Joint Venture to develop a geothermal plant in Aspern (Vienna-Donaustadt). The wells are planned to reach depths of over 3,000 meters to use the geothermal resources there. Once operating, the plant is expected to save up to 54,000 tons of CO_2 per year.[3] Planned to be commissioned in 2028, the plant will reach a capacity of around 20MWth. This project will serve as a starting point to then develop 7 deep geothermal installations with a capacity of up to 200 MW, heating 200,000 households in Vienna [4].

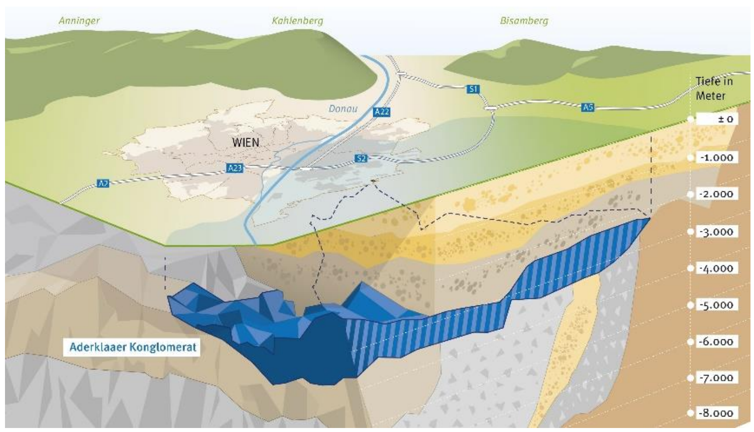

Figure 2: 3D-model of Vienna's underground. Source: GeoTief Wien

The roadmap below has been realised to showcase the peculiar phases the project has experienced during its development until phase 4, where it actually stands. In this case, phases 1 and 2 are reversed in order (considering a more traditional model), as the GeoTief project and a 3D campaign were first launched in 2015 and later followed by a site study in 2020. On a political and regulatory level, the inclusion of geothermal energyin local and regional frameworks has started in an early phase, due also to the attention given to deep geothermal technologies in the Energy Framework Strategy 2030

3 'Tiefengeothermie Wien » Wärme aus Thermalwasser', Wien Energie, accessed 7 February 2025, https://www.wienenergie.at/tiefengeothermie-aspern/.
4 'Preparations Are Being Made to Start Drilling for the First Deep Geothermal Plant in Vienna', accessed 13 February 2025, https://www.omv.com/en/media/press-releases/2024/preparations-are-being-made-to-start-drilling-for-the-first-deep-geothermal-plant-in-vienna.

for Vienna. From 2021 onward, the roadmap shifts towards more concrete project planning and pilot testing. The technical phase involves conducting production tests on existing boreholes and moving forward with project development and design. Contracts are awarded through tenders, and a pilot borehole is drilled to further validate the feasibility of large-scale geothermal energy extraction. This period also marks the beginning of financial structuring, with funding secured through equity capital and co-investment partnerships, including joint ventures with deep geothermal companies. From 2024, public co-funding sources, such as ELENA, KPC, and KLI:EN, are also leveraged to support the pilot drilling phase.

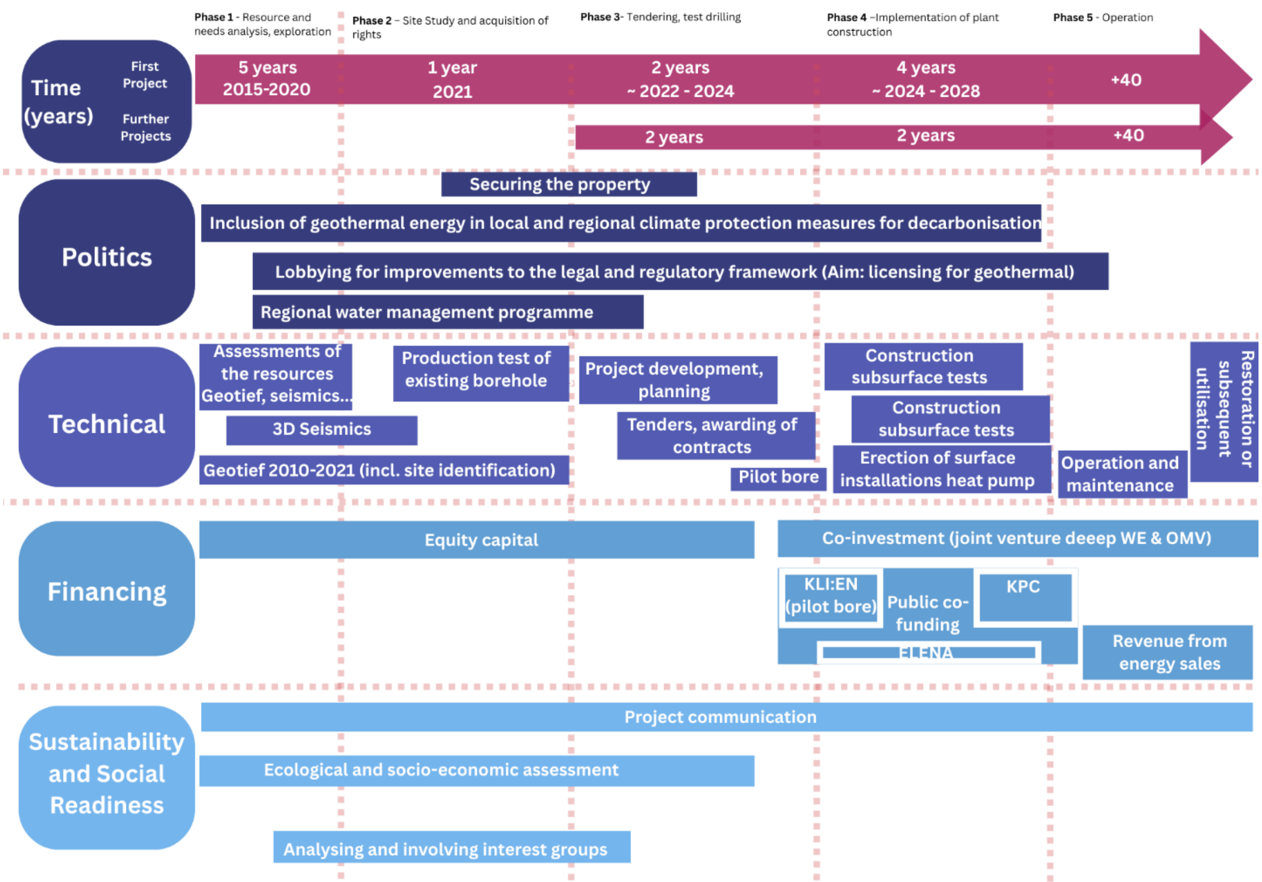

Figure 3: Roadmap for the development of deep geoDHC project in Aspern (Vienna-Donaustadt)

2.1.3. Underdeveloped areas: the case of Bad Waltersdorf region

While the city of Vienna is a frontrunner in geothermal energy use, other areas in Austria remain fairly underdeveloped, such as the Bad Waltersdorf region. Located above the Styrian basin, the region discovered the reservoir at the end of the ‚80s during oil exploration activities. Here, with the hottest geothermal well-producing water at temperatures of 125°c at 3,300 meters, the geothermal gradients are around 4°c/100 meters. The region utilises these resources primarily for thermal spas, balneological purposes, and district heating.

Despite the existence of some applications, the region lacks large-scale district heating deployment. Investment costs, lack of knowledge and data and high risk restrain the expansion of geothermal energy. Furthermore, geothermal is regulated by the national water rights, making its exploitation dependent on the property and/or landowner.

2.2. Denmark

2.2.1. Developed areas: the case of Aarhus

Denmark's sedimentary basins are characterised by large amounts of low-enthalpy geothermal resources [5]. Geothermal water temperatures range from 30°c to 80°c [6]. In theory, geothermal water could cover half of the total annual heating needs in Denmark, given the high quantities of hot water in the Danish subsoil [7]. Estimates assume that geothermal energy could cover up to 15-20% of the heating demand. Consequently, efforts are put into utilising geothermal energy in Copenhagen [8] and other cities.

Notably, Aarhus is becoming a hub for geothermal heating and cooling. With a strong commitment to transitioning toward sustainable energy sources, the city is embracing geothermal energy as a crucial step in electrification and the gradual phasing out of wood pellets, aligning with Denmark's broader sustainability agenda.

Innargi and Kredsløb, a district heating company, jointly work to set up geothermal district heating in Aarhus, the second-largest city in Denmark. Through a 30-year agreement with Innargi, Kredsløb clearly indicates its transformative shift toward renewable energy procurement without the burden of infrastructure ownership. Aiming for commissioning in 2030, the geothermal installation will be the biggest of its kind in the EU, with expected CO2 emission reduction ranging around 165,000 tonnes.

[5] 'Geothermal Group, Geoscience, Aarhus University', accessed 14 February 2025, https://geo.au.dk/en/research/research-areas/department-groups/geothermal-group.

[6] 'Geothermal Energy to Be Integrated into Greater Copenhagen's District Heating System', *State of Green* (blog), accessed 14 February 2025, https://stateofgreen.com/en/news/geothermal-energy-to-be-integrated-into-greater-copenhagens-district-heating-system/.

[7] 'Geotermi: Danmark ligger ovenpå et skatkammer af vedvarende energi – men hvor meget af den kan vi udnytte?', 5 February 2025, https://videnskab.dk/naturvidenskab/geotermi-danmark-ligger-ovenpaa-et-skatkammer-af-vedvarende-energi-men-hvor-meget-af-den-kan-vi-udnytte/.

