



Transnational Strategy for the structural change of fossil fuel producing regions to geothermal

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D.3.2.1 TRANSNATIONAL STRATEGY FOR THE STRUCTURAL CHANGE OF FOSSIL FUEL PRODUCING REGIONS TO GEOTHERMAL

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Glossary / List of Abbreviations

Well (borehole, wellbore)	A well is a hole drilled into the ground, to produce or inject fluids from/to the subsurface or to explore the subsurface.
Active	A well that is currently in use. It either produces the resource for which it was constructed or a fluid (e.g., wastewater or gas) is injected through it
Inactive, shut - in	No production or injection of liquids or gases in a certain time span, which could be 3 - 12 months (no clear definition). Shut - in wells may have been removed from active service in anticipation of workover, temporary abandonment, or plugging and abandonment operations. Generally, the well condition is such that its utility may be restored by opening valves or by energizing equipment involved in operating the well. Shut - in status should begin three months after production, injection, disposal, or workover operations cease.
Partly (temporarily abandoned)	All the downhole (artificial) lift equipment and tubing is removed, and a cast iron bridge plug is set. A temporarily abandoned well can be put back in production. Temporary abandonment should be used when an operator is holding a wellbore in anticipation of future utilisation, such as in an enhanced oil recovery project. This status should begin the day after the completion interval has been isolated from the wellbore.
(Permanently) abandoned (liquidated, suspended, decommissioned)	Setting of a bridge plug and cement on top of it, cut off of wellhead and reclamation of the land. Wells that have been permanently abandoned have been backfilled to the surface or cemented (with cement plugs from the surface). In most cases they are not suitable for geothermal purposes, especially not for closed loop or storage applications, but the information that can be obtained from them can be useful in the design of geothermal projects planned in their vicinity, provided that there is a suitable market.
Orphan well	There is no identifiable owner of a well.
Reuse, repurpose	The use of an oil or natural gas well for another purpose after production or drilling is finished. Multiple sections of a well can be cemented.
Workover	Any operation done on, within, or through the well after the initial completion (e.g., artificial lift installation, acid stimulation, scale and paraffin removal, hydraulic fracturing, sand control, etc.).
Recompletion	Activity intended to access a new source of supply from a reservoir that is accessible from an existing well with new/changed subsurface equipment. Well reuse could need a recompletion.
DBHE	Deep Borehole Heat Exchanger
BTES	Borehole Thermal Energy Storage
ATES	Aquifer Thermal Energy Storage
HE	Hydrothermal Energy



EGS	Enhanced Geothermal System
UTES	Underground Thermal Energy Storage
PTES	Pumped Thermal Energy Storage
MTES	Mine Thermal Energy Storage



Executive Summary

The project TRANS GEO - Transforming abandoned wells for geothermal energy production - is implemented by a consortium consisting of 11 partner organizations from 5 Central European countries (Austria, Croatia, Germany, Hungary and Slovenia), whereby the combination of knowledge, expertise and research in the field of geothermal energy utilisation results with high - structured, practice - based and scientific outputs in the forms of digital tools, documents and other sustainable solutions.

One document arising from the joint collaboration is this **Transnational Strategy for the structural change of fossil fuel producing regions to geothermal**, for which the starting inputs were numerous project activities and outputs, as well as the overall expertise of the consortium. The main sources of data were 3 socio - economic analyses of repurposing abandoned wells for industrial, agricultural and municipal use, the IT tool for well assessment and its corresponding report and a comparative analysis of policy frameworks in different regions. These data were collected from scientific and research papers, available databases, comparisons of the existing strategic documents, as well as joint consultations and knowledge sharing between the partner organizations. This strategic document was thus prepared with the intention to serve as a theoretical guideline for different public and private stakeholders, with the aim of directing them towards a more regulated and organized utilisation of geothermal energy from abandoned hydrocarbon infrastructure. Furthermore, the document and its findings reflect, exclusively, the views of the authors.

To achieve the set vision, purpose and goals, the Transnational Strategy covers the current situations in the 5 countries included in the project TRANS GEO on the legislative, legal and educational features, environmental impacts and financial opportunities for geothermal energy utilisation from abandoned hydrocarbon wells. The document's significance lies in the identification of challenges and obstacles emerging in the implementation of geothermal projects and investments, whereby thorough analyses showed that long-lasting administrative procedures, lack of quality and professional staff, technological gaps and insufficient comprehensive funding opportunities are the largest hindering factors.

In order to address the identified bottlenecks, the Transnational Strategy, also, presents proposals and solutions in the forms of Strategic Objectives, Priorities, and Measures, grouped into 4 main categories: legal, knowledge and social frameworks; technological opportunities; environmental impacts; and financing instruments. Their overall focus is placed on simplifying and improving the availability of the various resources needed to enhance geothermal energy utilisation from already existing infrastructure. Finally, since these focus categories and recommendations are presented only in a concise form, this document serves as the basis for the future development of the **Transnational Action Plan with intervention set for geothermal reuse of abandoned hydrocarbon wells**.

The project TRANS GEO (<https://www.interreg-central.eu/projects/transgeo/>) is co - funded by the European Regional Development Fund through the Interreg Central Europe 2021 - 2027 program. The overall objective of the project TRANS GEO is to investigate the potential to transform abandoned hydrocarbon (natural gas and oil) wells into new sources of green geothermal energy. To reach this goal, the TRANS GEO partner organizations are providing new tools and knowledge to support communities and industries in the energy transition and to break down economic and technical barriers to well reuse.

**Please note that this Executive Summary is provided in German, Croatian, Hungarian, and Slovenian languages in Annexes at the end of the document (pages 168-171).*



1. Strategy development process

Fossil fuels are formed over millions of years from the carbon - rich remains of dead flora and fauna that have been buried in the Earth's crust. Hidden between the soil layers, they are exposed to decomposition, compression, heat and pressure, which transforms them into highly used, mostly carbon - charged and shortly non - renewable energy sources. In the past, energy sources such as human and animal muscle, as well as biomass were used for hunting and surviving purposes and the use of fossil fuels began more actively during the Industrial Revolution, when they facilitated technological, social, economic and industrial progress (EESI, 2021; Richie, Rosado, 2022).

Today, several forms of fossil fuels are known, but the most used are coal and coal products, natural and derived gas, fuel and crude oil, petroleum and non - renewable wastes. Although the production and use of fossil fuels have a significant impact on the world's economy, industry, transport and human lives in general, their more frequent exploration and exploitation leave negative impacts on the environment and human health and showing them as major pollutants and drivers of the global climate changes faced during the last years. Their consumption causes extreme temperatures, catastrophic weather conditions (droughts, fires, storms, floods), as well as the emergence of new diseases and impaired health (Eurostat, 2024; Richie, Rosado, 2022).

Furthermore, the exploration, exploitation and production of fossil fuels require large infrastructure and human investments, including drilling wells, setting up the necessary machines and equipment, security activities and employing the trained workforce. After the final exploitation of the fossil material, the well is shut - in, abandoned and left to decay, but it may still contain useful material in the form of hot water. The water is renewable, non - polluting, widespread and, therefore, a good replacement for the existing fossil energy sources.

In recent years, due to faster climate changes, higher costs of fossil fuel production and consumption, and slow depletion of the hydrocarbon resources, new policies recommend the use of renewable energy sources to make a complete energy transition. The most common sources are solar, hydropower, wind and biomass, but the producers and consumers are, more and more, turning to a new energy source available underground: geothermal energy.

The project TRANSGEO - Transforming abandoned wells for geothermal energy production deals with exploration and exploitation of geothermal energy from the existing wells remaining from the abandoned hydrocarbon production in the Central European region. As the aim of the project is to transform the abandoned natural gas and oil wells into geothermal ones, the ultimate expected results focus on the following:

- Initiating an economically feasible and sustainable transformation in Central European region with hydrocarbon industries
- Structural changes in the hydrocarbon industry to transition to a sustainable and green energy using the existing infrastructure
- Promoting the use of geothermal energy, heat production and energy storage
- Extending the life cycle of the existing infrastructure
- Reducing Greenhouse Gas (GHG) emissions
- Employing and reusing the remaining hydrocarbon knowledge, technology and manpower.

Through various activities, including considering available geothermal repurposing technologies, analyzing the potential use of geothermal energy in industry, agriculture and municipalities, developing IT tools, criteria catalogues and well databases, assessing the repurpose potential of existing wells, writing feasibility studies, as well as preparing strategic and planning documents, the project TRANSGEO is addressing the key



issues regarding the reuse of currently abandoned hydrocarbon wells and their transformation into useful sources for geothermal heating, cooling, industrial production, storage and other applications in the Central European region.

One of the main documents arising from the project itself is this **Transnational Strategy for the structural change of fossil fuel producing regions to geothermal** developed by the partner organisations from 5 countries of the consortium (Austria, Croatia, Germany, Hungary, Slovenia) and intended to be shared with national and regional policy makers, local authorities, research institutions, development and energy agencies, private companies and the general public, with the aim of raising awareness about reducing the consumption of fossil fuels, as well as the importance and benefits of the transition to geothermal energy use.

Related to the above, the Transnational Strategy is the result of the joint effort of the project consortium, with the systematic presentation of the following topics:

- Legislative and legal framework for geothermal energy exploration, exploitation and use
- Geothermal and well repurpose potential of the observed countries
- Environmental impact of the geothermal energy use and well repurposing
- Financing options and schemes
- Identified challenges and associated Objectives
- Implementation process.

This document thus applies expertise and knowledge of the partner organizations and combines the theoretical approach to geothermal energy with practical experience at the national level.

VISION

The Transnational Strategy aims to guide the national, regional and local stakeholders of the Central European region in a faster, easier and more efficient transition from fossil fuels to geothermal energy use for heating, cooling, industrial production, storage and other applications in public and private buildings. Additionally, through its extensively developed and detailed Chapters the document intends to raise awareness about the various environmental, infrastructural and social benefits of using geothermal energy from repurposed wells. The overview of the current features, identified challenges, Objectives and defined Measures, as well as suggested implementation methods can lead to a more sustainable, greener use of the stored geothermal energy and can, thus, reduce the negative implications of fossil fuel consumption.

The infrastructure from the fossil fuels industry that is left behind after the open wells are shut - in and abandoned can slowly decay and, in the long term, cause significant soil and underground water pollution and change the biodiversity of the sites. Therefore, it is a significant opportunity to put the abandoned infrastructure in motion again to extend its life and use the full potential of the equipment and the previously drilled wells.

Finally, this document will provide a basis for future decision making and setting of goals in the process of transition to renewable energy sources in the Central European region and, possibly, beyond. Accordingly, the vision of the Transnational Strategy is as follows:

Making Central Europe a more sustainable and greener region through a more efficient transition to geothermal energy by using existing infrastructure and resources, as well as guiding national, regional and local stakeholders to a better understanding of the positive impacts of renewable energy sources.



PURPOSE AND GOALS

The fast modernization processes in the world (especially in the economy, industry, transport, agriculture and public sector) require increased consumption of different energy sources, mainly fossil fuels such as coal, natural gas and oil. With environmental pollution growing rapidly, and the occurrence of extreme, often catastrophic, weather phenomena and worsening health conditions, the idea of replacing non-renewable energy sources with green ones became an imperative among the policy makers. Apart from using solar, hydropower, wind and biomass energy, the consumption of available geothermal energy reserves is becoming more and more frequent.

Since the use of geothermal energy is only now becoming more common, it is not fully regulated by national legislatures. The project TRANSCEO shows that the geothermal potential of the involved countries is high, as the currently used and abandoned fossil fuel exploitation fields are also filled with geothermal water, which can be used to produce heating and cooling for the public and private buildings and other applications in the region. Given that the geothermal potential in the mentioned regions is not fully explored, this Transnational Strategy will guide the national, regional and local stakeholders in the process of incorporating geothermal energy use into their future considerations, planning and investments, whereby its findings and recommendations are intended as support to policy makers in the development of their future strategies, action plans and laws regarding renewable, and especially, geothermal energy. Finally, stakeholders such as research institutions, development and energy agencies, private companies and the general public will get an overview of the economic, industrial, social and health benefits of using geothermal energy in their daily work and life.

The Transnational Strategy serves as an overall guideline document, which combines theoretical facts and practical experiences from the partner organizations regarding geothermal potential, as well as well repurposing activities and plans in their 5 countries. The structure of the document implies various analyses of strategic and legal documents, geothermal and well repurposing potential and financial options, as well as identifies the largest challenges and possible objectives on the national levels. The ultimate outcomes of this document are the implementation recommendations and guidelines for overcoming the identified challenges and achieving the Objectives on the path to an easier, faster and more efficient energy transition.

In order to emphasize the relevance and achieve its purpose, the Transnational Strategy summarizes the goals and the corresponding stakeholders/target groups as outlined in Table 1.