[8] 'Geothermal Energy to Be Integrated into Greater Copenhagen's District Heating System'.

Started in 2023, the first 17 wells are expected to deliver heat in 2025 [9] (3 are already operational). With the primary objective of procuring 111 MW of heating supplied to the DH grid, Aarhus is positioning itself at the forefront of sustainable energy adoption.

Socially, the project's noiseless facilities and minimal surface footprint alleviate concerns about noise pollution and community resistance. Furthermore, economic analyses demonstrate superior socio-economic benefits compared to alternative heating methods, paving the way for long-term financial stability and consumer savings.

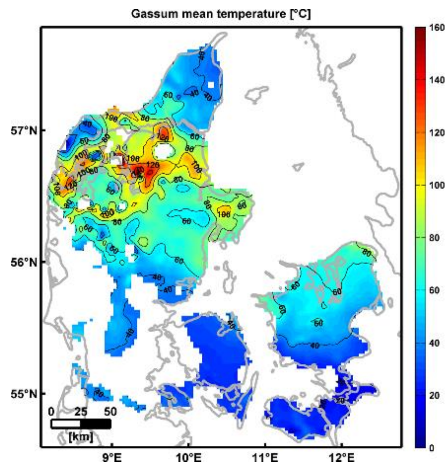

Figure 4: subsurface temperature Denmark

Financing, primarily driven by private investments, underscores the project's autonomy and financial viability, while notable public and private actors—including Kredsløb, the Danish government, and local drilling companies—play instrumental roles in project execution.

2.2.2. The Aarhus project and its roadmap

The roadmap developed for the Aarhus project spans a timeline beginning in 2022 and extending beyond 2029, into a long-term operational period of over 25 years. On the policy front, efforts started in 2022 with the simplification of the permitting process and the introduction of specific incentives to ease project development. These measures laid the groundwork for longer-term policy integration, including geothermal energy in local and regional climate action plans to support decarbonisation goals. Concurrently, national and European funding opportunities have been leveraged to support these initiatives throughout the project timeline.

[9] 'Project Aarhus, Denmark', Innargi, accessed 14 February 2025, https://innargi.com/project/aarhus/.

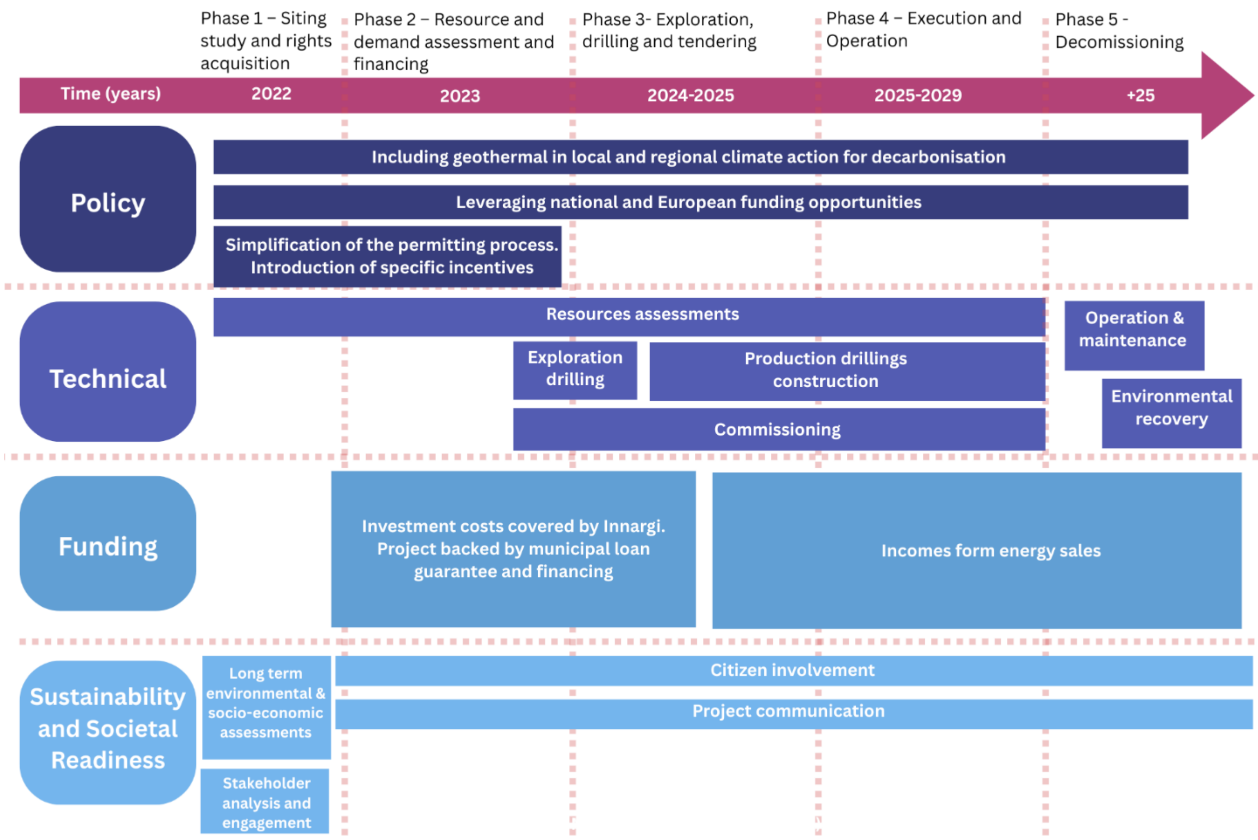

Figure 5: Roadmap for the development of deep geoDHC in Aarhus (Denmark)

From a technical perspective, the process starts with resource assessments beginning in 2022, running parallel with policy developments. These assessments continue into the 2024–2025 period, feeding into exploration drilling, which marks the transition to more tangible project execution. Exploration is followed by production drillings and construction activities, which lead directly into commissioning. From 2025 onward, the focus shifts to the operation and maintenance of the geothermal systems, alongside plans for eventual environmental recovery. Funding for the project is secured through a mix of public-private mechanisms. Initially, investment costs are covered by Innargi, underpinned by a municipal loan guarantee and associated financing. As the geothermal system becomes operational, the project begins generating income from energy sales.

The final dimension, sustainability and societal readiness, is addressed through early and ongoing stakeholder engagement. Starting in 2022, the roadmap emphasises stakeholder analysis and environmental and socio-economic assessments, both of which extend well into the future. Project communication and citizen involvement are key themes, running continuously to ensure public support, transparency, and community integration throughout the lifespan of the project.

2.2.3. Underdeveloped areas: the case of Greater Copenhagen region

Several regions in Denmark remain underdeveloped despite possessing significant geothermal potential. One such area is the Greater Copenhagen area, which, despite its size and energy demands, has only recently begun integrating geothermal energy into its district heating system. Studies conducted show that the subsurface of Copenhagen has considerable potential for residential heating in the city. At depths of 2000 meters, geothermal fluids are present at temperatures of 60°C, hence suitable for district heating plants [10].

The potential of this area has finally been recognised through a recent agreement between Innargi and Vestforbrænding, Denmark's largest waste management and energy company, to develop a geothermal heating plant supplying heat to 10,000 households by the end of 2028. With a capacity of around 26MW, the plant will expand Vestforbrænding's total heat capacity for district heating by 12,5% [11].

The main hindering factors for large-scale deployment in the area relate to scarce geological data and consequently, uncertainties in the geological models. Several projects have been carried out to investigate and map the area and allow geothermal development [12]. Additionally, Denmark has heavily invested in other renewable technologies such as wind and solar, which have therefore become more attractive due

[10] Henrik Vosgerau et al., 'Towards a Geothermal Exploration Well in the Gassum Formation in Copenhagen', *GEUS Bulletin* 38 (31 July 2017): 29–32, https://doi.org/10.34194/geusb.v38.4393.
[11] 'Greater Copenhagen, Denmark', Innargi, accessed 17 February 2025, https://innargi.com/project/greater-copenhagen/.
[12] Vosgerau et al., 'Towards a Geothermal Exploration Well in the Gassum Formation in Copenhagen'.

to technological advancements and favourable policies. The absence of a streamlined regulatory framework, as in many European countries, has hence contributed to the underdevelopment of geothermal in this area.

2.3. France

2.3.1. Developed areas: the case of Île-de-France region

The region of Paris has 5 large aquifers underground that have been exploited for geothermal heating for decades already. Representing the most productive reservoir in Europe in terms of geothermal potential, the Dogger, the main aquifer exploited, is located between 1,5 and 2 km deep with temperatures ranging between 56 °C and 85°C [13].

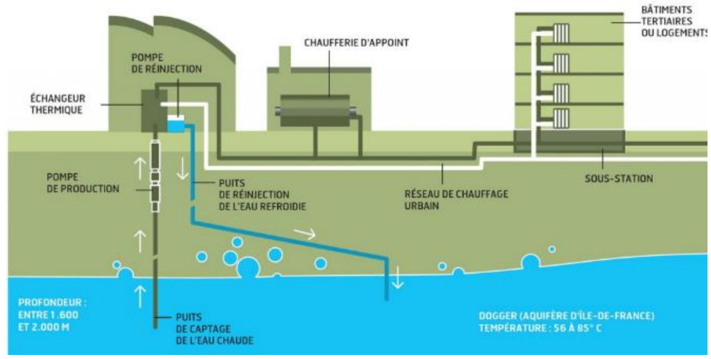

Figure 6: Functioning of geothermal heating system in Paris region (2020). Source: Révolution énergétique

After the first drilling in the area of Melun in 1969, many geothermal projects have been undertaken, providing heat to more than 250,000 homes in the area [14]. The Île-de-France region hosts the highest number of installations and the majority of geothermal heat production in France, with 1.69 TWh produced in 2022, heating 1 million inhabitants, and preventing the emission of 400,000 tons of CO_2 per year compared to a gas boiler [15].