Table 1: The goals of the Transnational Strategy and the corresponding stakeholders/target groups

No.	Goal	Stakeholder/target group
Goal 1	Addressing the key elements of the geothermal and well repurposing potential in the Central European region	Public authorities, public entities, private entities, general public
Goal 2	Raising awareness about the positive impacts of renewable energy sources, with special emphasis on geothermal energy	Public authorities, public entities, private entities, general public
Goal 3	Providing guidance in future planning and investing into geothermal projects, with special emphasis on well repurposing	Public authorities
Goal 4	Recommending measures and giving advice about the implementation and financing of geothermal and well repurposing projects in the Central European region	Public authorities, public entities, private entities



Goal 5	Encouraging knowledge exchange and cooperation between the countries of the Central European region in the topics of renewable energy sources, with special emphasis on geothermal energy and well repurposing	Public authorities, public entities, private entities, general public
Goal 6	Enabling a faster and greener energy transition from fossil fuels to geothermal energy in the Central European region	Public authorities, public entities, private entities, general public

***Note:** the stakeholders/target groups are defined as follows: public authorities (national, regional and local policy makers and authorities), public entities (higher education and research institutions, development and sectoral agencies, infrastructure and public service providers, NGOs), private entities (industry, small and medium enterprises), general public

DEVELOPMENT METHODOLOGY

As mentioned, the Transnational Strategy is the result of a joint effort between the partner organizations, whereby they included their knowledge and technical experience, as well as practical experience and information from the 5 partner countries. The document has been developed and finalized with approval by the most relevant stakeholders/target groups.

The content of the Transnational Strategy is mainly based on several activities implemented within the project TRANSCEO, of which the most significant and influential are:

- A1.2 Socio - economic analysis of energetic use options of repurposed wells
- A1.4 Development of well assessment tool
- A2.2 Assessment of transnational well repurpose potential
- A3.1 Comparative analysis of policy framework of different regions.

In particular, the following deliverables informed the work on the Strategy:

- D.1.2.1 Socio - economic analysis report of repurposing abandoned wells for industrial processes
- D.1.2.2 Socio - economic analysis report of repurposing abandoned wells for agriculture use
- D.1.2.3 Socio - economic analysis report of repurposing abandoned wells for municipalities
- D.1.4.1 Web - based IT tool for well repurposing
- D.2.2.1 Report on the transnational repurpose potential in Central Europe
- D.3.1.1 Report on regional comparison of policy frameworks for well repurposing.

In order to ensure the replicability of the documents generated within the project TRANSCEO, the same are publicly available on the project official website (<https://www.interreg-central.eu/projects/transgeo/>), while the IT tool for well repurposing is placed on a separate website (<https://transgeo.eu>).

Also, the analysis of the current situations in the 5 countries of the consortium and their pilot areas, as well as the best practices and examples regarding geothermal energy and well repurposing, represent the key practical parts of the document.

To have a clear insight into the Transnational Strategy development process, the main steps are presented in Figure 1.

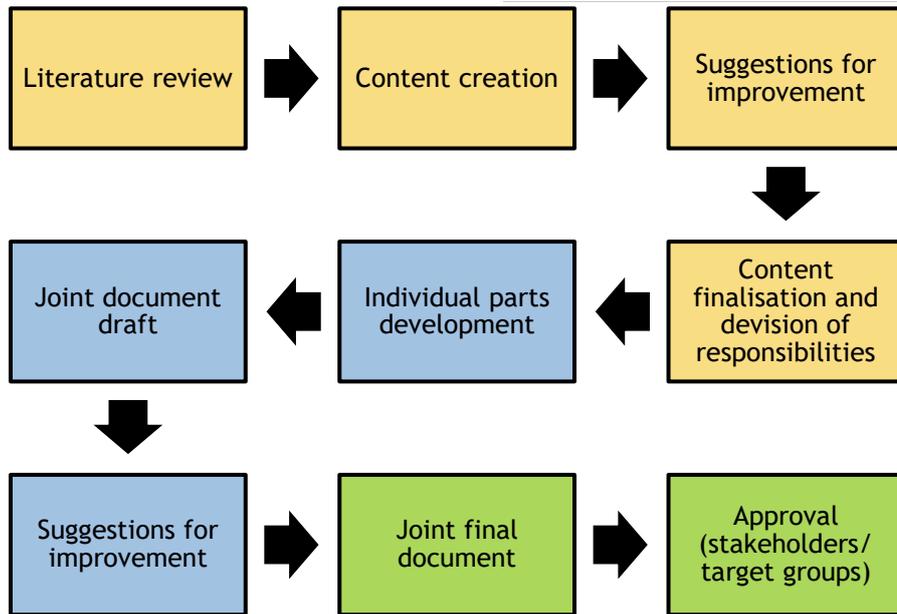


Figure 1: Development steps of the Transnational Strategy

According to Figure 1, the development process of the Transnational Strategy consists of preparatory activities (marked yellow), creation of the chapters and joint document (marked blue) and finalisation of the document (marked green). Furthermore, the finalisation of the document has been supported by various external organizations and institutions, which provided their practical knowledge and expertise in order to ensure a quality and broad applicability of the document. Finally, the Transnational Strategy was presented to relevant key stakeholders/target groups with the aim of gathering signatures for its approval and potential further implementation.

The methodology resulted in a document with 7 Chapters and detailed insights into the topics of renewable energy sources, geothermal energy, with special emphasis on well repurposing potential, funding opportunities for repurposing projects, as well as challenges, Objectives and Measures for a faster transition from fossil fuels use to geothermal energy consumption. Several Chapters combine the theoretical background with practical examples from the 5 countries of the consortium giving, thereby, a basis for implementing geothermal and, especially, well repurposing projects in the Central European region.

Finally, together with fossil fuels (coal, natural gas and oil) geothermal energy can be observed as one of the oldest energy sources hidden beneath Earth's surface. Decreasing exploitation of fossil fuels and abandonment of the exploitation fields leaves behind the infrastructure, professional equipment, expert manpower and wells containing significant geothermal fluids. In order to use the remaining potential by applying currently available and suitable geothermal technologies, the existing wells can be transformed and the geothermal material used as a green, renewable energy source, while having positive influence on the environment, economy and health conditions in the region. This Transnational Strategy, therefore, serves as a universal document providing information on technologies, actions, Measures and funding opportunities for transforming abandoned, decaying and forgotten wells into meaningful energy sources not only in the 5 countries of the consortium, but also throughout Europe.



2. Overview of the current features of geothermal energy utilisation in the Central European region

This Chapter provides an in - depth exploration of geothermal energy utilisation in Central Europe, focusing on the sustainable repurposing of abandoned hydrocarbon wells as part of the project TRANSGEO. It examines opportunities in geological basins such as the North German, Molasse, Vienna and Pannonian Basin and their alignment with EU goals such as the European Green Deal. The Chapter is divided into three 3 main parts. The first part gives an overview of the strategic, legislative, and legal framework for geothermal energy exploration and exploitation. It also outlines existing national strategies, such as development plans, alongside legislative frameworks covering mining, water rights, permitting, fees and risk mitigation. The second part describes the geothermal potential of the countries involved in the project TRANSGEO, assesses the geothermal capacity across the region and the potential for the use of geothermal energy in heating, power generation and industrial applications. The last part gives an overview of the well repurpose potential of the Central European region by evaluating the feasibility of converting abandoned wells into geothermal systems using the web - based IT tool for well repurposing developed within the project TRANSGEO.

2.1. Strategic, legislative and legal framework for geothermal energy exploration, exploitation and use in the Central European region

The transition towards sustainable energy sources in Central Europe presents a unique opportunity to repurpose abandoned hydrocarbon wells for geothermal energy production. The Central European region's history of hydrocarbon extraction has left behind thousands of abandoned wells, posing environmental risks but also untapped potential for renewable energy. Geothermal energy, a reliable and low - carbon alternative, offers substantial opportunities in geological basins like the North German, Molasse, Vienna and Pannonian Basin, which are regions of interest within the project TRANSGEO.

2.1.1. Austria

Related to the above, the following Subchapter gives insights into the strategic, legislative, legal, as well as educational features and opportunities in Austria related to geothermal energy in general, but, also, with focus on the energy utilisation from abandoned hydrocarbon wells.

2.1.1.1. Strategy for geothermal energy usage

In Austria, several deep geothermal projects have already been realised or are currently under development. The federal state of Upper Austria is regarded as a pioneer with 7 geothermal district heating networks, while most of the other heating plants are located in the federal state of Styria. The city of Vienna is also currently working on a large deep geothermal project. In terms of near - surface geothermal energy, there were around 90.000 installations in 2020, the installed heat output was 1.100 MW and the heat produced was 2.300 GWh. This corresponds to around a 4% share of the renewable heating market. With regard to deep geothermal energy, in 2020 there were 2 power generation plants with an installed capacity of 1,2 MW and 10 heat generation plants with an installed capacity of 100 MW_{th}, producing 300 GWh_{th} of heat.

Austria plans to continue expanding geothermal plants in the future. This strategic direction is reflected in Austria's National Energy and Climate Plan (NEKP) (BMK, 2024) and the Roadmap for Geothermal Energy (Zillner et al., 2022): As 700 - 1.000 MW_{th} of utilisable hydrothermal energy is available in Austria, the



targets for deep geothermal energy are the utilisation of at least 25% of known geothermal resources for district heating, supplying up to 500.000 residential units with geothermal district heating and saving up to 600.000 tonnes of CO₂ by replacing fossil fuels.

The Austrian government detected improvements for the legal framework for geothermal energy systems and integrated the following 3 points in the National government programme (Austrian Government, 2025):

- Development of a federal strategy for geothermal energy. The central objective is to define and initiate concrete expansion targets and the necessary implementation steps.
- Establishment of the necessary legal regulations in the Mining Act (MinRoG, in particular on the right of disposal, use of third - party land at great depths without touching the near - surface area, and treatment of the carrier medium) and the Water Rights Act (in particular the utilisation of the heat content of deep water and the obligation to tolerate the drilling and transmission of water at great depths, as well as the reintroduction of thermally utilised thermal water).
- Creation of risk - based subsidy instruments to mitigate the exploration risk and the risk of drilling failure.

2.1.1.2. Legislative and legal framework for geothermal energy

Hydrothermal systems in legislation are represented in an inadequate way. The legal definition and classification of raw materials and the regulations regarding the exploration, production, storage and distribution of geothermal energy are not clearly defined. In contrast to other raw materials, the extraction of deep geothermal energy is currently not clearly regulated in Austria and is fragmented across several laws (Mining Act, Mineral Resources Act, Water Rights Act, Commercial Law, etc.).

For geothermal projects, various regulations must be applied, for example the Mineral Resources Act (MinroG) when it comes to the exploration of potentials and mining permits, the Water Rights Act (WRG 1959) as soon as thermal water is pumped to the surface, the Electric Industry and Organisation Act 2010 (ElWOG) for electricity generation from geothermal energy and the Industrial Code 1994 for the construction of plants for the use of groundwater for heat generation. Under certain circumstances, geothermal wells are not subject to authorisation, whereas the use of thermal groundwater requires authorisation. Wells deeper than 300 m depth require permits in accordance with the Mineral Resources Act (MinroG) and Mining Law and deep drillings require an environmental impact assessment (EIA, in German: UVP) under certain circumstances. Larger groundwater extractions with a certain annual extraction or recharge volume are also subject to an EIA in specially designated areas. No single authority is solely responsible for the relevant authorisation procedures. Depending on the type of geothermal project, the necessary approvals must be obtained from the relevant authorities. In addition, there is a lack of professionally trained staff and clearly predefined processes at the individual contact points. The approval time is therefore difficult to estimate and is heavily dependent on the respective inspector.

As geothermal energy or the extracted water is not defined as a raw material in its own right, it belongs to the property owner together with the underground earth body. The development of geothermal energy must not impair the rights of third parties and administrative regulations must also be complied with. Furthermore, land ownership is not restricted in terms of depth and landowners can object if deep geothermal energy is drilled thousands of metres below their property.

There is no concession system for hydrothermal exploration, which means that the explorer of an area does not have the sole right to develop it, even though expensive seismic surveys or similar cost intensive methods were applied beforehand. The data sovereignty of wells currently still lies with oil companies or the operator of a well. There is no obligation to publish data, which means that the data is not available to the general public.



Depending on their scope, shallow geothermal projects can currently be realised more quickly than deep geothermal projects. This is mainly due to manageable investment costs, lower geological requirements and regulatory hurdles. In addition, near - surface geothermal energy can be customised using different technologies depending on requirements and local conditions. This allows greater scope for realisation.

In the sector of deep geothermal energy extraction with wells deeper than 300 m, due to regulatory hurdles and a lack of financing and insurance instruments, there are only a few projects realised or are currently being implemented in Austria. The lack of legal foundations, state incentives and instruments to insure against the discovery risk remain the biggest hurdles to the realisation of deep geothermal projects. The necessary framework conditions are also being created in Austria through the Climate and Energy Fund and new laws. It is therefore expected that the potential of deep geothermal energy can also be utilised to a greater extent in Austria in the future. On the one hand, the interest of industrial companies, as well as energy suppliers and municipalities in geothermal applications is increasing and, on the other hand, the cascading utilisation of various players such as industrial companies, operators of glass houses and other heat consumers will play a major role.

2.1.1.3. Educational opportunities for geothermal energy

Secondary and Technical Schools (HTL)

HTL Jenbach offers a 5 year higher technical education course in Energy and building technology, conducted in German. Located in the Austrian Tyrol, this program emphasizes sustainable building technologies and covers renewable energy sources such as geothermal systems. Graduates gain practical expertise in heating solutions, energy efficiency, and intelligent building systems, preparing them for careers in climate - friendly engineering.

Bachelor's Degree Programs

FH Technikum Wien offers a 6 semester BSc program in Renewable Energies, taught in German, providing a comprehensive engineering education in renewable energy for urban systems. Geothermal energy features prominently, with students learning about ground - source heat pumps and integrating geothermal solutions into building and energy infrastructures.

Montanuniversität Leoben provides an English - language BSc in Geoenergy Engineering. This unique six - semester program trains students in the sustainable use of underground resources, particularly geothermal energy, including reservoir assessment, drilling technology and geothermal applications for heating and power generation.

Master's Degree Programs

The NAWI Graz joint Master's in Geosciences, taught in English at the University of Graz and TU Graz, offers specialized courses such as "Geothermal Energy". This program prepares students with advanced knowledge in geothermal resource evaluation, hydrogeology and practical implementation techniques.

The University of Leoben also offers a four - semester MSc in Geoenergy Engineering in English, building on the BSc program. The curriculum includes geothermal reservoir development, enhanced drilling methodologies and management of integrated energy projects, qualifying graduates for specialized roles in geothermal energy production and storage (geoenergy engineering).

TU Wien offers a part - time MSc in Renewable Energy Systems, taught in English over 4 semesters. This postgraduate programme targets professionals from engineering, natural sciences, economics, or law. The curriculum covers a broad spectrum of renewable technologies, with a dedicated module on geothermal energy, wind power, and small hydro power. It combines theoretical instruction with case studies and excursions, awarding 120 ECTS credits. The MSc equips graduates with the expertise to plan, implement, and manage renewable energy systems across various sectors.



FH Burgenland offers a part - time MSc in Sustainable Energy Systems, delivered in German at the Pinkafeld campus, which provides an extensive education in renewable energy. It includes dedicated modules on heat pump technology and shallow geothermal systems, preparing graduates for professional roles in municipal and industrial geothermal heating and cooling projects.

Paris Lodron University Salzburg's MSc Geologie program, taught primarily in German with some English materials, includes applied geology modules relevant to geothermal energy. Students specializing in Environmental and Hydrogeology study geothermal groundwater utilisation and reservoir geology, equipping them for careers in geotechnical consultancy or further research.

PhD and Postdoctoral Programs

The University of Leoben offers a PhD in Petroleum and Geoenergy Engineering, conducted in English, allowing researchers to specialize in geothermal areas such as reservoir simulation, advanced drilling technologies, and thermal energy storage. The university's Petrophysics & Geothermics research group provides robust academic support for doctoral candidates.

The NAWI Graz Doctoral School of Earth Sciences supports doctoral research related to geothermal energy, particularly in hydrogeology and geophysics. Researchers investigate geothermal reservoirs, heat transport, and innovative extraction methods, significantly contributing to Austria's geothermal research landscape.

The Technical University of Wien (TUW) offers both PhD and postdoctoral research opportunities through its Institute of Geotechnics and Energy Economics Group (EEG). Doctoral and postdoctoral researchers can focus on geothermal - related topics such as energy geostructures (e.g., energy piles and diaphragm walls), underground thermal energy storage, and the integration of geothermal systems into decarbonised energy networks. Their work includes numerical modelling, experimental investigations, and interdisciplinary collaboration. Postdoctoral research additionally explores applied studies in shallow geothermal systems, flexible heating and cooling, and the optimisation of renewable energy integration. TU Wien thus provides a robust academic environment for specialisation and innovation in geothermal energy technologies.

Postdoctoral research opportunities exist at major Austrian research institutions like the AIT Austrian Institute of Technology and GeoSphere Austria. These institutions recruit specialists in geothermal energy for projects focusing on district heating, geothermal simulation, resource mapping, and feasibility assessments.

Apprenticeships and Vocational Training

The apprenticeship "Well and foundation engineer", conducted in German, provides 3 years of training in well and ground construction, specifically focusing on geothermal borehole drilling. Apprentices become qualified professionals capable of installing geothermal probes and groundwater heat pump wells, which are essential for geothermal system installations.

"Installation and building technician" is a modular apprenticeship lasting 3 to 4 years, also delivered in German. Trainees gain skills in planning and installing modern heating systems powered by renewable sources, including geothermal technology. Specialized modules, such as eco - energy technology, further deepen expertise in heat pumps and ground - source systems.

Adult and Continuing Education

The WIFI institutes, operated by the Austrian Economic Chambers, offer certified professional training in heat pump installation. For example, WIFI Steiermark provides a course for certified heat pump technician/installer, covering the practical aspects of heat pump design, installation, and troubleshooting, including geothermal borehole regulations.

Geothermie Österreich (GTÖ) offers various professional development resources, including webinars and training sessions on shallow geothermal systems, drilling techniques and project case studies. These resources help industry professionals stay current with technical advancements and regulatory standards.



TU Wien provides a Compact Programme diploma in geothermal energy, wind power and small hydro power. This intensive, English - language course spans 9 full - day sessions over 2 separate blocks, covering theoretical foundations and practical applications in geothermal energy, wind power, and small hydro systems. The programme emphasises project feasibility assessments, environmental impacts, and case studies, awarding participants a certificate that can also contribute credits towards TU Wien's MSc (CE) Renewable Energy Systems.

Several universities, including FH Wien WKW, offer postgraduate continuing education courses that integrate geothermal energy topics. These programs allow professionals to extend their expertise, particularly in district heating solutions and energy consultancy, enhancing their credentials and practical competencies in geothermal energy applications.

2.1.2. Croatia

The second Central European country providing input on the strategic, legislative, legal and educational characteristics related to geothermal energy is Croatia. As in the previous case, the most relevant information is summarized in the paragraphs below.

2.1.2.1. Strategy for geothermal energy usage

In 2023 the Croatian Hydrocarbon Agency published a document called Geothermal potential development plan of the Republic of Croatia until 2030, where broader areas for geothermal exploration, development and exploitation were defined, as well as extraction methods of the geothermal brine, techniques and technologies of extraction, methods of use by the end user, while directing the energy development of the Republic of Croatia towards green energy. The development plan considers the geothermal use in the Croatian part of the Pannonian Basin where the geothermal potential is good, due to higher - than - average geothermal gradient (0,049 °C/m). The geothermal potential development plan is in line with the Energy development strategy of the Republic of Croatia for 2030 with a view to 2050, as well as with the Spatial Development Strategy of the Republic of Croatia, where the necessity for promoting the cascade use of geothermal energy is of significant importance and should be developed. Besides developing cascade geothermal power plants, the emphasis should also be on promoting the use geothermal brine for district heating systems, domestic hot water, use in agriculture, industrial use, fish farming, etc. The plan asserts economic justification of using existing geothermal wells, as well as further development of medium temperature reservoirs and geothermal well increase in the near future in Croatia.

The development of geothermal resources for energy purposes is also a part of the Integrated national energy and climate plan for the Republic of Croatia for the period 2021 - 2030, where the use of geothermal energy is predicted to have a share in the energy mix in order to achieve set goals in increasing the use of renewables, decrease of GHG emissions and increase of energy efficiency. Currently in Croatia the use of geothermal energy is the lowest of all energy resources in the energy mix, in both the power production and heating sector. As a part of the strategy to increase the geothermal share, the first steps were done in 2018 with the new Hydrocarbon Exploration and Exploitation Act and with setting up a data room for gathering existing well data, as well as geological and geophysical data in one location and setting up incentive pricing for geothermal exploration. In this way, energy resources are combined in one place in Croatia, which increases the effectiveness of the administration in getting to know potential investment opportunities.

The changing economic environment in the period of energy transition and the growing interest of investors who, for the purpose of investing in the exploration and exploitation of geothermal waters, needed to be provided with a higher degree of legal certainty and flexibility in the implementation of projects, pointed to the need to regulate the exploration and exploitation of geothermal resources in a manner that is defined



and accepted in world practice. Also, the new amendments to the Act eased administrative barriers that primarily relate to spatial planning procedures (planning of areas with geothermal potential in the procedures for preparing spatial plans), as well as the possibility of determining geothermal potential before conducting a tender.

The authority to carry out exploratory work prior to the announcement of a tender for geothermal waters for energy purposes has been given to the Croatian Hydrocarbon Agency on behalf of the Republic of Croatia, in order to determine the geothermal potential. In this way, the Agency, with its expertise and available data, is actively involved in encouraging the development of geothermal potential through the implementation of geothermal projects, especially those that can contribute to improving the quality of life of local communities. This is done through the project for geothermal heating, financed through the National Recovery and Resilience Plan (NRRP), within which the Agency had nominated 6 areas, the so - called preliminary exploration areas, of interest for geophysical surveys. All areas are suitable for the use of geothermal waters for heating purposes and sites are recognised based on geological potential and the vicinity of the towns with an existing central heating network. Using EU funds, the Agency planned to significantly reduce the geological risk by drilling new wells in selected estimated areas of geothermal potential and eliminate a large share of CAPEX. Out of selected 6 areas for geophysical surveys, 4 of them, (Velika Gorica, Zaprešić, Osijek and Vinkovci), were selected to proceed with exploration drilling phase and well testing. The projects prepared in such a manner can be offered to the future investors for further development. The value of approved projects is over 50 million EUR.

2.1.2.2. Legislative and legal framework

The exploration and exploitation of geothermal waters in Croatia is regulated by the Hydrocarbon Exploration and Exploitation Act (Official Gazette, 52/18, 52/19, 30/21). Bylaws under the Act, applicable to Geothermal energy are:

- Ordinance on Fees for the Exploration and Exploitation of Hydrocarbons (OG, 25/20, 43/23)
- Reserves Ordinance (OG, 95/18, 87/22)
- Ordinance on Petroleum Projects and the Procedure for the Review of Petroleum Projects (OG, 87/22)
- Ordinance on the construction of Petroleum Installations and Facilities (OG, 95/18, 101/22)
- Ordinance on Professional Qualifications for the Performance of Certain Task in Petroleum operations (OG, 95/18, 87/22)
- Ordinance on Technical Standards for the Exploration and Exploitation of oil, gas and reservoir waters (OG, 53/91).

According to the Act, all activities required for an investor to go through the tender procedure for an exploration licence are prescribed, up to the implementation of the activities and finally the contract for the extraction of geothermal water.

The granting of licences for exploration begins with a public tender, which can be initiated in 2 ways - the licensing procedure can start on Ministry initiative or on investor request. The Ministry will launch a tender in a case when it assesses that there is need to determine individual reserves of geothermal waters in an area. In the case the initiative comes from the investor, he/she can express interest in a particular area by submitting request to the Ministry which contains: a map position of the area, a program of total exploration works by type and scope with cost estimates, total amount of funds required for the performance of the planned exploration works and the manner of their provision, registration for exploration and exploitation of geothermal waters, geological pre - study of the area and compatibility with spatial planning documents. The Croatian Hydrocarbon Agency conducts all preparatory actions for the announcement of the bid round,



including conditions and criteria for the same. In both cases, bid round is publicly announced. Direct negotiations are not possible.

When submitting a proposal for a tender, the investor has to indicate or attach to the proposal the following:

- The map position, boundaries and area of the proposed exploration area, which must be delimited by the coordinates of the peak points in the official reference coordinate system of the Republic of Croatia (HTRS96 / TM) and the name of the proposed exploration area
- The programme of the entire exploration works by type and scope with cost estimate and detailed plan of the works to be carried out in each individual exploration year
- Total amount of funds required to carry out the proposed exploration works and the manner in which they will be provided
- Excerpt from the court register showing that the applicant is registered for the exploration and exploitation of geothermal waters
- Geological or other documentation on the possibility of the existence of geothermal waters in the proposed exploration area, if any
- Evidence that there are no obstacles in the spatial planning documents to carrying out of the exploration.

As for the costs incurred during the tendering process, they include several categories such as:

- Bid fee - each investor wishing to submit a bid is obliged to pay a bid fee. The bid fee includes the available data on the exploration block which includes all geophysical and engineering data available on the proposed block.
- Bid guarantee - the bidder is obliged to include a guarantee of the seriousness of the bid. Amount of a bid fee is determined for each tender, but it must be valid for 180 days longer than the validity period of the tender.
- Bank guarantee for the fulfilment of obligations - the guarantee for the fulfilment of work obligations in the exploration period must be paid in the event of a successful bid. The investor who has submitted the best bid and thus won the licence for the exploration of geothermal waters must deposit a bank guarantee for the work to which it has committed itself in its bid. The percentage to be paid is also determined in each individual tender, with the minimum amount being 10% of the value of the work offered.
- Decommissioning guarantee - the winning investor will be required to provide a bank guarantee for the decommissioning of the exploration block after the licence is granted. The cost of decommissioning will be proposed by the bidder in its bid and will depend on the work offered. The decommissioning guarantee must be valid for 180 days after the end of the exploration period.

The exploration phase lasts 5 years and can be extended twice by 6 months. During the exploration phase, the investor must fulfil the work programme proposed in the tender, which is part of the licence. In the event of non-fulfilment, a bank guarantee is activated. During the exploration phase there are no fees.

During the production phase, the investor is obliged to pay surface fee - in the amount of 3.981,68 EUR/km² for geothermal plants that primarily produce electricity from geothermal reservoirs or 132,72 EUR/km² for plants that primarily produce thermal energy from geothermal reservoirs. The fees for the surface of the exploitation field are the income of the local community.