2.3.2. Underdeveloped areas: the case of Provence-Alpes-Côte d'Azur around Marseille

Around the area of Marseille, geothermal is still not as densely used as in the Paris region. Located in the Southeast basin, with hot sedimentary aquifers where water ranges between 60°C to 90°C, the area has considerable geothermal potential untapped. As

[13] Bernard DEBOYSER, 'Géothermie : l'Ile-de-France exploite de mieux en mieux son énorme potentiel', *Révolution Énergétique* (blog), 23 July 2020, https://www.revolution-energetique.com/geothermie-lile-de-france-exploite-de-mieux-en-mieux-son-potentiel/.

[14] Think GeoEnergy and Alexander Richter, 'Gethermal - Greater Paris Area Making Better and Better Use of Enormous Potential | ThinkGeoEnergy - Geothermal Energy News', 29 July 2020, https://www.thinkgeoenergy.com/geothermal-greater-paris-area-making-better-and-better-use-of-enormous-potential/.

[15] L'ADEME Île-de-France, 'scientifique pour identifier le potentiel de la géothermie profonde', n.d.

France's second-largest city, the demand for residential and commercial heating represents a great opportunity for geothermal district heating and cooling systems.

Recently, several projects have been developed for untapped geothermal potential in the area, such as the ADEME programme GEOSCAN-ARC for a 3D seismic exploration campaign on étang de Berre [16]. As in other cases addressed in this report, the region to which Marseille belongs, Provence-Alpes-Côte d'Azur (PACA), has prioritised solar and wind energy, leaving geothermal largely unexplored. Furthermore, unlike the Paris area, this region does not benefit from strong policy support for geothermal and hence the availability of specific geothermal-tailored financial mechanisms.

2.3.3. Roadmap for the development of deep geothermal district heating and cooling in France

The French roadmap outlines the typical trajectory of a deep geothermal energy project, spanning over 25 years. In the policy dimension, the initial focus lies on simplifying permitting procedures and introducing targeted incentives to reduce barriers for project initiation. From the early stages onward and throughout the development and construction period, there is an emphasis on leveraging both national and European funding mechanisms to support geothermal development.

The technical phase begins with resource assessments in the first year, establishing the geothermal potential of the targeted area. This is followed by exploration drilling to confirm subsurface conditions. As the project progresses, production drillings and infrastructure construction take place, alongside commissioning activities,, which typically occur around the end of the third year. The operational phase then extends into the long-term, during which the system is maintained. Environmental recovery actions are scheduled towards the later stages of the project's life cycle, ensuring responsible and sustainable closure or repurposing of the site.

[16] 'L'intérêt de La Géothermie Pour La Métropole Aix Marseille Provence', accessed 17 February 2025, https://www.geothermies.fr/sites/default/files/inline-files/03_AMP_GeoscanArc22mai.pdf.

In terms of funding, the early phases rely on total equity and subsidies to initiate resource assessment and exploratory work. These are considered high-risk phases and thus require soft loans and grants. As the project moves into lower-risk construction and production stages, financing shifts towards commercial loans and additional grants. Once operational, the project begins to generate revenue through energy sales, providing returns on earlier investments.

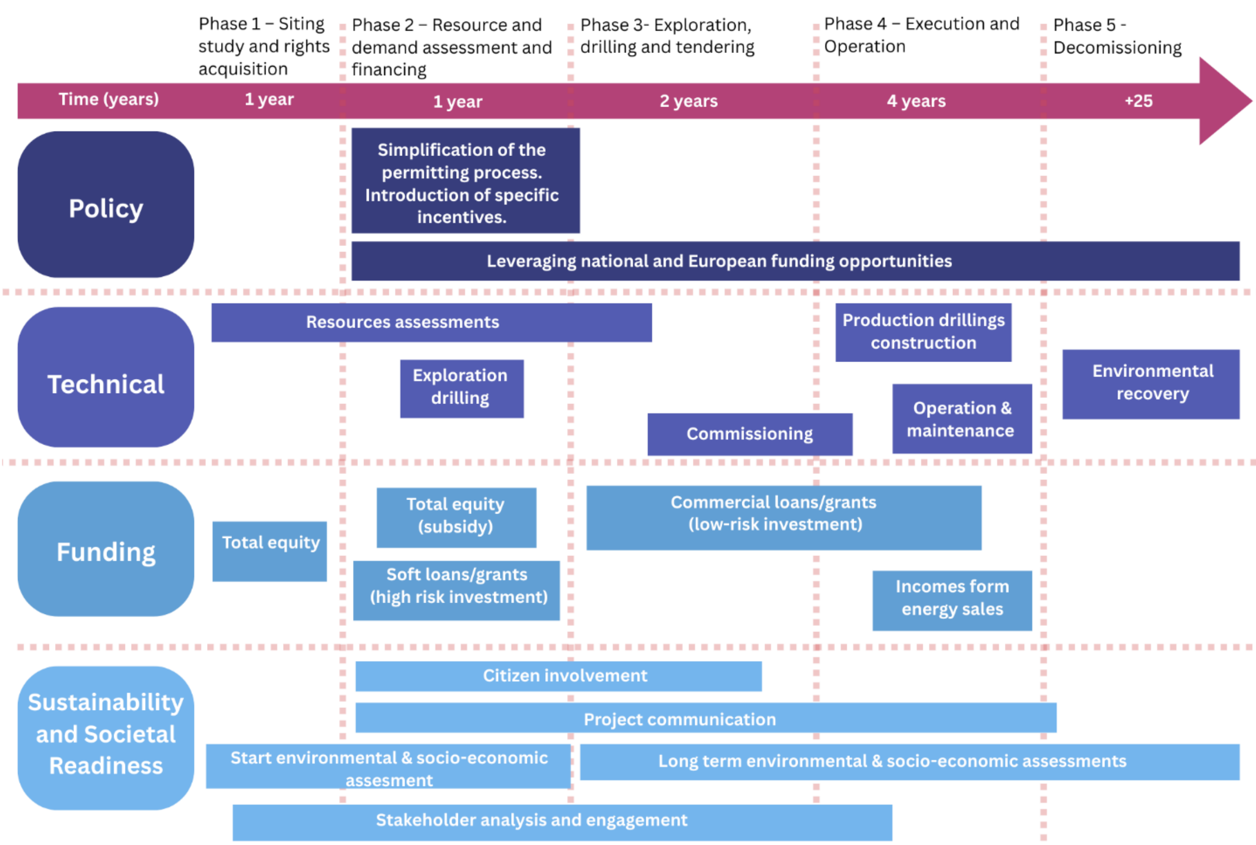

Figure 7: Roadmap for the development of deep geoDHC in France

Sustainability and societal readiness are addressed through continuous engagement with stakeholders, beginning with analysis and outreach from the project's inception. Environmental and socio-economic assessments are initiated early and continue through the project's lifecycle to ensure alignment with community interests and environmental standards. Citizen involvement and project communication are central elements, maintained throughout to build trust and transparency with the local population.

2.4. Germany

2.4.1. Developed areas: the case of Munich

3km deep under Munich, the Molasse Basin contains the so-called Malm reservoir with favourable temperatures around 100°C for geothermal heating and electricity production[17].

Already in 2019, the Bavarian state capital set the ambitious goal of reaching climate neutrality by 2035, focusing on the decarbonisation of its heating system [18]. By joining the EU mission „100 climate-neutral and intelligent cities by 2030", Munich has adopted further measures to meet its objective, considering the consistent geothermal potential lying underground.

Within the Munich area, the regional energy utility Stadtwerke Munich (SWM) operates six geothermal plants as part of the ambition to ensure CO2-neutral coverage of demand for district heating by 2040. The existing geothermal district heating network (1,000 km) is expanding with another plant in development that will provide heat to 75,000 Munich residents [19]. Increasing attention is given to the potential of integrating the 5th Generation District Heating Network (5GDHNs) in Munich's quarters, with low-temperature networks operating at a mere 10°C, coupled with heat pumps [20]. This transformation brings numerous positive impacts, including GHG reductions, increased energy independence, and cost stability. However, alongside these benefits come notable challenges, such as increased investment costs, legal uncertainties, and potential conflicts that could threaten to derail progress. Deployment strategies, financing mechanisms, and pilot installations form the bedrock of this endeavour, underpinned by

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[17] 'Geothermal Plants in Bavaria - Geothermie-Allianz Bayern', 2 March 2022, https://geothermie-allianz.de/en/geothermal-plants-in-bavaria/.

[18] 'City of Munich', Energy Cities, accessed 28 March 2025, https://energy-cities.eu/members/city-of-munich/.

[19] Stadtwerke München GmbH, 'SWM: Information für die Medien', accessed 3 February 2025, https://www.swm.de/unternehmen/presse/pressemitteilungen/2024/09-2024/swm-bew-foerderung.

[20] Karl Martin Heissler, '5th Generation District Heating Networks - Potentials for Reducing CO2-Emissions and Increasing the Share of Renewable Energies in Residential Districts', n.d.

national funds, local initiatives, and private investments. Nevertheless, financial bottlenecks, legal uncertainties, and environmental concerns cast shadows on Munich's path toward sustainability.

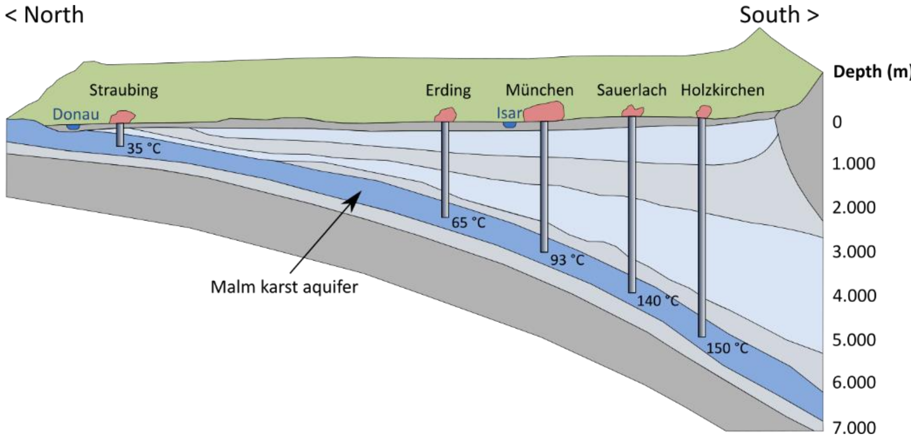

Figure 8: Schematic representation of the subsurface from the Danube to the Alps. Source: Geothermie-Allianz Bayern

2.4.2. Underdeveloped areas: the case of Brandenburg

In 2022, 83% of German energy consumption derived from the space heating and hot water systems in private households [21]. This data underscores the huge potential for geothermal DHC in the country, especially in areas where geothermal resources are present. In this analysis, we took into account the north German basin due to its significant geothermal potential related to its deep sedimentary aquifers [22].

While the region of Brandenburg has some developments in terms of district heating projects, mainly utilising shallow geothermal energy (e.g., heat pumps), the large-scale use of deep geothermal energy remains limited compared to Bavaria or other regions. In the city of Prenzlau, a borehole from 1989 has been used to study the area and subsequently prepare for further drilling in 2025. A second well is prepared to be drilled reaching 1000 meters for accessing 44°C warm thermal water. Through the support of a

[21] 'Germany: Household Energy Consumption, by Use', Statista, accessed 14 February 2025, https://www.statista.com/statistics/1297381/final-energy-consumption-in-residential-buildings-in-germany-by-end-use/.
[22] 'Geothermal Resources and ATES Potential of Mesozoic Reservoirs in the North German Basin', accessed 14 February 2025, https://www.mdpi.com/1996-1073/15/6/1980?utm_source=chatgpt.com#B1-energies-15-01980.

heat pump, this water shall be heated to 80°C in order to be injected into the existing district heating system. The installation is supposed to deliver 60% of the heating requirements of all district heating clients in Prenzlau [23].

Among the main hindering factors are regulatory challenges to further expansion of geothermal installations. Additionally, permission procedures can be very long and complex. There are also drilling limitations and high investment costs, production risk and the need to build further district heating grids.

2.4.3. Roadmap for the development of deep geothermal district heating and cooling in Germany

The German roadmap for the development of deep geoDHC networks adopts a national perspective. During the first phase (the feasibility study), a quantitative and qualitative potential assessment is carried out. From the second phase, all thematic layers are involved. At this stage, citizens are involved in the project development, while project communication campaigns are initiated. These activities will evolve according to the project development and will support it until its decommissioning.

From a policy and regulatory point of view, this phase will require the application and approval of the exploration permit, together with the carrying out of the environmental impact assessment. At a technical level, this stage is characterised by the preliminary exploration and evaluation of the site.

After 2 years, the project moves to the third phase, where drilling is conducted. At this point, in Germany, it is necessary to proceed with the authorisation for the exploration according to German water law. Between the third and the fourth phase, the plant construction and the following connection to the DHC grid are realised. Trial operations can start at the end of this period. From a funding perspective, this stage sees the shift from a high-risk investment towards a low-risk investment initiative.

[23] 'Geothermie', Ministerium für Wirtschaft, Arbeit, Energie und Klimaschutz (MWAEK), accessed 14 February 2025, http://brandenburg.de/de/bb1.c.478390.de.

Finally, after almost 5 years from the beginning of the process, the plant starts its operations, receiving income from energy sales. Ideally, the plant will work for around 30-50 years.

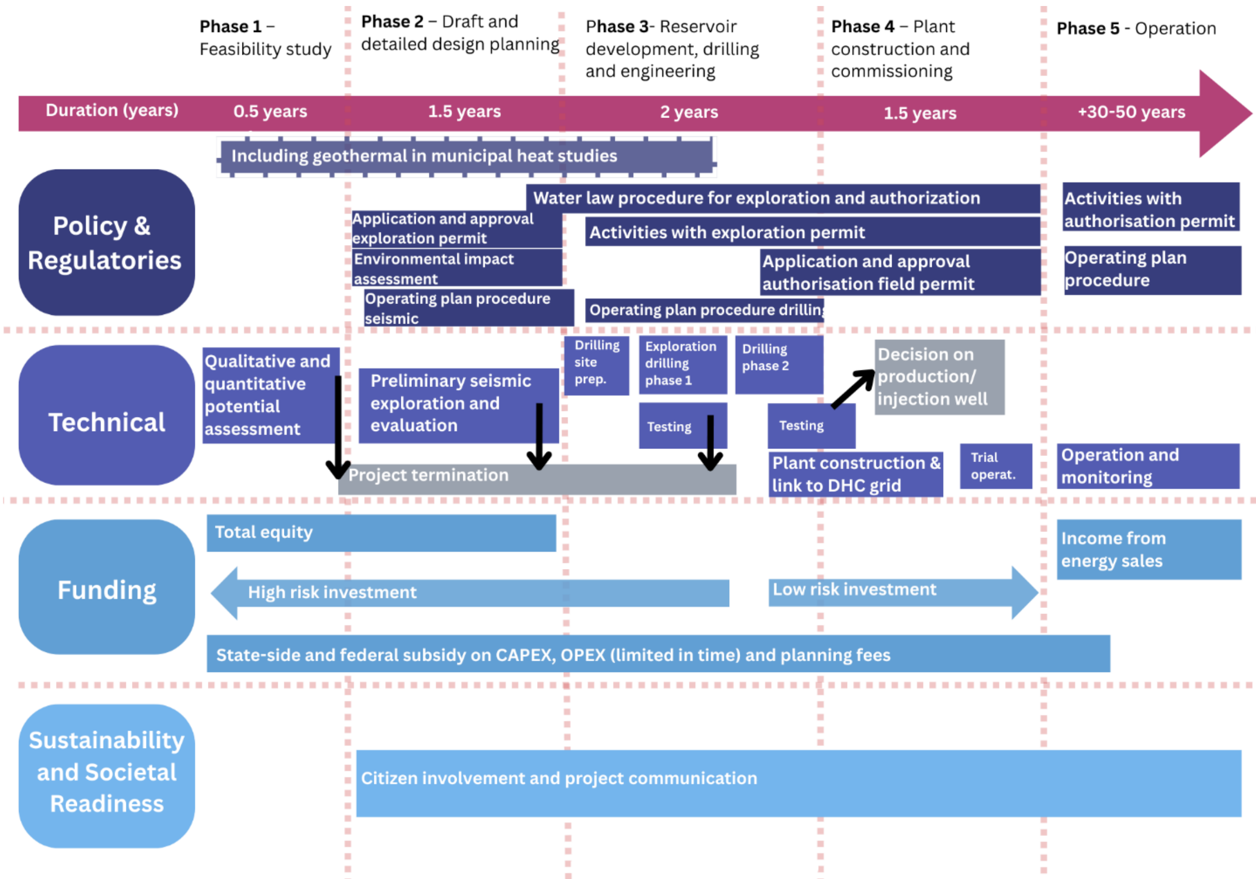

Figure 9: Roadmap for deep geoDHC development in Germany

2.5. Italy

2.5.1. Developed areas: the case of Tuscany

Tuscany is the core geothermal region of Italy, if not even Europe, with the first-ever geothermal power plant installed in 1913. The volcanic system of Mount Amiata that lies below the region holds heat derived from the intrusion of a magmatic pluton. Consequently, the provinces of Pisa, Siena and Grosseto are very fitting for geothermal exploitation [24].

2.5.2. Underdeveloped areas: the case of Piemonte region

The Piemonte region has significant geothermal potential, particularly for low-enthalpy applications, which can support sustainable heating and cooling solutions. In 2021, the University of Politecnico di Torino [25] conducted a broad analysis of the potential in the territory, highlighting the variety of geological formations that exhibit favourable conditions for geothermal energy exploitation. These conditions make it indeed possible to extract thermal energy from the subsurface to provide heating and cooling services with high efficiency and low environmental impact.