During the production phase, the investor also pays a royalty which amounts to at least 3% of the market value of the quantities of geothermal water extracted. The minimum amount is defined in the Regulation on Hydrocarbon Exploration and Exploitation Fees and is imposed. Royalty amount is a biddable item so in



some cases it can be a higher percentage if the investor has offered such an option during the tender process. The royalty is divided in such a way that 40% goes to the local self - government unit, 20% to the regional self - government unit, while 40% is paid directly into the state budget of the Republic of Croatia.

The exploration period lasts 5 years and can be extended twice by 6 months. During the exploration phase, the investor must fulfil its obligations under the permit, which must ultimately lead to the drilling of a well to confirm the commercial quantities of geothermal water, i.e. to confirm the flow and temperature of the geothermal reservoir. In order to proceed with the drilling of a geothermal exploration well, the investor is required to prepare a project for the drilling of an exploration geothermal well. Such a project is submitted to the Ministry for review. An essential part of the project is a mandatory environmental impact study and a location permit for the well.

In the event of a commercial discovery and in order to obtain a production licence, the investor is obliged to obtain a decision on the quantity and quality of the geothermal water reserves. After receiving the decision on geothermal water reserves, the investor must submit an application for the determination of a development area, which must be accompanied by a map of the proposed area with the outline of the confirmed reserves, a document from one of the procedures under the provisions of environmental and nature protection regulations and a certificate of compliance of the proposed area with the spatial county plan. Within 6 months of the decision on the determination of the exploitation field, the investor is obliged to submit to the Ministry the Geothermal Water Development Plan for review.

Before submitting an application for a geothermal water production licence, the investor is obliged to resolve the ownership of the land within the development area in accordance with the Development Plan for the period for which it wishes to conclude a contract for the use of geothermal water. The production licence of geothermal water is granted by a decision of the Ministry and, after obtaining the licence, the procedure for signing a contract for the production of geothermal water follows as a single procedure. The longest term of the contract for the exploitation of the geothermal water is 25 years and can be extended if it is determined that there are sufficient reserves of geothermal water for further exploitation.

2.1.2.3. Educational opportunities for geothermal energy

Secondary Vocational Schools

Vocational secondary education in Croatia lasts 3 or 4 years, depending on the program, and focuses on acquiring practical knowledge and skills for a specific profession. After graduation, students can either enter the labour market immediately or, if they complete a 4 - year program, continue their education at higher education institutions. Education is delivered through theoretical classes and practical training, often in cooperation with employers. There are several high schools that have a curriculum in the area of mining, geology and mechanical engineering. The School of Civil Engineering, Natural Sciences and Mining in Varaždin offers vocational education for mining technicians, as well as geology technicians, with a duration of 4 years. The mining technicians afterwards work in raw mineral underground/surface exploitation, tunnel construction, drilling - blasting - transportation operations, georesearch and geomechanical works, groundwater exploration and exploitation, natural gas and oil exploration and exploitation, most commonly as drillers. The geology technician learns how to conduct geological research, determine rock and soil composition, how to determine potential for mineral and non - mineral materials in an area, etc. Additionally, Vladimir Prelog School of Natural Sciences in Zagreb also offers a 4 - year programme for geology technicians. High school Ivan Švcar in Ivanić Grad offers a 4 - year vocational education for petroleum - mining technicians, with focus on drilling, completion and well testing, safety technology, natural gas/oil reservoirs, coal deposits, etc.



Bachelor's and Master's Degree Programs

University education for engineers is provided at technical faculties and polytechnics, lasting 3 years for undergraduate studies (bachelor) and an additional 2 years for graduate studies (masters). The programs focus on acquiring professional knowledge in mathematics, physics, computer science and engineering disciplines, with an emphasis on problem - solving and practical application. Upon graduation, students gain the qualifications needed to work in engineering professions or continue their education. The Faculty of Mining, Geology and Petroleum engineering in Zagreb offers a 3 - year undergraduate programme in Petroleum and Geoenergy Engineering, where students acquire the ability to apply acquired knowledge to tasks of medium complexity in exploration, exploitation and distribution of energy mineral resources, geothermal water exploitation and the energy sector.

The 2 - year graduate programme Petroleum and Geoenergy Engineering and Management is a continuation of the undergraduate studies. The first year is joint for all the enrolled students, while the second year offers a choice between three elective modules - Drilling and Production Engineering, Reservoir engineering and Geoenergy Engineering and Management. The subjects of geothermal exploration and exploitation are covered in the joint first year, but with special attention to the subject in the module Geoenergy Engineering and Management in the second year with more specific courses. These study programmes are available in Croatian, however for Erasmus+ exchange students the courses are available in English.

The Petroleum and Geoenergy Engineering and Management graduate programme is also offered in English, with a tuition fee of 4.000,00 EUR (1.000,00 EUR per semester). The study programme relies for the most part on the graduate programmes of petroleum engineering carried out in the European Higher Education Area. Having this in mind, the study programme ensures horizontal mobility with universities which have similar programmes, primarily University of Leoben, University of Clausthal and Stavanger, as well as Norwegian University of Science and Technology.

There are two faculties offering subjects either with topic of geothermal resources or closely related. The Faculty of Geotechnical Engineering in Varaždin offers only one elective course with the topic of geothermal, hydrothermal reservoirs, within the 2 - year graduate study programme in Environmental Engineering. The programme itself is focused on managing the environment in a sustainable way. The Faculty of Mechanical Engineering and Naval Architecture in Zagreb offers courses in undergraduate and graduate programmes from the standpoint of constructing and design of power plants (ORC), heat transfer, surface pipeline construction, energy system modelling, heat pump design, drilling rig design, etc., which cover topics of surface equipment design and geothermal energy utilisation.

PhD and Postdoctoral Programs

Doctoral studies, which last 3 years or more, are research - oriented and prepare engineers for academic, scientific or high - level industry roles. Postgraduate education emphasizes innovation, critical thinking, and the ability to lead complex engineering projects or contribute to technological development. The Faculty of Mining, Geology and Petroleum engineering in Zagreb offers a curriculum in the area of geothermal subsurface engineering in 2 studies: Petroleum engineering and Geology engineering in the field of technical sciences. The research is offered in number of topics - geological modelling, reservoir engineering, drilling and geothermal well completion, deep and shallow geothermal utilisation, etc. The Faculty of Geotechnical Engineering in Varaždin offers the course Geothermal energy within the doctoral study Environmental Engineering, module Energetics. The Faculty of Mechanical Engineering and Naval Architecture in Zagreb doesn't have direct geothermal courses, however in any number of construction, design, modelling, heat pumps, etc. regarding the surface equipment which utilises deep or shallow geothermal energy, a number of options are available. All 3 faculties offer postdoctoral research within active research projects.



2.1.3. Germany

In this section the German geothermal and well repurposing features in terms of strategic, legislative and legal environments are presented. As in the previous ones, the Subchapter concludes with an overview of the educational opportunities for geothermal energy in Germany.

2.1.3.1. Strategy for geothermal energy usage

Even if geothermal energy had been explored and used since the 1980's in Germany, only after the 2000's the applications rose significantly. More than 480.000 near surface installations (ground heat collectors or borehole heat exchangers with heat pumps) with more than 4,8 MW exist so far. Each year around 15.000 new ones are installed.

The number of deep geothermal energy (>400 m) installations, which are operational in 2025, is 42. Out of these, facilities used for heating only comprise 40 and the ones used for both power generation and heating sum up to 11 (2 only for power generation). The reported installed thermal capacity is 408 MW and the electrical capacity is 55 MW. More than 170 geothermal spas exist. Large geothermal facilities primarily exist in the South German Molasse Basin. Especially close to the city of Munich several facilities exist, and recent investments will further expand the geothermal energy use. Apart from this pioneer region, in Germany the Upper Rhine Graben and the North German Basin are of interest.

Several incentives shall help to further enhance the use of geothermal energy. District heating networks are financially supported with 40% federal resources. In general, the German government funds projects, provides market incentives and credit offers, as well as a feed-in tariff for geothermal electricity (Agemar et al., 2014). According to the BMWK, in Germany geothermal heat has not been explored/used as it potentially could be utilised. As a consequence, in 2022 a plan with 8 measures was established to meet the goal of reaching 50% of heat to be produced climate neutral by 2030, exploiting 10 TWh if possible, as well as initiate more than 100 additional geothermal projects.

The 8 measures of the plan are:

- Stakeholder dialogue on the necessary measures
- Data campaign - systematic collection of the existing data to provide a basis for successful projects
- Exploration campaign - exploration partly funded by the Federation in highly promising areas for specific projects
- Acceleration of planning - identifying and leveraging potential for optimisation of the approval process
- Funding programmes - stimulating market preparation and competitiveness
- Risk mitigation - consideration of instruments to hedge against risks
- Securing skilled labour - development of strategies to recruit young staff
- Public acceptance - information events and public acceptance programmes as an integral part of each project.

More recently, proposed legislation changes shall improve the bureaucracy by streamlining the processes. Further geothermal heat extraction is combined with lithium production; in Germany a 1.1 billion EUR investment fund was created for critical raw material extraction and green projects.



2.1.3.2. Legislative and legal framework

In Germany, geothermal heat is a raw material free to mine, according to the mining law (BBergG). Also, as for now, brine is a different resource from heat, which makes it necessary to get permits for both in most cases. Hence, before any exploration (or later extraction) activity can start, the necessary permits and licenses have to be obtained by applying to the Mining authority. The law (BBergG) behind the procedures is a federal law, but nonetheless, each state in Germany applies the law with slight variations (differing interpretation).

In short, the steps to get a geothermal project approved are:

- Exploration and licensing - before drilling, companies must obtain exploration licenses and conduct environmental impact assessments
- Approval procedures - projects often require multiple permits, including those related to water use, environmental protection, and land use (individual case decision)
- Public participation - local communities and stakeholders are typically involved in the approval process, which can lead to delays due to opposition.

The main hindering factors, apart from long processing times of any permit/license application, are the high investment costs and associated exploration risks.

In reuse projects, the land where surface facilities are placed is usually leased. Generally, the well is owned by the company/investor (different from the “operator” that effectuates the drilling itself). Some wells are transferred to state property. When monitoring (mining authority) ends, the drilling site goes back to the original owner of the land.

If the well is no longer used for its intended purpose, a new permit is needed. In theory, getting a permit/license for reusing a hydrocarbon well for heat/brine extraction is easier than the other way around. The Bundesberggesetz (BBergG) regulates these cases. Generally, wells which are no longer used (abandoned) must be cemented after 1 - 2 years and the abandonment is regulated by the closure plan. According to the legal requirements of mining law, the final operating plan must be submitted if the use of the well is interrupted for 2 years. A longer interruption is only permissible with the consent of the mining authority. For other drilling locations, a new operation plan is needed. Some wells are still open, as the regulations of former times were different.

By law, the data related to any mining activity (including wells) has to be handed in to the State Geological Surveys. Depending on the type, the data are either restricted or free. Master data is publicly available (data that assign the content of the geological investigations in terms of person, place, time and general content). The second data type is raw data (comprises technical/geological “measured” data, as for example borehole measurements and bore logs that are not “interpreted”). They can be purchased from the company or provided by the State Offices or, under certain circumstances, data can be free to use. The categorization of data into the 3 groups is made by the State Offices. There is a differentiation between private and State drillings. The interpretation data is not available (only if the owner agrees), but technical measured data is free after 10 years (industry), 5 years (other private drillings) or always (state, research, etc.) Most of the raw data is company - owned, but also stored at the Geological Surveys of each State Office.

2.1.3.3. Educational opportunities for geothermal energy

Technical Schools

Technical schools which cover research and teaching in the field of renewable energies or environmental technology sometimes offer degree programs in which geothermal energy plays a role. Examples are the TH



Köln with the program Renewable Energy, TH Wildau with Regenerative Energy Technology and the Ostfalia Hochschule for Applied Sciences Wolfenbüttel with Energy System Technology. These study programs focus especially on the field of engineering and application of shallow geothermal energy systems.

Bachelor's Degree Programs

Because geothermal energy is a highly specialized field, it is usually only offered as part of master's degree programs. The range of courses varies depending on the faculty or department and has different focuses. Bachelor's study programs in the field of geothermal energy are rather unusual. An exception is Geo - Energy Systems at TU Clausthal, which is based on engineering and geotechnical, but also geological issues.

Master's Degree Programs

Pioneering degree programs that have transcended the conventional boundaries of departments and faculties have been developed at 2 locations. First, the degree program Geothermal Energy/GeoEnergy of the FAU Nuremberg - Erlangen and TU Munich within the framework of the Geothermal Alliance Bavaria and second, the degree program Geothermal Energy Systems, which was developed with a practical focus at Bochum University of Applied Sciences in collaboration with the Bochum Geothermal Center. Since 2024, the TU Bergakademie Freiberg offers the Master's degree Geothermal Energy, which also combines engineering and geoscientific aspects in the education.