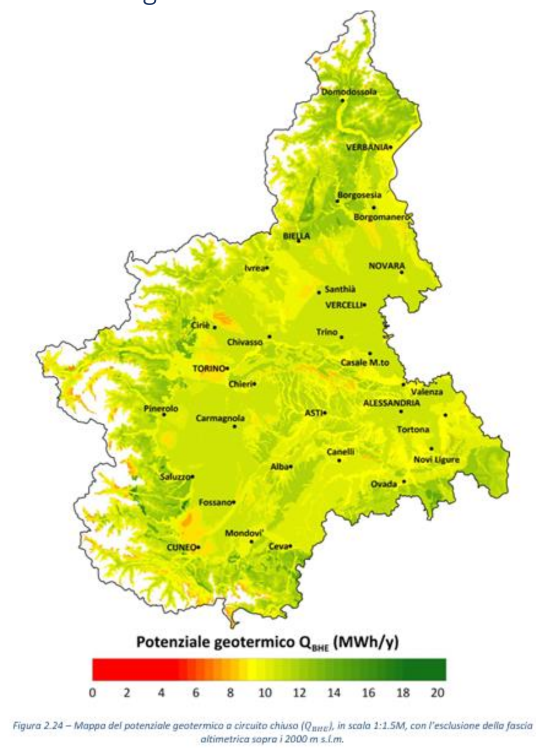

Figure 10: Map of geothermal potential in Piemonte region. Source: Regione Piemonte (2021)

[24] 'Geothermal Energy in Italy: Where and How It Is Produced', accessed 7 February 2025, https://www.enelgreenpower.com/learning-hub/renewable-energies/geothermal-energy/italy.

[25] Alessandro Casasso et al., 'Il potenziale geotermico a bassa entalpia nella Regione Piemonte', n.d.

Ground temperature varies between 10°C and 15°C at shallow depths (0-100m) and remains relatively stable throughout the year, making it suitable for heat pump integration. The study reports that in areas with favourable geological characteristics, a single borehole of 100 meters in depth has been estimated to be capable of extracting between 5 and 10 MWh per year.

Despite the promising geothermal potential, several barriers limit the development of geoDHC systems in the region, such as the complexity of the regulatory market, the absence of dedicated financial incentives, and the availability of infrastructures supporting the integration of geothermal. The permitting process results in being lengthy and complex, discouraging investments and slowing down project implementation. Multiple agencies and authorities are involved in the process due to the overlapping jurisdiction at the regional and national levels, contributing to delays in the process.

Another hindering factor is represented by the lack of dedicated financial incentives specifically targeting geothermal energy. While some subsidies for renewable energy are available, geothermal projects seem to receive less support than other technologies, such as solar and wind. The absence of a strong policy further discourages investment and project development. Also, the social acceptance of geothermal is complex due to environmental and seismic impacts.

Finally, the technical feasibility of geothermal energy projects further depends on the availability of existing infrastructure that can support the integration of geothermal heating and cooling into the regional system. In the region, the limited presence of district heating networks poses a serious challenge, since individual installations may be less cost-effective while requiring additional investments in local distribution infrastructure.

2.5.3. Nizza Monferrato district heating system

The SAPHEA project identified the municipality of Nizza Monferrato as a key study area due to the interest of EGEA, the owner of the existing district heating systems, in the integration of shallow geothermal in the network.

Nizza Monferrato district heating network was built in 2011 for the production of heat for the city's district heating network and electricity. The plant currently consists of a single cogeneration unit with an electrical output of 1,131 kw and a thermal output of 1,143 kw. The fuel used by the engine is natural gas. Adjacent to the cogeneration plant are installed 3 boilers of integrated thermal, natural gas-fired, with a total capacity of 9,600 kW.

The useful heat produced in the form of hot water at about 90°C is fed into the Nizza Monferrato district heating network and delivered to users through the heat exchange stations installed at the user's premises. Thermal energy is produced and released in the form of hot water and is used for the air conditioning of buildings and for domestic hot water.

Currently in its pre-feasibility phase, the project explores the potential of shallow reservoirs, ranging from 0 to 150 meters deep, as a valuable resource for district heating integration. Envisioned at the neighbourhood scale, the project aspires to bring renewable heating solutions to a small rural town. The anticipated long-term impacts of the project span environmental, social, and economic dimensions, with consistent reductions in PM10 emissions, pollution mitigation, and a lower CO2 footprint. Furthermore, the social benefits are equally significant, promising improved health conditions and a better quality of life through cleaner air and more affordable heating services. From an economic perspective, the initiative holds the potential to lower energy prices and enhance financial resilience for local communities. However, alongside these advancements, economic transitions bring their own challenges, including potential shifts in traditional industries and employment patterns. As the region moves toward renewable energy adoption, a balanced approach is essential to mitigate job losses and sectoral disruptions.

2.5.4. A roadmap for the development of deep geothermal district heating and cooling in Italy

The Italian roadmap provides a structured approach to developing deep geoDHC in Italy, assuming an optimistic approach in particular regarding the regulatory and policy environment.

The roadmap begins with an initial phase of resource assessment, taking approximately one year. At this stage, geothermal potential is evaluated through geological surveys and data collection, which are then elaborated to identify viable locations for deep geothermal exploitation and mitigate risks associated with subsurface uncertainties. Here, the financial support is primarily based on total equity investment, often supplemented by subsidies and high-risk soft loans or grants, encouraging private and public stakeholders to invest in exploratory activities. It is important to promote public and stakeholder engagement at an early stage, as well as conducting public communication campaigns to increase awareness of geothermal energy's benefits.

Ideally, during the third year, a simplification of the permitting process should be introduced at a national or regional level, and specific incentives should be made available to facilitate geothermal project development. At this stage, leveraging national and European funding opportunities plays a crucial role in securing financial support for further project development. On the technical side, exploratory drilling is conducted to confirm resource availability and temperature levels, while the commissioning of necessary infrastructure is planned. Over the following two years, project development advances to production drilling and the construction of geothermal infrastructure, requiring at this point capital investments. In this phase, the financial model transitions from high-risk to low-risk commercial loans and grants, supporting the large-scale deployment of geothermal district heating networks. At a political and regulatory level, policy measures should evolve to incorporate geothermal into local and regional climate action plans for decarbonising energy systems. Here, sustainability and societal readiness remain key aspects, with continued environmental and socio-economic assessments, as well as citizen involvement initiatives to address potential concerns while promoting public acceptance.

The fourth year marks the beginning of the operational phase, with geothermal heat supply becoming available to end-users. Operation and maintenance commence to ensure system reliability and efficiency, while energy sales allow for financial returns. At this point, environmental recovery strategies should be integrated into the long-term strategy to minimise any potential ecological impact and ensuring geothermal project remains a sustainable solution.

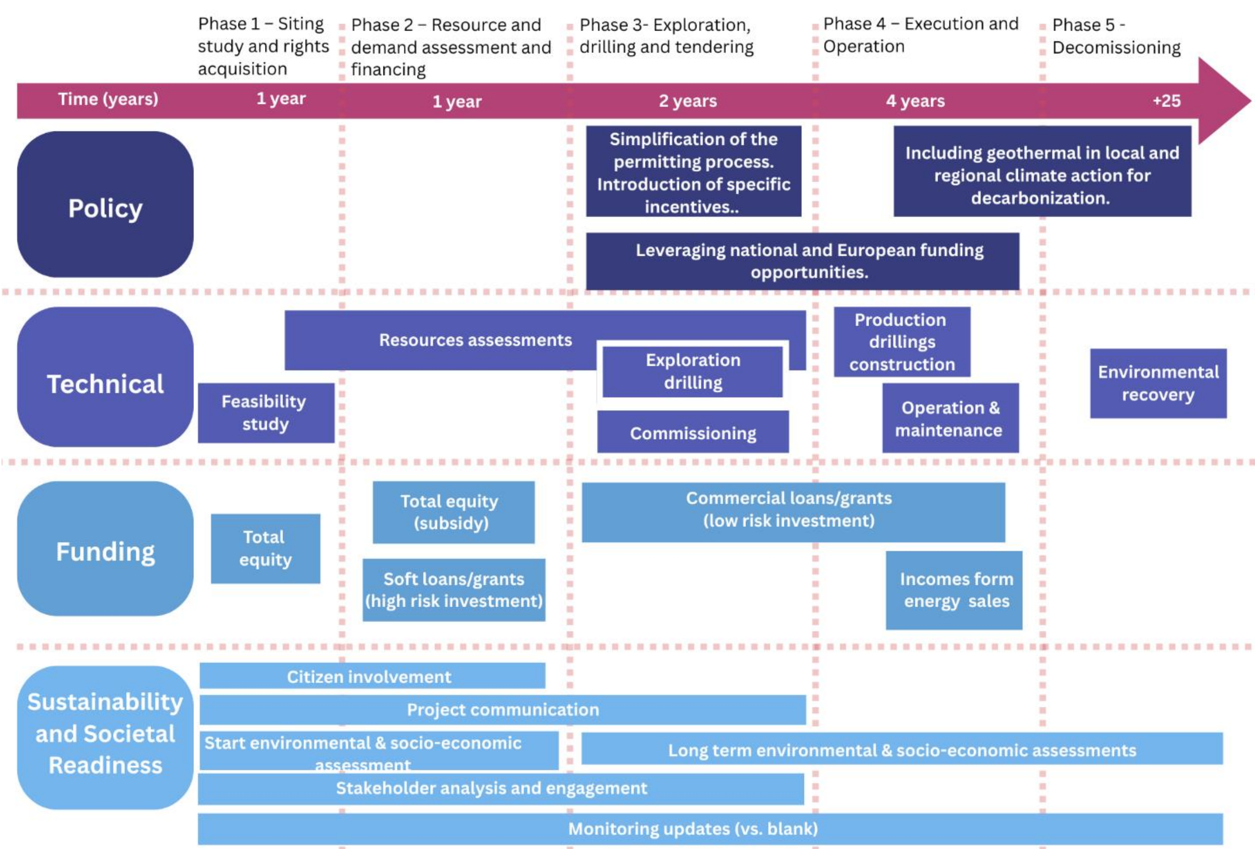

Figure 11: Roadmap for the development of deep geoDHC in Italy

2.6. Poland

2.6.1. Developed areas: the case of Podhale region

The subsurface of the Podhale region hosts a rich geothermal reservoir at depths of 2,200–3,400 meters. The geothermal district heating system has been in operation since 1993, and it represents one of the largest in continental Europe[26]. Three artesian wells produce a total water flow of approximately. 1,070 m³/h, with temperatures ranging from 82 to 86°C and TDS content of 2.5–2.7 g/L. The installed geothermal capacity was 40 MW [27] , with annual geothermal heat production reaching 653 TJ. During peak heating seasons, natural gas accounted for only 2–3% of total heat production. By 2022, around 2,000 customers were connected to the geoDH system, primarily in Zakopane—the region's main city and largest heat market, where geothermal energy met approximately 40% of total heat demand. Spent geothermal water was partially reinjected through three wells, while the remaining portion was supplied to two recreational centres.

Between 2020 and 2022, further investments focused on optimising and expanding the system, leading to an increase in installed geothermal capacity to 70 MW by 2023. The project has played a crucial role in reducing air pollution from local coal-fired heating boilers[28]. Between 1999 and 2020, coal consumption was reduced by 333 tons, significantly lowering CO_2 emissions by as much as 667 tons. Over the years, the significant geothermal resources of the Podhale Basin have continued to attract major investments. In 2023, drilling operations (Bańska PGP-4 well) began in Szaflary to reach an impressive depth of 7,000 m. Once completed, the geothermal resource will supply heat to the commune of Szaflary and the city of Nowy Targ[29]. Since the expected bottom

[26] Beata Kepinska and Marek Hajto, 'Geothermal Energy Use, Country Update for Poland, 2019–202', n.d.
[27] Beata Kępińska, Marek Hajto, 'Geothermal Energy Country Update Report from Poland, 2020– 2022', September 2023.
[28] "Poland - Podhale Geothermal District Heating and Environment Project", Text/HTML, World Bank, accessed 17 February 2025, https://documents.worldbank.org/en/publication/documents-reports/documentdetail/en/731691468763220932.
[29] "Drilling Resumes on 7-Km Geothermal Well in Szaflary, Poland - World-Energy", accessed 17 February 2025, https://www.world-energy.org/article/43239.html.

hole temperature will reach 150-180°C production of electricity in the binary system is also considered.

2.6.2. Underdeveloped areas: the case of Krakow

Krakow city is located outside Poland's primary geothermal reservoirs. Its position at the intersection of three major geostructural units in southern Poland adds complexity to its geological and geothermal conditions. Limited exploration by the oil industry in the city has resulted in scarce geological and hydrogeological data, making a reliable assessment of its deep geothermal potential challenging. Additionally, no seismic studies have been conducted in the area. The existing knowledge of Krakow's deep geothermal potential is solely based on several exploration oil wells drilled in the late 1960s in the Nowa Huta district in the eastern part of the city. Regional studies and published findings indicate that only this area holds promise for deep geothermal exploration. However, despite its potential, geothermal water has yet to be exploited in Krakow.

Medium-depth geothermal resources are expected to provide heating for planned buildings, including recreational facilities such as a wellness Centre with thermal pools. Given the area's unfavourable conditions for full reliance on high-temperature district heating (135/70°C), once geothermal resources are confirmed, a low-temperature district heating system is expected to be developed. This system may incorporate thermal energy storage, heat pumps, and, to a lesser extent, high-temperature district heating. If verified, the deep geothermal well could provide ca. 3 MW of heating, while the total heating demand for the "Kraków – Nowa Huta District of the Future" project exceeds 60 MW_t—most of which is expected to be met by shallow geothermal resources or gas boilers [30].

To advance geothermal energy development, the Krakow municipality in 2013 secured PLN 12 million (EUR 3 million) in subsidies from the National Fund for Environmental Protection and Water Management (NFEPWM). The planned well will reach a depth of up

[30] 'Homepage - Nowa Huta Przyszłości', nhp, accessed 28 March 2025, https://knhp.com.pl/en/home-page/.

to 1,820 meters, with an expected water temperature of 50–55°C [31]. Drilling is scheduled to begin in late 2025 or early 2026.

The remaining areas of Krakow offer highly favourable conditions for shallow geothermal energy, including both ground-source heat pumps (GSHPs) and water-source heat pumps (WSHPs). This potential is particularly significant due to the presence of shallow groundwater reservoirs beneath the city, which can serve as sources for geothermal heating and cooling collectors [32].

The city of Kraków presents very suitable conditions for geothermal, especially its shallow use. This is because of the various groundwater reservoirs located below the city for geothermal heat and cooler collectors. In 2023, the city of Krakow received funding for the development of a geothermal research well reaching a depth of around 1,820 meters[33].

In Poland, geothermal development is restrained because of long-term procedures, meaning about 8-10 years from the concept to the production. High salinity water in deep wells and lower geothermal water temperatures than in the existing heating networks may also limit geothermal development in Poland. However, financial support from NFEPWM priority programs in 2017—2023 provided an opportunity to drill 56 wells and hopefully launch new geothermal heating plants in Poland soon. It is worth mentioning that during the 2017—2023 years, total funding for geothermal projects, primarily drilling, through NFEPWM amounted to nearly PLN 1 billion (EUR 250 million).

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[31] 'Umowa Na Dofinansowanie Badawczego Odwiertu Geotermalnego Podpisana- Oficjalny Serwis Miejski - Magiczny Kraków', accessed 28 March 2025, https://www.krakow.pl/aktualnosci/289474,2163,komunikat,umowa_na_dofinansowanie_badawczego_odwiertu_geotermalnego_podpisana.html.

[32] 'Geotherm, Potential Maps, Interreg', Interreg CENTRAL EUROPE, accessed 28 March 2025, http://programme2014-20.interreg-central.eu/Content.Node/GeoPLASMA-CE.html.

[33] 'Pierwszy głęboki odwiert geotermalny w Krakowie – znamy szczegóły', GLOBENERGIA, 8 January 2025, https://globenergia.pl/pierwszy-gleboki-odwiert-geotermalny-w-krakowie-znamy-szczegoly/.

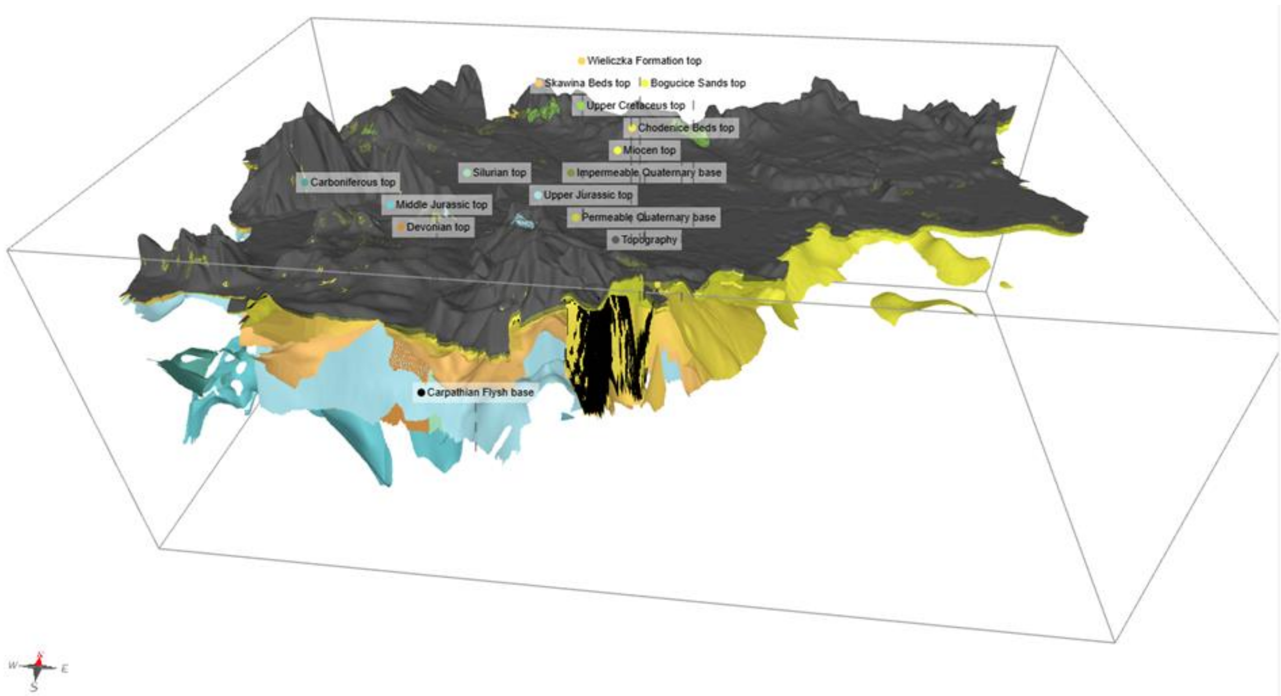

Figure 12: 3D geological model of the Krakow area. Source: GeoPLASMA-CE project

2.6.3. A Roadmap for the development of deep geothermal district heating and cooling in Poland

Building on the general phases identified in Chapter 1, the roadmap for Poland identifies the key phases characterising the development of deep geothermal district heating and cooling projects in the country. The first year focuses on the preliminary resource assessment, together with the preparation of the geological works project and the drilling design, taking around four months. At a technical level, rights acquisition occurs in this phase, requiring two months for its finalisation. Already at this point, geothermal should be included in local and regional action plans for the decarbonisation of energy systems, introducing incentives for geothermal project development, improving data accessibility and streamlining the permitting process. Environmental and socio-economic assessment should be carried out, as well as actions to involve citizens and communication about the project. These activities will be carried out throughout the project life, adapting towards a more long-term assessment approach. During the second year, no technical work will be conducted prior to the acquisition of funding.