Furthermore, there is a variety of other Master's study programs that deal with geothermal energy in a specific scientific field, whether through compulsory modulus or as elective examination subjects. Examples are:

- Energy and Mineral Resources at the RWTH Aachen
- Geotechnology at TU Berlin
- Geoscience at RU Bochum
- Petroleum Engineering at TU Clausthal
- Applied Geoscience at TU Darmstadt
- Regenerative Energy Systems at TU Dresden
- Geoscience at FAU Nuremberg - Erlangen
- Geotechnic and Mining at TU Bergakademie Freiberg
- Sustainable Energy Resource Storage at Karlsruher Institute for Technology

PhD Programs

PhD programs in the field of geothermal energy in Germany are offered by research institutions and the already mentioned universities. Common research institutes are for example the GFZ Potsdam, UFZ Leipzig (shallow geothermal energy), the Fraunhofer IEG and the State Research Centre for Geothermal Energy. Furthermore, it is possible to pass a PhD program in the private sector. Therefore, a collaboration with a university is required.

2.1.4. Hungary

Following the previous, this section covers the most significant strategies, legislatives and laws regulating the geothermal energy usage, with emphasis on utilisation from abandoned repurposed hydrocarbon wells. Furthermore, the Subchapter ends with additional information about the educational programs and training for future experts in mining and geothermal energy utilisation.



2.1.4.1. Strategy for geothermal energy usage

Geothermal energy can be an outstanding resource in Hungary due to its geological and hydrogeological endowments, but for this it is essential that the development of this field of expertise is based on strategic planning, which includes not only the endowments and goals but also the means for their implementation.

This strategic planning activity began in the late 1950s. From the point of view of the present project, the most important period was the drilling of thermal wells for the Szeged cooperatives and the hospital in Szentes from 1957 - 1958 and, as a result of this, the period from 1963 to the mid - 1980s, at the initiative of the National Technical Development Committee (OMFB), with the state - subsidised drilling of thermal wells and the exploitation of barren hydrocarbon exploration wells. Under the OMFB's geothermal programme, it has funded technical R&D work to support practical exploitation, assisted geological exploration and mapping, explored exploitation targets, sites and specific objects for demonstration and experience, as well as helped to finance a significant part of this. Geothermal energy activities were transferred from the OMFB to the National Water Board after the 1960s and then slowly died out.

In 2004, Hungary joined the EU and received development funds, which also supported geothermal investments (geothermal networks in Bóly, Kistelek, Törökszentmiklós, Orosháza, Gárdony, Mórahalom, innovation programmes). In 2008, the use of renewable energy sources in Hungary amounted to 63. 1 PJ, which accounted for 5,8% of total primary energy use. However, under the EU's Energy and Climate Change Package, a 13% share of renewables was planned to be reached by 2020 for Hungary. In order to meet this goal, the Hungarian government adopted the Strategy for increasing the use of renewable energy sources in Hungary 2008 - 2020 in September 2008 and prepared the Hungary Renewable Energy Utilisation Action Plan 2010 - 2020 (National Action Plan) in accordance with the formal requirements of the EU Decision 2009/548/EC. The document, which was prepared with the broad involvement of the industry, set out objectives alongside the forecast energy use, reviewed the regulatory and licensing system in force at the time, the support system for renewable energy sources, and defined the expected results, impact assessment and the means of monitoring the processes and implementation along the objectives. As a result, support for renewable energy systems has been given a prominent role in EU support programmes, however, and a separate energy support programme was launched for the 2014 - 2020 planning cycle, but unfortunately the number of successful geothermal projects has fallen dramatically.

The National Energy Strategy 2030 document published in 2012 also addressed geothermal energy systems but did not treat them as a separate entity. The document emphasised the priority of geothermal heat production. The EU Strategy for the Danube Region Action Plan 2020, also, mentions geothermal energy as a means to increase energy independence and support for cross - border renewable energy projects, using the DARLINGE project and district heating projects in Romania as examples. In autumn 2022, the Hungarian Parliament adopted a new legal framework for the exploration, extraction and exploitation of geothermal energy. The following year, a new strategy making process was launched, leading to the adoption of the National Geothermal Strategy (NFS) (2024), which has been criticised and is structured more as an action plan. It is structured as a very brief analysis of the situation, including the geothermal potential and its exploration and current use. The strategic objective is to increase Hungary's domestic use of geothermal energy by 20%, i.e. to 8 PJ by 2026, compared to the baseline of 6,4 PJ, and to double it to 12 - 13 PJ by 2030. Assuming a similar increase in geothermal heat production of 3,1 PJ for heat supply only, the share of geothermal energy in gross heat production could be increased to about 12% by 2030. New uses are forecast to replace 0,5 - 0,7 billion m³ of natural gas by 2030 and a total of 1 - 1,2 billion m³ by 2035. In addition to deep geothermal, a significant contribution can be made by boosting shallow geothermal energy, especially if the energy needed to power the heat pump can also be produced from renewable sources.

The existence of significant geological potential, the availability of geothermal databases and the high level of preparedness of geothermal industry players will help to meet the NFS objectives. Challenges include capital requirements and access to finance, the industry value chain facing consolidation, the low share of building stock capable of accommodating geothermal heating and the need to expand construction capacity.



The potential for growth can be provided by generating new projects and increasing the efficiency of recovery (residual heat recovery, cascade systems). The main challenges in implementing the strategy include geological risk, overcoming the geotechnical and geological constraints of injection back into porous media and ensuring the sustainability of production from existing capacities. The NFS is essentially considering the development of cascade systems, where industrial, agricultural and district heating uses can be realised. This applies to both new and retrofitted systems. Although the NFS's intervention strategies are forward - looking in many respects, at the same time, there are elements that may warrant further professional consultation and careful consideration of the details of implementation (e.g. financing processes, investment management and practical issues related to the application of the recovery mechanism). Although there are calculations and ideas for this, and many research projects for combined heat and power generation are under approval or have been approved, there is no mention of the use of abandoned hydrocarbon wells for geothermal purposes.

In January 2025, the State Audit Office of Hungary prepared a detailed analysis entitled Geothermal Energy Utilisation in Hungary - Strategic, Legal and Financial Framework, which reviews the strategic environment related to geothermal energy (2008, 2011, 2024 and 2018 NES2), the geothermal energy research base, the licensing procedure and the geothermal exploration process, summarizing its positive and negative aspects, the exploration activity and its financing, with a special focus on the issue of back - end injection, the registration and monitoring of geothermal data, the exploitation of back - end injection, the registration and monitoring of geothermal data, the exploitation of geothermal energy, its legal status and financing system, including and highlighting the opinions of the relevant Ministries and specific sectoral organisations. The aim of the analysis was to identify and critically review the problems encountered in this field, making a number of recommendations. The main findings are the following:

- The strategic and climate policy context for geothermal energy is not coherent. The integration of geothermal energy into strategic energy policy and climate targets is not yet fully harmonized, which creates opportunities for further coordination (clear definitions are needed for policy makers).
- Regulatory environment for agricultural and balneological exploitation is not coherent, needs to be simplified, definitions and processes in the legal background need to be more precise. The regulatory environment for agricultural and balneological use currently needs improvement, particularly in terms of simplification and clarification of legal definitions and procedures, which could contribute to strengthening legal certainty and practical applicability.
- The Geothermal Energy Committee of the Mining Inspectorate gives an opinion on the application for a research permit, but the issues it examines are not in line with the Mining Act, i.e. it would be advisable to include their criteria in the regulatory procedure
- Consideration should also be given to strengthening the protection of the interests of thermal water users against each other (the issue of protection zones)
- The risks of geothermal extraction justify the involvement of the state in mitigating the risks and the aim is to establish a fair, predictable and sustainable system for mitigating the risks of drilling, but the financial possibilities for this are questionable. In the case of financial resources for private companies, particular emphasis should be placed on the requirements of economic, efficient and effective management and incentives should be provided to companies to ensure successful projects (avoiding waste).
- The recirculation of extracted water also needs to be addressed for sustainability and EU legal compliance reasons and this requires a review and tightening of the current control and sanction system
- Thermal water and geothermal energy are part of the national heritage and an up - to - date, uniform and continuous inventory of their status is necessary. The technical conditions for this are



in place. It would be necessary to unify and harmonise the registers of thermal water and geothermal energy kept by the General Directorate of Water Management (OVF), the Geological Service of the Water Authority of the Supervisory Authority for Regulatory Affairs (SARA) and the National Mining Authority of the Supervisory Authority for Regulatory Affairs (SARA).

- The new way of calculating the profit factor will bring the conditions for the Return On Investment closer to market conditions and can therefore be expected to facilitate the expansion of geothermal energy in the district heating sector
- The method of recognising justified costs, in particular the validation of investment and maintenance costs, leads in some cases to disputes, which are the subject of a price negotiation between the producer/provider and the Hungarian Energy and Public Utility Regulatory Authority (MEKH). However, this annual price negotiation is more disadvantageous for geothermal district heating suppliers than for natural gas users because of the different cost structure. In addition, the system does not dynamically track the different heating demand due to different weather changes in the cash - flow, as it is based on the previous year's data. Clear rules and a uniform interpretation of the law are needed to clarify when geothermal heat is considered as district heating.

In summary, the national geothermal strategy sets out important directions and formulates valuable policy objectives, but several elements are not given sufficient emphasis in their current form and require further elaboration in order for the document to fully fulfil its strategic role. It would be necessary to revise the strategy with the broad involvement of professional society, to add a detailed description of the problems and opportunities, to specify the objectives and to identify and describe the monitoring tools, and to prepare a detailed action plan, fine - tuning the legislative environment.

2.1.4.2. Legislative and legal framework

In 2022, the Hungarian Parliament adopted the Act LXIV of 2022 amending certain mining and economic acts, which replaces the former Act XLVIII of 1993. It supplemented and replaced parts of the Mining Act of 1993 (Act XLVIII of 1993) and parts of Act LVII of 1995 (the Water Management Act). This partly replaced the previous highly confusing geothermal regulation and clarified the licensing process for geothermal exploration, although it does not cover primarily medicinal and agricultural uses. Article 4 of the Act XLVIII of 1993 on Mining has been amended by adding the following Subchapter: Exploration and exploitation of geothermal energy after the Subchapter Licensing of mining activities.

Accordingly, geothermal energy exploration may be carried out on the basis of a permit issued by the Mining Inspectorate under the National Mining Authority of the Supervisory Authority for Regulatory Affairs. The exploration licence is valid for 4 years and may be extended once for half of the licensed period, subject to the approval of an exploration plan and the provision of a financial guarantee. The defined exploration tasks must be carried out and an application may be submitted within 3 months of the end of the exploration for the geothermal protection zone to be defined. A register of the geothermal exploration area is kept, which is a public record, except for personal and company data (name, address, title, registered office of the person entitled).

The geothermal protection zone is designated by the Mining Supervisory Authority upon request, and the protection zone must guarantee the amount of geothermal energy to be extracted for at least 25 years. Geothermal protection zones shall not overlap. Water sources and water bodies already used for drinking, mineral, spa and thermal water purposes cannot be designated as geothermal protection zones. In its decision to designate a geothermal reserve, the Mining Inspectorate shall, by administrative decision of the water authority, determine the annual volume of extractable thermal water, the method of disposal of the extracted water and the data required for the establishment of the water resource fee. The construction of a facility for the extraction and utilisation of geothermal energy within the geothermal protection zone not covered by this Act shall require the prior consent of the Mining Inspectorate. The Mining Inspectorate shall



keep records of the geothermal energy utilisation facilities, the amount of geothermal energy extracted and utilised and the geothermal protection zones established. After the designation of a protected area, a contract for the use of geothermal energy for energy purposes may be concluded with the Authority, subject to the approval of the Minister, on the basis of a set of conditions, which include the annual amount of geothermal energy to be extracted, the duration of the concession (max. 35 years, renewable once for half of the duration of the concession), the obligation to recover water, the conditions for termination of the contract, the way in which the contract may be terminated, the reclamation, the purpose of the geothermal energy extraction, the intended form of exploitation and the extraction technology used and the provisions on compliance with the obligation to recover water. Article 5 deals with the regulation of mining sites and is perhaps the most controversial point of the new law, which implicitly allows for overlapping of mining sites and may lead to controversial situations.

Government Decree 178/2023 established the Geothermal Energy Commission, composed of representatives of the ministries, which will comment on applications and recommend their approval or rejection. The Commission's opinion is not public. The Mining Inspectorate has a 60 - day time limit, on which the Commission's 45 - day time limit is based, but as the Commission does not have the function of a public authority, it cannot be held accountable. This results in a lengthy case process in practice. In addition to the 2 important pieces of legislation mentioned above, a further 9 laws, 27 government decrees, 21 ministerial decrees and 8 executive decrees of independent regulatory bodies have some impact on activities related to geothermal exploration and production.

Although the adoption of a more unified legal framework for geothermal research is an important step forward, certain issues remain unresolved that could affect the pace and smooth running of projects. One of these is the aforementioned agricultural and medicinal uses, which are not covered by the law and which may lead to overlapping at the level of research sites, aquifers and geothermal protection zones, which does not serve to protect reservoirs. There is also a problem with the aforementioned deadlines for the procedures, which can lead to long waiting periods for projects after the application for a research permit. Legal, environmental and aquifer protection problems can also arise in the law when allowing overlapping geothermal protection zones. In issuing the permits, the exploration period was set at 20 months, instead of the maximum of 48 months, which is very short for the tasks to be carried out, which include geological surveys, well location and drilling of two wells and evaluation of the results. This is particularly difficult given the available drilling capacity. The deadlines currently applied in geothermal research licensing procedures may, in certain cases, lead to longer waiting times after the research license application has been submitted. In addition, according to the legislation, legal, environmental and water protection issues may arise due to the overlap of several geothermal protection zones, which may require further clarification. The exploration period is currently set at 20 months, compared to a maximum of 48 months, which requires an intensive pace in terms of geological exploration, drilling site selection, drilling of two wells and evaluation of results. This poses a particular challenge for projects, given the available drilling capacities. In addition, the State has become a market player in several areas, so that, for example, the acquisition of a competent drilling company has reduced competition in the market.