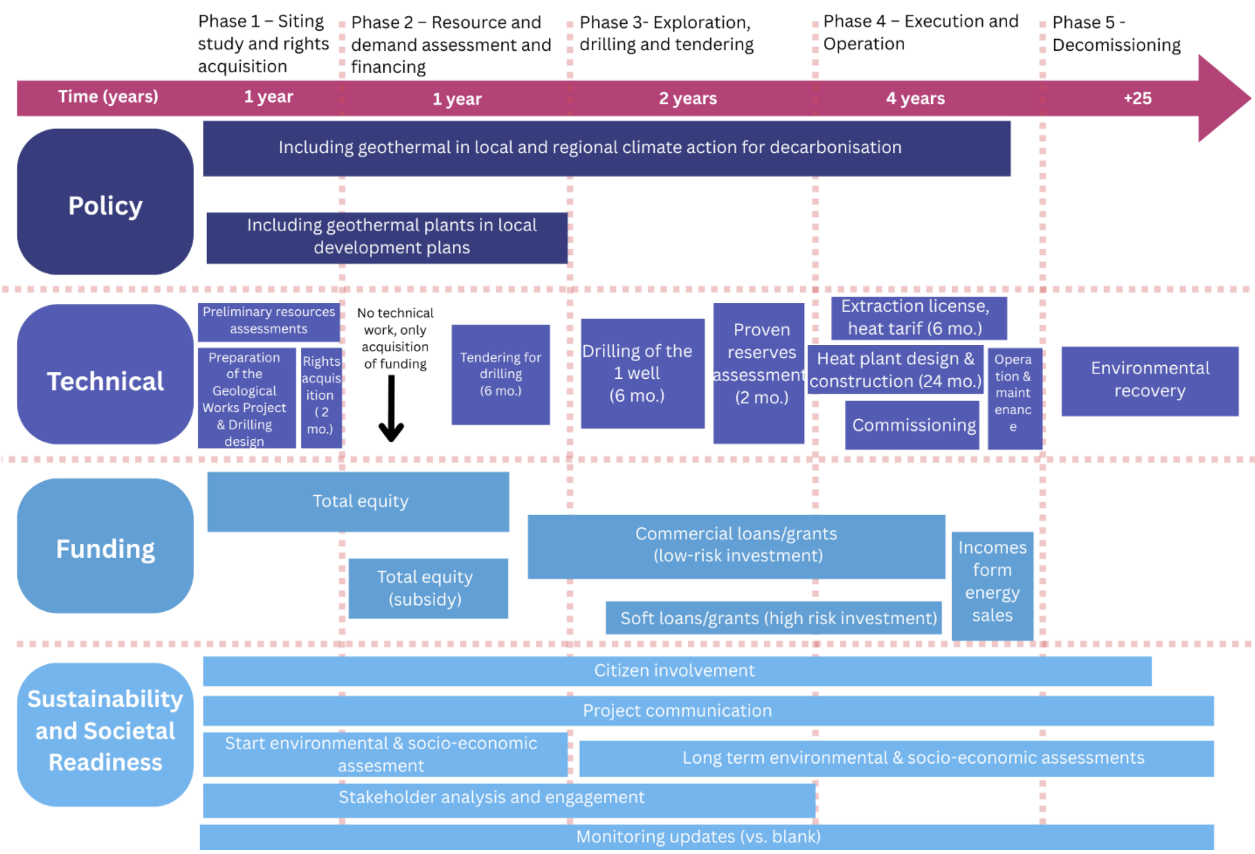

Figure 13: Roadmap for the development of deep geoDHC in Poland

After two years, the drilling of the first well can commence, taking around 6 months for its finalisation. Following this stage, two months will be required to assess the resource potential. In this phase, the project should rely on commercial loans or grants characterised already from a low-risk profile of investment, together with soft loans and grants defined as a high-risk investment level.

In 4 years from the beginning of the project, the heat plan will be designed and then put in place, requiring around one year for its realisation. From a technical perspective, this phase is characterised by the commissioning of the plan and later from the beginning of its operation and maintenance. Here, the project will start receiving income from energy sales from the operating plant, moving to a more mature funding stage.

2.7. The UK

2.7.1. Developed areas: the case of Cornwall

In the Southwest of the UK lies the county of Cornwall, which presents fitting conditions for geothermal exploitation. With a heat flow of 120-140 W/m², Cornwall is one of the most suitable places for deep geothermal energy production in the country. With the 300 million-year-old granites that run through the peninsula, the focus has been put on geothermal electricity generation. Granite is a naturally hot rock that in Cornwall is particularly close to the surface. Thereby, drilling costs are reduced. The region holds the potential to reach as much as 4 GW of electricity with 13 GW of heat as a by-product that provides heating to local housing and businesses.[34]

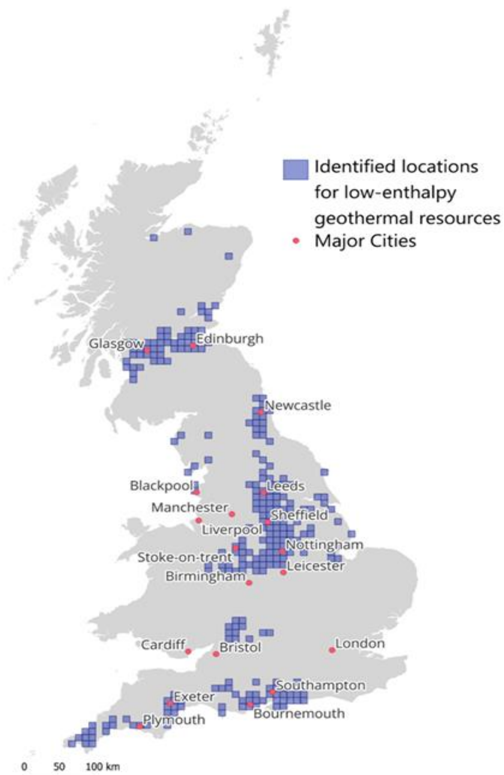

Figure 14: map of identified most suitable areas for deep geothermal networks (2024). Source: Elsevier

[34] 'Geothermal Potential in Cornwall and the UK', *Eden Geothermal* (blog), 12 July 2021, https://www.edengeothermal.com/about/geothermal-energy/uk-and-cornwall-potential/.

2.7.2. Underdeveloped areas: the case of Central Britain

The region of central Britain has a considerable geothermal potential at depths around 4km below the surface. Through recent 3D modelling methods, scientists have been able to identify the richest areas and estimate their heat in place [35]. Despite the importance of geothermal resources in the UK, geothermal heating and cooling still represent a niche market in the country. Several reasons can be taken into account to explain this result.

Firstly, since geothermal energy is not recognised as a natural resource, unlike others such as water or gas, there is no specific framework for licensing and managing geothermal heat, leading to a regulatory gap. Indeed, even though geothermal developments are regulated, with differences considering the technology used, diverging approaches apply on the basis of the administration involved [36].

Another challenge lies in the lack of governmental support and investment opportunities. Geothermal technologies are eligible to bid for funding under the main government's subsidy for low-carbon electricity generation, the „contracts for difference" scheme, as well as the „boiler upgrade scheme" assisting homeowners and businesses in England to replace their fossil fuel boilers with heat pumps. Even with the availability of these measures, geothermal technologies suffer from competition with other renewable technologies, mostly wind and solar, that are more subject to political attention.

2.7.3. The United Downs project in Cornwall

The United Downs Project is the flagship project of Geothermal Engineering Ltd (GEL), a geothermal developer and operator based in Cornwall. The aim is to output the UK's first geothermal electricity to the grid, producing a gross output of 3 MWe. However, in addition to power, there is potential for the 15 MWth heat production. Furthermore, GEL

[35] B. G. S. Press, 'Scientists Discover Regions of the UK with Greatest Potential to Use Heat from Deep Thermal Waters', *British Geological Survey* (blog), 30 March 2023, https://www.bgs.ac.uk/news/scientists-discover-regions-of-the-uk-with-greatest-potential-to-use-heat-from-deep-thermal-waters/.

[36] 'Future of the Subsurface: Geothermal Energy Generation in the UK (Annex)', GOV.UK, accessed 7 February 2025, https://www.gov.uk/government/publications/future-of-the-subsurface-report/future-of-the-subsurface-geothermal-energy-generation-in-the-uk-annex.

possesses planning permission for two further sites in Cornwall, which have been designed to produce up to 5 MWe, 20 MWth each.

GEL has explored the potential use of geothermal heat post-power production at United Downs, holding discussions with a number of industries, local businesses and working with local government (Cornwall Council) on the conceptual, commercial and technical details of a potential district heating system in Cornwall. High fuel costs across the UK and extensive fuel poverty in Cornwall make district heating an environmentally and socially important development.

Throughout the period of the SAPHEA project, the United Downs project has progressed, and work with Cornwall Council continues. At this time, there is no end-user for the heat available post-power production at United Downs due to a lack of local heat users and issues transporting heat. As development continues, United Downs remains an early-stage case study for the development of geothermal district heating in the UK, as the potential for such a development remains.