Further consideration is needed regarding the maximum profit margin specified in the district heating regulation, which in its current form is lower than the inflation rate and may therefore limit investment willingness. The use of geothermal district heating may also be hampered by the fact that, if the extracted natural gas is not used, the service provider will have to reckon with regulatory consequences that will place an additional burden on it. Another long - term problem is that Hungarian universities, with a few exceptions, are not participating in international tenders and cooperation projects, so there are not enough R&D resources for the R&D tasks needed in the field of geothermal energy, and this is already causing a short - term backlog.

In conclusion, although there are signs of progress, it would be advisable to review, amend and, where appropriate, supplement the relevant laws following the problems encountered and to include agricultural and medicinal uses in the single system. Another challenge currently facing the use of geothermal district



heating is that district heating providers face financial obligations if they do not use the contracted natural gas volumes, which may hinder the increase of the share of geothermal energy in the multi - level energy mix. In the longer term, there are further opportunities for research and development activities if domestic higher education institutions become more actively involved in international tenders and professional collaborations. Currently, with a few exceptions, research resources are somewhat limited, which requires short - term replacement of the background solutions necessary for the rapid development of the geothermal sector.

2.1.4.3. Educational opportunities for geothermal energy

Secondary Education

In secondary schools, there is practically no teaching about renewable energy, including geothermal energy. For years, curricula have been dismantling science education, so that fewer and fewer lessons and fewer subjects are available. In the secondary school geography curriculum, the use of geothermal energy is included in the topic of rock cover among the everyday applications of geological processes and adaptation strategies. However, in practice, this is mostly suitable for imparting basic knowledge, with more limited potential for promoting deeper understanding. The Zoltán Bay Institute's Raw Materials Ambassador programme and student competitions are a very good initiative to raise students' interest in this area.

Bachelor's and Master's Degree Programs, PhD Programs

In higher education, at all universities where earth sciences are taught, geothermal energy training is basically included in the curriculum, depending on the university, but in most cases, it appears in 1 or 2 subjects and is not specifically mentioned separately. The Department of Geology at the University of Szeged and the Institute of Geography and Earth Sciences at Eötvös Loránd University play a prominent role in geothermal education, largely due to the fact that the department employs internationally renowned geothermal experts. The subjects of the bachelor's degree in geology are Water and Hydrocarbon Geology and the master's degree in geology are Geofluids and Geological Resources, Applied Geothermal Engineering, Geothermal and Hydrocarbon System, Geofluids Field Practice, Modelling and Data Analysis Methods in Geofluids Research and, as well as Geofluids Project Work.

Theoretical and practical teaching of hydrodynamic and transport modelling at the University of Szeged, the University of Miskolc and the Budapest University of Technology and Economics also touches upon the subject. At the University of Miskolc, the Bachelor of Engineering in Geotechnical Engineering, the specification of water and raw materials exploration engineering is mainly concerned with engineering (e.g. water carotage, well diagnostics). At the Budapest University of Technology and Economics, the Department of Energy Machinery and Systems has a course on Geothermal Energy and formerly on Solar Energy and Geothermal Utilisation. Although only partially related, at the University of Miskolc, a number of areas can be linked to technology and the topic in bachelor's and master's programs, as well as in specialized engineering courses, so in bachelor's programs, you can choose the specialization Oil and Gas Engineering/Oil and Gas Specialization, or Water and Raw Materials Exploration Engineer/Earth Science specialization, in the master's program, Earth Science Engineer (English and Hungarian), Hydrogeology Engineer (English and Hungarian), Oil and Gas Engineer, Petroleum Engineer (English) and Hydrocarbon Exploration Earth Science Engineer (English) training. In addition to the Geothermal Engineer detailed below, further training also includes hydrogen supply specialist training, petroleum engineer and hydrocarbon industry raw material exploration specialist engineer training. In particular, the oil industry also aims to teach drilling technology.

Postdoctoral Programs

At the University of Miskolc, the geothermal engineer/specialist training is continuously announced. Graduates will gain competence in both geothermal energy production and utilisation. The training lasts 4 years and the condition for participation in the training is a minimum BSc engineering degree in the field of



technical training. There is no entrance exam. The training takes place partly in a distance learning system (correspondence training) in English and Hungarian. The total training time is 300 hours, of which 30% is classroom teaching, 70% is conducted via an online portal, under the guidance of a specialist teacher, in an e - Learning system. The decision to start the training will be made based on the number of applicants. The main subjects of the curriculum cover the specialized knowledge of energetics, heat and fluid mechanics, geology, geophysics, water chemistry, hydrogeology, reservoir geology, drilling technology, energy management, energy and heat production and use, the description of the environmental impacts of geothermal energy production, legal, economic and tender knowledge with special regard to geothermal projects in Hungary.

Adult and Continuing Education

In addition, several universities offer continuing education courses in the field of energy, which also touch upon the use of geothermal energy, but typically only indirectly or tangentially (e.g., University of Pécs - Facility Energy Engineer Training, Budapest University of Technology and Economics - Energy Industry Engineer). Accredited adult education programs are also available, such as the geothermal heat pump system installer training program offered by Paladin Human Solutions Zrt., but these are typically advertised on an ad hoc basis.

In summary, it is gratifying that the concept of geothermal energy appears at least at the subject level, and that courses dealing with the field are available at specialized universities. It can be emphasized, although unfortunately due to the number of applicants, the training often does not start, that there is a specialized degree in engineering training in the field. It would be very helpful to embrace and induce initiatives such as the Bay Zoltán Foundation and to arouse the interest of primary and secondary school students, as well as to train geography teachers in this field. The harmonization of the diverse range of training at BSc and MSc level and the training of geothermal experts at this level could also be improved, building on the already existing professional engineering training, with the involvement of industrial experts and a small number of internationally renowned university researchers.

2.1.5. Slovenia

Finally, the last country which presented their strategic, legislative, legal and educational features for geothermal energy utilisation is Slovenia. Continuing this, the following paragraphs cover in more detail the mentioned Slovenian opportunities for geothermal energy use.

2.1.5.1. Strategy for geothermal energy usage

The National Energy and Climate Plan (2021 - 2030) outlines appropriate steps to promote the use of geothermal energy, but implementation has not kept pace with ideas. For many years, there have been several attempts to encourage systematic research into the geothermal potential under major cities that need to restructure their heat energy production with renewable resources such as geothermal, but the response has been poor. As not enough research activities have been done no major breakthrough could be achieved. Only through research with drilling deep boreholes (2 - 5 km) can new potential underground resources be identified. The financial burden with uncertainties plays a major role and without proper financing and support schemes it is very hard to research in Slovenia. In this outline a need for systematic support is mandatory to form feasible a geothermal energy strategy, which encourages and financially helps potential investors to make the first steps and research the underground geothermal potential.

The potential for geothermal heat extraction is highest in NE Slovenia due to geological conditions. In this region the temperature rises most rapidly and can reach values between 150 and 200 °C at a depth of 4 km. The calculated available thermal resource base is 957 EJ up to a depth of 3 km and 2.597 EJ up to a depth



of 5 km. A regional and cross - border geothermal aquifer in quartz sands and sandstones extends up to a depth of 2 km, which is shared mainly with Hungary. Its extent is relatively well known, making the positioning of new boreholes much less risky than elsewhere in Slovenia. However, targeted geophysical surveys are still recommended to increase the likelihood of a successful well. Currently there are 10 locations using the HE potential without reinjection wells. Although there have been some motions, two users are developing the reinjection systems. With presentation of the doublet system for HE production there will be room for more potential investors and, also, for development of existing ones.

The other geothermal area is located in SE Slovenia, although less explored and exploited. Here, the stored heat is estimated at 6,8 EJ. An increased geothermal gradient is also detected in the vicinity of Ljubljana, in the Celje Basin and elsewhere, but the geological structure at depths below 1 km is much less known.

All geothermal energy, both shallow systems and thermal water use, accounted for only 0,7% of gross domestic energy use at the primary energy supply level in Slovenia in 2022. Direct use of thermal water in 2022 took place at 29 sites with 58,3 MW_t of installed capacity and an annual production of 552 TJ or 153,3 GWh of heat, mostly for space heating, greenhouses and bathing. This type of use is stagnating in the absence of dedicated incentives. Only one geothermal district heating system is currently in operation, in Lendava. There are only 3 geothermal greenhouses in operation in Slovenia, in Dobrovnik, Renkovci and Čatež.

2.1.5.2. Legislative and legal framework

The exploration and exploitation of geothermal waters in Slovenia is regulated by different laws which regulate Mining (ZRud - 1), Waters (ZV - 1) and Environment (ZVO - 2). In case of geothermal project implementation, the following laws and Acts are applicable:

- Mining Act (ZRud - 1), Official Gazette of the Republic of Slovenia, No. 44/22, 18/23 - ZDU - 10, 78/23 - ZUNPEOVE, 23/24 and 21/25 - ZOPVOOV
- Water Act (ZV - 1), Official Gazette of the Republic of Slovenia, No. 67/02, 2/04 - ZZdl - A, 41/04 - ZVO - 1, 57/08, 57/12, 100/13, 40/14, 56/15, 65/20, 35/23 - decision of the Supreme Court, 78/23 - ZUNPEOVE and 52/24 - decision of the Supreme Court
- Act on the introduction of devices for the production of electricity from renewable energy sources (ZUNPEOVE), Official Gazette of the Republic of Slovenia, No. 78/23 and 95/24
- Environmental Protection Act (ZVO - 2), Official Gazette of the Republic of Slovenia, No. 44/22, 18/23 - ZDU - 10, 78/23 - ZUNPEOVE, 23/24 and 21/25 - ZOPVOOV
- Rules on mining technical documentation, Official Gazette of the Republic of Slovenia, No. 32/17 and 58/17 - amended
- Rules on requirements for ensuring occupational safety and health and technical measures for work in the exploration and exploitation of mineral resources by deep drilling, Official Gazette of the Republic of Slovenia, No. 68/03, 65/06 and 61/10 - ZRud - 1

There is no system or protocol in place to carry out geothermal energy exploration in Slovenia. Geothermal energy exploration can be carried out from 2023 in 3 ways, according to ZRud - 1, ZV - 1 and ZUNPEOVE. The 3 legal bases are intertwined and include environmental aspects according to the ZVO. The procedures for obtaining an exploration permit under the listed legal bases are following:

According to ZRud - 1

The exploration licence shall be granted based on a call for competition. The decision to hold a call for tenders shall be taken by the Ministry responsible for mining based on:



- A finding of interest in the economically justified exploitation of the mineral raw material
- The application submitted to the ministry responsible for mining by an individual of the legal or natural person concerned.

A permit to research mineral resources may be obtained by a legal or natural person in the manner and under the conditions laid down in the Mining Act (ZRud - 1):

- Which is established in the Member States of the European Union, the European Economic Area and the Swiss Confederation and in the Member States of the Organisation for Economic Cooperation and Development (States Parties) or is a national of a Contracting State
- Which is not from a Contracting State but from a third country, but only if the condition of substantive reciprocity is fulfilled. This condition shall be deemed to be fulfilled if the interested party, who is from a third country, has his registered office or residence in the Republic of Slovenia and can carry on an activity in his country under the same or similar conditions under which he may pursue an activity in the Republic of Slovenia. In the case of the place of establishment of a legal person or the place of residence of a natural person in several third countries, the legal order of the state which is the strictest shall be considered in determining reciprocity.

According to ZV - 1

A legal or natural person intending to investigate groundwater must comply with the prescribed conditions and obtain a permit for research before carrying out works related to groundwater exploration. The permit shall specify the conditions under which groundwater surveys may be carried out. The water that the research provider is pumping can only be used for research. All information obtained must be communicated free of charge by the survey provider within one month of completion of the groundwater survey to the Ministry.

In order to obtain a permit for groundwater research, an application shall be made to the Water Management Department of the Republic of Slovenia on the prescribed form. The following documents must be attached to the completed application:

- Professional basis or hydrological research program to produce wells
- For wells/wells (not applicable to observation wells intended for groundwater monitoring), depths of 50 m and above, a well project designed for complex facilities in accordance with the building act
- For wells/wells deeper than 300 m, a revised borehole mining project, which is manufactured in accordance with the mining act
- A copy of the plot with the plot of the intended facilities (wells)
- A statement by the owner of the property (or water supply in case of water use from the water supply) on which the removal facility is intended
- The opinion of the competent public service provider carrying out the activity of water supply (in the case where the said public service is not also an applicant for authorisation), in the case of a survey in the area of the drinking water aquifer
- Written authorisation (if the applicant is represented by a delegate).