2.7.4. A Roadmap for the development of deep geothermal district heating and cooling in the UK

The roadmap for the development of the deep geothermal district heating and cooling in the UK slightly differs from the other roadmaps analysed until now. As usual, the project starts with the site evaluation, requiring a field study as well as data collection to assess the characteristics of the site. A few months later, the geophysical study commences, contributing to the elaboration of a detailed geological analysis. As in the previous cases, the early stages are also characterised by the involvement of citizens in the project development through different actions to raise public awareness and acceptance. Within this roadmap, a stakeholder analysis takes place from the beginning, maintaining their engagement until the end of the project.

During the second phase, the resource assessment will be carried out, spanning over the following phases to the execution and operation stage. From a policy point of view, after the preparation of the planning application, usually requiring between six and nine months to be prepared, the project will require obtaining planning consent, taking around 12 or 18 months to be earned.

Depending on the length of the resource and demand assessment, the exploration drilling begins. Here, the permitting process should be simplified, while incentives should be introduced to support the development of geothermal projects. This phase is also characterised by the shift towards more low-risk investment through commercial loans and grants, rather than the initial high-risk investment characterising the previous phase.

This stage is then followed by the production drilling, testing and simulation, construction of the plant, commissioning, and finally the beginning of operation and maintenance. At this point, geothermal should be included in local and regional climate actions for decarbonisation, some years later than the other roadmaps analysed in this report. From a funding perspective, the operation of the plant marks the beginning of energy sales and consequently new income for the project.

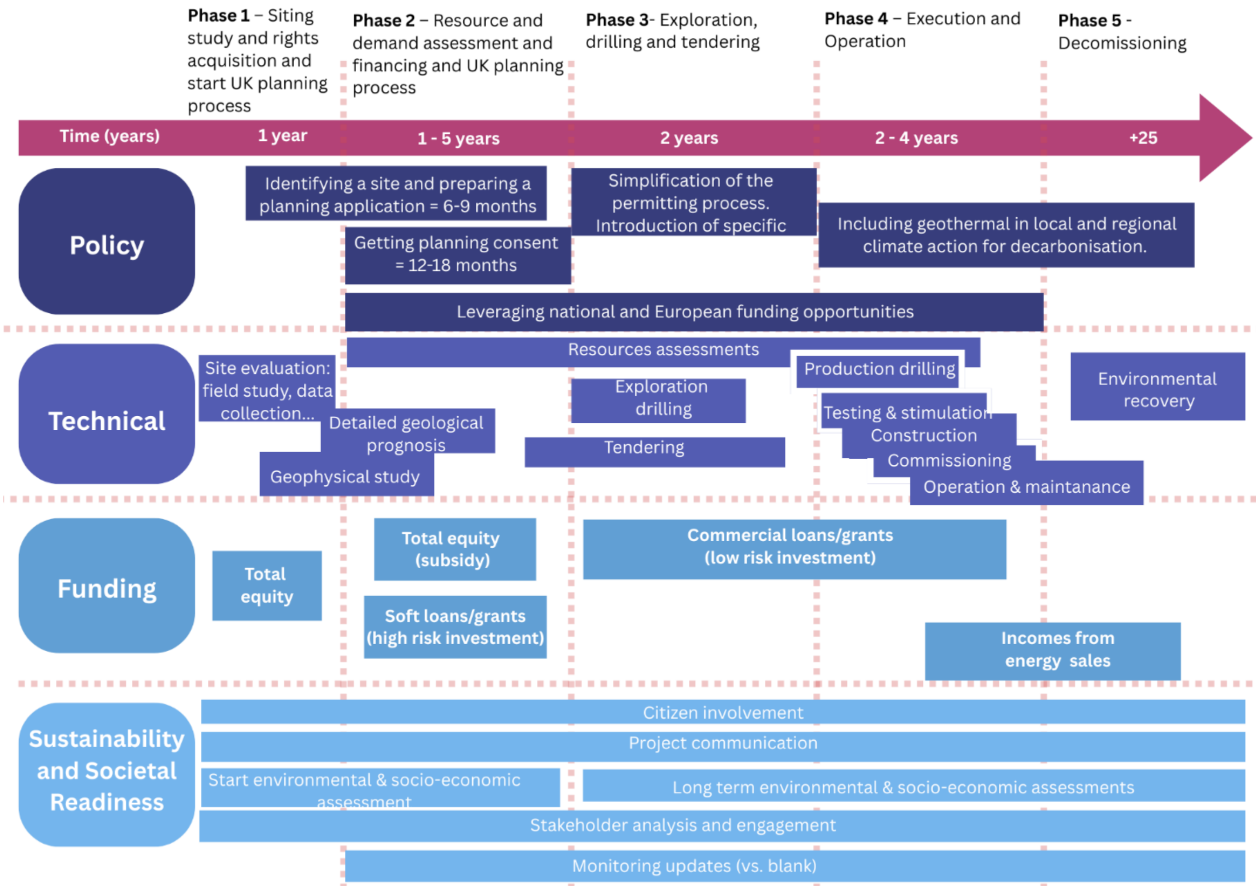

Figure 15: Roadmap for the development of deep geoDHC in the UK

3. European Roadmap for deep geothermal DH networks

Building on the roadmaps developed by SAPHEA partners for Austria, Denmark, France, Germany, Italy, Poland, and the UK, it was possible to determine common trends and key performance indicators (KPIs) that should be considered at the European level for geoDHC development. The following exercise consisted of summing up the similarities among the roadmaps developed, resulting in the elaboration of five phases that should guide the process of geoDHC development:

1. More Exploration and resource assessment,
2. Streamlining of policy and regulatory framework,
3. Fund Infrastructure development and pilot projects,
4. Allow Market expansion in both already developed areas and new areas,
5. Ensure Long-term sustainability of the European economy.

These phases reflect in part the thematic layers identified in the structure of the roadmaps considered in this report. For each phase, several KPIs (not exhaustive) have been selected that provide a quantitative reference for guiding the completion of each phase. In this analysis, the attempt was to go further with the geoDHC project development and envisage the impact at a broader and long-term level (2050), considering a process towards the streamlining of the regulatory and policy framework, the market expansion and long-term sustainability.

Phase 1: More exploration and resource assessment (years 1-3)

The first phase focuses on confirming the geothermal resource potential through data collection, feasibility studies and initiate pilot projects. More data acquisition is needed and data availability for project developers is crucial. Digitalsaition of this resouce data will support the process.

Relevant KPIs for phase 1: exploration and resource assessment
N. of geothermal resource assessment campaigns completed
N. of exploration drilling conducted
Percentage of the region covered by high-resolution geothermal mapping, with data publicly available
Increase Stakeholders engagement level
Funding secured for feasibility studies

Phase 2: streamlining of policy and regulatory frameworks (years 2-5)

This phase consists of the simplification of the permitting process and the introduction of targeted geothermal-specific incentives, also leveraging national and European funding opportunities to support infrastructure development. Geothermal energy should also be included in local and regional climate action plans to ensure its contribution to national decarbonisation goals and the EU's Fit for 55 strategy.

Relevant KPIs for phase 2: streamlining of policy and regulatory frameworks
Reduction in permitting time: adapt national laws and regulations, adopt new guidelines and standards, ensure capacity building of permitting authorities
Financial support schemes available for de risking the resource and fund the grid infrastructure
Adopting a national roadmap/strategy

Phase 3: Fund infrastructure development and pilot projects (years 4-7)

This phase focuses on building the necessary infrastructure to integrate geothermal into the grid, by establishing pilot geothermal installations in public buildings, industrial areas and residential communities and upgrading existing heating networks to integrate geothermal resources. The pilot projects will serve as proof of concept to showcase financial and environmental benefits.

Relevant KPIs for phase 3: infrastructure development and pilot projects
N. of pilot geothermal systems installed
Geothermal District heating network expansion
Installed geothermal heat and cold capacity (MWth) from pilot projects
Reduction in fossil fuel consumption where geothermal has been integrated
Public awareness level (e.g., surveys on acceptance of geoDHC)

Phase 4: Allow Market expansion in both already developed areas and new areas (years 6-10)

Phase 4 focuses on scaling up geothermal adoption from pilot projects to major deployment in residential, commercial and industrial sectors all over the EU countries. By this time, project developers should also implement public information campaigns to highlight cost savings and sustainability benefits, as well as secure long-term financing.

Relevant KPIs for phase 4: market expansion
N. of full-scale geothermal systems implemented
Reduction in heating and cooling costs
Job creation in the geothermal sector

Phase 5:Ensure Long-term sustainability of the European economy (years 10+)

Finally, the long-term sustainability of geothermal projects must be implemented through advanced monitoring and optimisation systems. This phase will require a longer period of time with a broader impact at the regional or national level.

Relevant KPIs for phase 5: long-term sustainability
Operational geothermal capacity vs planned capacity
Growth in research and development projects
Geothermal energy cost competitiveness
Percentage of municipalities and industries integrating geothermal in their energy transition plans

The roadmaps collected have served the purpose of reflecting on the specific characteristics for geoDHC development that we experience at the national and even project levels. The identification of 4 general thematic layers for all countries allows for the comparison among the roadmaps elaborated and the subsequent summing up of them through the identification of five phases reflecting on the medium and long-term rollout of geoDHC networks in Europe. The “translation” of the stages of the project development into concrete phases and KPIs supports policymakers to understand what steps are needed for the successful implementation of geoDHC systems in Europe. The broader approach undertaken here allows for the adaptation of this structure according to the local needs of each region or country.

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„SAPHEA will tackle this challenge to promote more geothermal energy supply heating and cooling networks to become a key element of the green and sustainable transformation of the European energy sector."

Gregor Götzl – main proposer