According to ZUNPEOVE

The granting of a geothermal research concession approves the implementation of a project that includes researching the geothermal energy potential and execution of exploratory electricity production using geothermal energy. The obtained geothermal research concession consists of the following implementation phases:



- Phase of geothermal potential research
- Preparatory phase (which includes the preparation of a spatial implementation act, obtaining the necessary permits and the construction of a geothermal power plant)
- Phase of exploratory electricity production. Unless otherwise specified, the placement of devices for the exploration and exploratory exploitation of geothermal energy for the production and storage of electricity within the framework of a geothermal research concession shall be subject to the provisions of regulations governing water management, mining, environmental protection and nature conservation and to the exploratory exploitation of geothermal energy, the provisions of regulations governing spatial planning, construction and the protection of cultural heritage shall also apply.

In summary, Slovenian geothermal energy business is driven by a handful of users and engineering companies. It has a potential for development but the knowledge has to do it and government support is limited. Therefore, it would be reasonable to develop a system of licensing the existing potential geothermal areas to investors with knowledge and financial capabilities to develop the geothermal industry.

2.1.5.3. Educational opportunities for geothermal energy

Summer Schools and Short Courses

International Summer School on Thermogeology organized by the Geological Survey of Slovenia and the University of Ljubljana is a week - long program that covers exploration, heat pumps, reservoir engineering, drilling, and economic/policy aspects. Lectures are complemented by field trips (e.g., pilot geothermal power plant at an abandoned gas well, heat pump installations). Also, Advanced Methods of Geothermal Energy Exploitation is a dedicated course at the Faculty of Natural Sciences and Engineering, offering a theoretical-practical blend (35 h lectures, field/lab practice), targeted at professionals and MSc students aiming to design and assess geothermal systems in Slovenia and beyond.

Degree Programs

Master's Degree in Geotechnology at the University of Ljubljana in duration of 2 years, covers mining and geotechnology broadly, but students can tailor it towards geothermal through electives and project work, gaining both theoretical and hands - on skills. Bachelor's Course in Environmental Technologies at the University of Nova Gorica provides an overview of renewable energy including geothermal systems (e.g., hydrothermal exploitation and deep heat mining), with laboratory exercises. Optional Energy Resources Course in Applied Physics at the University of Ljubljana is a 3-ECTS elective covering geothermal among other energy sources and their environmental impacts.

Research and Practice

The Geological Survey of Slovenia (GeoZS) is active in geothermal research mapping resources, designing/exploiting thermal groundwater, heat pump systems, numerical modelling, permitting support, and maintaining Slovenia's geothermal GIS database. Further collaboration regarding geothermal energy centres around projects such as Danube GeoHeCo (EU - funded project focused on shallow geothermal hybrid systems and decision support tool) and Si - Geo - Electricity (a collaboration among UNILJ, UM, GeoZS, Petrol Geo, which includes pilot geothermal power plant pilots in abandoned wells).



2.2. Geothermal potential of the Central European region

The Subchapter on the geothermal potential of Central European region offers a detailed analysis of the renewable energy prospects within key geological basins - the North German, Molasse, Vienna and Pannonian Basin, which are integral to the project TRANSCEO. It explores the geological and thermal attributes that underpin geothermal development, with a focus on repurposing abandoned hydrocarbon wells to advance sustainable energy goals aligned with EU initiatives to increase renewable energy in the energy mix.

2.2.1. Austria

Austria possesses significant geothermal potential derived primarily from its varied geological settings, notably sedimentary basins adjacent to the Alpine orogeny (Figure 2). These geological formations result in low - to - medium enthalpy geothermal resources, making them predominantly suitable for heating due to geothermal gradients typically ranging from 25 to 35 °C per kilometre, achieving temperatures between 60 - 100 °C at depths of approximately 2 - 3 km.

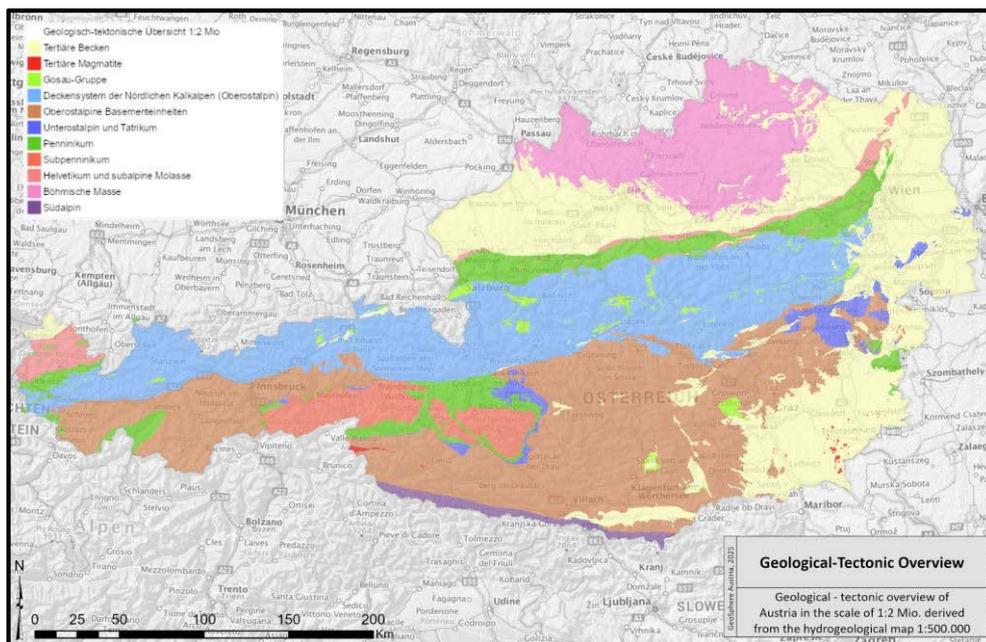


Figure 2: The geological map of Austria

***Note:** Sedimentary basins, where most of the geothermal resources lie (yellow)

Source: GeoSphere Austria/CC BY 4.0

Regions with reservoir temperatures exceeding 40 °C are considered “hydrothermal reservoirs” in the Austrian context (Figure 3). Warm water at these temperatures is primarily in deep aquifers within sedimentary rocks (sandstones and carbonates) or fractured crystalline basement. Shallower thermal springs (below 40 °C) exist and can be used locally for balneology or private heating.

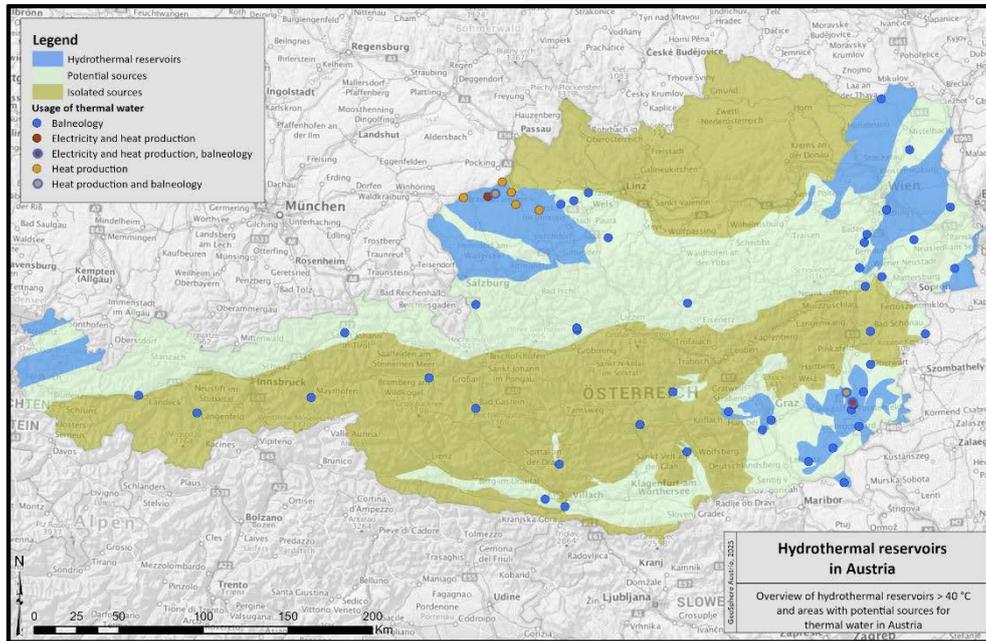


Figure 3: Geothermal reservoirs in Austria according to current knowledge

***Note:** Hydrothermal reservoirs (> 40 °C) (blue); potential occurrence of thermal water (light blue); areas where individual occurrence of thermal water is possible (green)

Source: Bottig, 2025

Key areas include the Vienna Basin in the east, the Molasse Basin in the north (foreland of the Northern Calcareous Alps), the Styrian Basin as part of the Pannonian Basin in the southeast and localised deep aquifers in the far west (Vorarlberg).

Eastern Austria - Vienna Basin

The Vienna Basin is a deep Neogene sedimentary basin located along the Alpine - Carpathian margin. It contains thick Miocene sediment sequences and is structurally underlain and bordered by older Alpine - derived carbonate nappes. Multiple proven geothermal aquifers are present within the Basin:

- **Rothneusiedl Formation (Neogene Conglomerate)**

This unit comprises poorly cemented, coarse, gravelly conglomerates, predominantly in the southern part of the Basin. The Rothneusiedl Formation reaches thicknesses up to approximately 370 m and depths of around 3,4 km in the central Basin. Reservoir temperatures range from ≈40 °C near the Basin margins to ≈140 - 150 °C in deeper zone. Due to its high porosity and permeability, the formation represents a significant hydrothermal reservoir. A test well drilled to ≈3,1 km yielded thermal waters at ≈120 °C.

- **Triassic Carbonate Nappes (Hauptdolomit & Wettersteinkalk)**

These units are part of the Northern Calcareous Alps (notably the Göller and Frankenfels - Lunz nappes) and dip beneath the Basin. The fractured and karstified carbonates form deep geothermal reservoirs at depths ranging from ~1 km near the Basin edge to 4 - 5 km in the depocenter. Estimated temperatures vary between 40 - 120 °C, with potential values up to 150 °C in fault zones. Theoretical maximum temperatures may reach ≈200 °C in the deepest, untested sections. Salinity ranges from 9 - 36 g/L Cl, indicating mixed fresh and mineralised waters. These reservoirs are prime targets for geothermal district heating in the Vienna metropolitan area.



Northern Austria - Molasse Basin (Alpine Foreland)

The Molasse Basin, a foreland Basin north of the Alps, contains deep Cenozoic sedimentary sequences. It reaches depths of 4 - 5 km in Upper Austria and Salzburg, with shallower sections in Lower Austria. Geothermal reservoirs are found in both clastic and carbonate formations.

- **Egerian Sands (Melk Formation, Oligocene)**

These coarse, sandy to gravelly sediments of Late Oligocene age occur at depths of $\approx 1,5 - 2,4$ km in the northern Molasse Basin. While generally less explored, they show good permeability and moderate geothermal potential. A thermal spa at Laa an der Thaya extracts ≈ 42 °C water from ≈ 1 km depth. Predicted temperatures range between 40 - 75 °C in deeper sections.

- **Cretaceous Sandstones (Cenomanian and Campanian)**

These older clastic units, found at 1 - 3 km depths, offer moderate geothermal potential with temperatures between 40 - 100 °C. Though less continuous than the Malm limestones, local productivity has been observed, such as the Cenomanian "Hössgang" sands near Salzburg, which yield 50 - 65 °C water from $\approx 1,5$ km depth.

- **Upper Jurassic Limestones (Malm)**

This thick sequence of karstified limestone underlies much of the Basin and is the most productive deep geothermal aquifer in the Alpine foreland. At depths of $\approx 2 - 3$ km, reservoir temperatures range from $\approx 50 - 105$ °C. In deeper parts, temperatures may exceed 130 °C. For example, the Braunau - Obernberg wells produce ≈ 60 °C water at $\approx 1,2$ km depth, while > 100 °C is projected at > 3 km. This aquifer features high permeability and low salinity ($\approx 1 - 2$ g/L Cl) near recharge areas and supports numerous district heating systems across Austria and southern Germany.

Southeastern Austria - Styrian and Pannonian Basins

This Miocene Basin features volcano - sedimentary sequences underlain by a pre - Mesozoic basement and transitions eastward into the Pannonian Basin. It hosts both shallow and deep geothermal reservoirs.

- **Pannonian Sandstones (Late Miocene - Pliocene)**

These younger sandstones in Burgenland lie at 1 - 2 km depth. Expected temperatures range from 40 - 75 °C (Güssing) to ≈ 100 °C (Seewinkel). Though underutilised, studies suggest promising conditions (e.g. 70 - 90 °C at the base of Upper Pannonian sediments).

- **Miocene Sandstones (Badenian/Sarmatian)**

These units, found at 1 - 2,5 km depth, exhibit moderate to good permeability. Reservoir temperatures range from ≈ 40 °C to 85 - 100 °C, with potential maxima of ≈ 125 °C. Notable geothermal sites include Bad Waltersdorf, Bad Blumau, and Fürstenfeld. In the case of Blumau, the shallow Neogene aquifer (Blumau 3) supplies the spa, while deeper wells (e.g. Frutura GT1/GT2, Waltersdorf 1) access Devonian carbonate reservoirs used for electricity and greenhouse heating.

- **Karpatian Volcanic Rocks (Neogene)**

Fractured volcanic rocks (e.g. basalts and andesites) near Gleichenberg and Klösch, at depths of 0,5 - 1,5 km, provide local geothermal potential. Temperatures range from 50 - 85 °C. Bad Gleichenberg has an active well yielding $\approx 80 - 85$ °C water from volcanic tuff.

- **Permo - Mesozoic Basement**

In areas such as Bad Radkersburg, the fractured and karstified pre - Tertiary basement (including Palaeozoic carbonates, green schists, and phyllites) forms high - temperature aquifers at 1,5 - 3 km depth. Thermal waters reach 60 - 100 °C, the Bad Radkersburg well (2 km) yields 80 - 82 °C. These reservoirs show high



permeability along fault zones and are important for spa and heating applications. The Palaeozoic succession is of prime importance for the geothermal potential of the Styrian Basin (Schreilechner et. Al, 2024).

Western Austria - Alpine Foreland (Vorarlberg)

- **Helvetic Limestone Units (Upper Jurassic - Lower Cretaceous)**

In Vorarlberg and the Rhine Valley, deep Helvetic carbonate units (Malm equivalent and Schrattekalk) occur at 3 - 5 km depth due to Alpine thrusting. Though currently undeveloped, these karstified limestones may reach 80 - 130 °C, with modelled values up to 150 °C. These units represent potential targets for future geothermal exploration, particularly in cross - border cooperation with Liechtenstein. Table 2 below summarises the main hydrothermal formations, their typical depths, temperature ranges, lithology, and permeability.

Table 2: Geothermal reservoirs of Austria with depth range, temperature range, lithology and permeability

Region and reservoir	Depth range (m)	Temp. range (°C)	Lithology	Permeability
Vienna Basin - Rothneusiedl Fm Middle Miocene	≈500 - 3.400 m	≈40 - 150 °C	Coarse conglomerate (gravel)	High (porous, loosely cemented)
Vienna Basin - Triassic Carbonates	≈1.000 - 5.000 m	≈40 - 120+ °C	Dolomite and limestone (karstified)	Moderate (fracture networks)
N. Molasse - Malmian Carbonates	≈1.500 - 3.500 m	≈50 - 130 °C	Karstic limestone (reef)	High (karstic conduits)
N. Molasse - Sandstones (Upper Oligocene to Lower Miocene)	≈800 - 2.000 m	≈40 - 75 °C	Coarse sand and gravel	Moderate - High (porous)
S.E. Styria - Basement (Meso - to Palaeozoic)	≈1.000 - 3.000 m	≈60 - 100 °C	Fractured/carbonate basement, phyllites, green shists	Moderate (fault - controlled and karstified)
S.E. Styria - Sandstones (Miocene)	≈700 - 2.500 m	≈40 - 100 °C	Sands (fluvial and deltaic)	High (in well - sorted intervals)
S.E. Styria - Volcanics (Lower Miocene)	≈500 - 1.500 m	≈50 - 85 °C	Fractured basalt/andesite	Variable (high near faults)
Burgenland - Pannonian Sands (Upper Miocene)	≈800 - 1.800 m	≈40 - 100 °C	Sandstone (lake/fluvial)	Moderate (locally good)
W. Vorarlberg - Helvetic Carbonates	≈3.000 - 5.000 m	≈80 - 130 °C	Dense limestone (some karst)	Low - Moderate (requires fracturing)

Source: Bottig, 2025.

As described previously, Austria possesses substantial geothermal potential, primarily distributed across five key geological regions. These areas are characterised by significant hydrogeothermal resources, supported by extensive geological data accumulated through decades of hydrocarbon exploration. The estimated total



hydrogeothermal potential ranges between 700 MW_t and 1.500 MW_t, with the Vienna Basin alone capable of providing over 1.000 MW_t at a sustainable extraction level.

Geothermal energy use in Austria spans across three main categories: deep geothermal, shallow geothermal, and underground thermal energy storage (UTES). Deep geothermal energy is primarily utilised for district heating, spa (balneological) applications, and limited electricity production, with an installed heating capacity of approximately 104 MW_t concentrated in Upper Austria and Styria. Although small in scale, electricity generation from geothermal sources exists in locations such as Bad Blumau and Fuerstenfeld in Styria. Shallow geothermal systems, dominated by over 104.000 installed ground - source heat pumps, are increasingly important for both small - and large - scale heating and cooling applications. Technologies employed include borehole and horizontal loop heat exchangers, as well as groundwater systems. In parallel, Austria is actively exploring UTES solutions like Aquifer Thermal Energy Storage (ATES) and Pit Thermal Energy Storage (PTES), with significant projects underway in Vienna, Graz and Linz, aimed at integrating seasonal heat storage into district heating networks.

Current applications of geothermal energy in Austria include heating, cooling, balneology, and electricity generation, delivering wide - ranging benefits. Cities such as Vienna and Graz are spearheading efforts to decarbonise their district heating networks, with Vienna targeting a geothermal capacity of 200 MW_t by 2040 - enough to serve approximately 200.000 households. In agriculture and industry, geothermal systems support projects like the Frutura initiative in Fuerstenfeld, enhancing sustainability and productivity. Balneological use remains significant in spa towns such as Geinberg and Bad Waltersdorf, which leverage geothermal heat to promote tourism and wellness. Additionally, shallow geothermal applications contribute to urban heat island mitigation through innovations such as asphalt thermal collectors. Ownership of geothermal energy infrastructure is shared among private entities, public utilities, and specialised geothermal companies. Key players in exploration and geothermal energy production include Wien Energie, OMV Austria, RAG Exploration & Production (REP) and Adx Energy. Overall, geothermal energy plays a critical role in Austria's energy transition, offering economic, environmental, and social benefits, including job creation, emissions reduction and enhanced energy security aligned with national climate objectives.

2.2.2. Croatia

The Pannonian Basin, partly located in Croatia, is well known for its higher - than - average geothermal gradient with good potential for geothermal energy exploitation. Most of the currently known geothermal potential locations in the Croatian part of the Pannonian Basin were discovered during the natural gas and oil exploration and exploitation from the mid - 20th century onward. Unfortunately, recent geothermal energy utilisation in Croatia, which began in the late 1980s, developed very slowly and sporadically, even though the utilisation of it has been known since the Roman times. Most of the discovered geothermal sources are used for balneology in numerous thermal spas. In the last decade low - temperature geothermal resources have also been used in agriculture, namely in greenhouses.

The Drava depression is the most prolific region of the Basin for geothermal energy development and due to the good geothermal properties, most licenses are located within this depression and with possibilities of high increase of geothermal potential from deep gas fields within Drava depression after hydrocarbon lifetime expiration. The planned use varies from electricity to agricultural use by the local community. Aside from classic geothermal brine production, there is also a good potential of geothermal brine exploitation from bottom aquifers in mature natural gas and oil fields, especially in the Drava depression. Many hydrocarbon reservoirs in Croatia consist of natural gas and oil in the upper part of the reservoir and massive aquifer in the bottom part. During initial depletion - drive exploitation, pressure in the reservoir declines, causing brine from the aquifer to slowly invade the oil zone. While the reservoir is in its final stages of production, some waterflooded peripheral wells could be turned into geothermal ones, even if oil is still produced or after the field is abandoned. So far, several locations with relatively high temperatures



of the bottom aquifer have been identified as a good potential for deep geothermal energy exploration and exploitation. At the time when there was intensive drilling for natural gas and oil in Croatia in the last century, almost 4.000 wells were drilled. Currently, there are 500 wells outside the existing production natural gas and oil fields, with most of them being abandoned and do not present possibility for revitalization due to age, incompleteness of casing or being negative for geothermal fluids.

From the geological and tectonics standpoint, the Mohorovičić discontinuity in the Pannonian Basin varies from 30 km to 20 km, while its depth in the Dinarides is up to 40 km (Šumanovac et al., 2009), thus creating 2 very different geothermal regions in Croatia with different geothermal gradients. The Dinarides area has an average geothermal gradient of 0,018 °C/m with a heat flux of 29,0 mW/m² and thus has no significant geothermal potential, while the Pannonian Basin has an average geothermal gradient of 0,049 °C/m and a heat flux of 76,0 mW/m² and thus has an above average geothermal potential in Europe (Jelić et al., 1995). The Pannonian Basin is characterized by low seismicity and high heat flow (Lenkey et al., 2002). A high heat flux, followed by high temperatures, has developed in the Pannonian Basin (Horváth et al., 2015). Recently, Macenić et al. (2020) presented a novel geothermal map of Croatia, based on gathered data from 154 deep exploration wells (Figure 4).

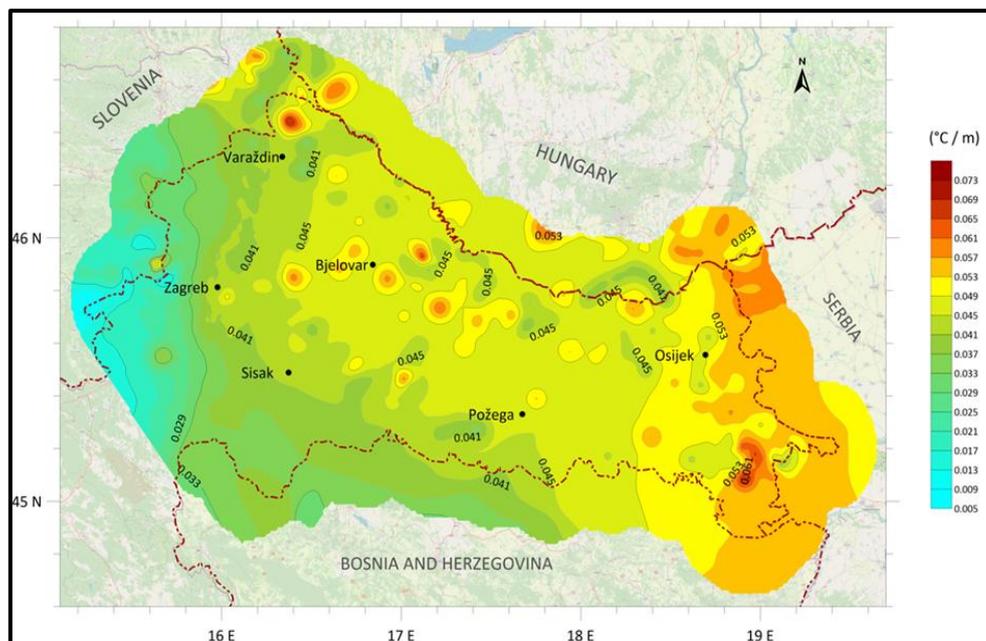


Figure 4: Novel geothermal gradient map of the Pannonian Basin

Source: Macenić et al., 2020

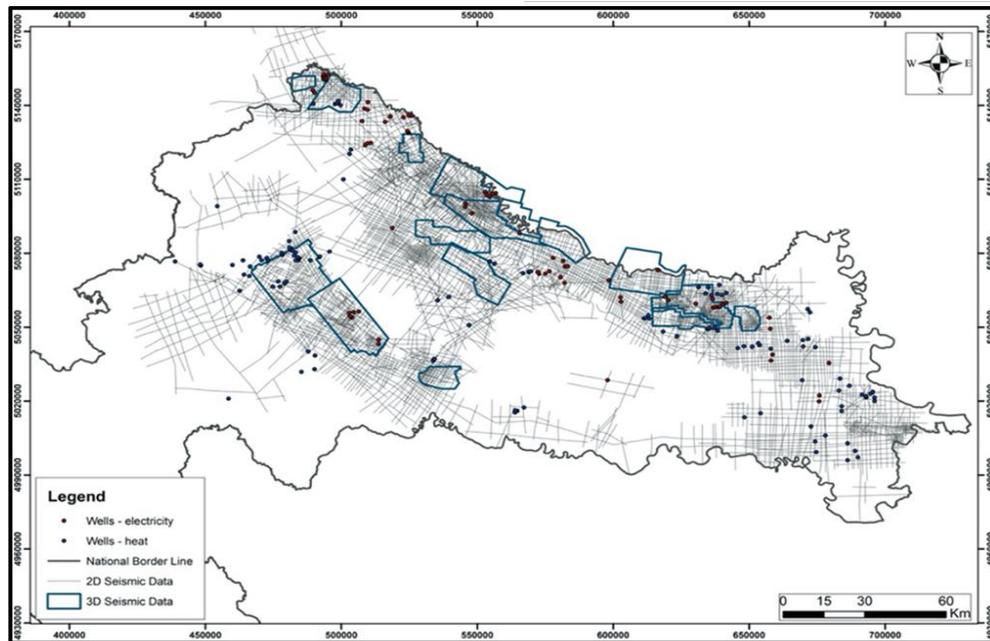


Figure 5: 2D and 3D seismic data from hydrocarbon exploration available for geothermal reservoirs exploration and geological modelling

Source: Tuschl et al., 2022

The Pannonian Basin, as the largest Miocene - Quaternary Basin, has been developed within the Alpine - Carpathian - Dinaridic orogenic system (Prelogović et al., 1998). According to Cvetković et al. (2019) the tectonic evolution of the Basin started by the Cretaceous - Paleogene collision of Adria Microplate and European foreland. In the Early to Late Miocene, European plate roll - back subduction induced lithospheric extension and back - arc - type extension in the Basin. The Neogene sedimentation process occurred within three 2nd order megacycles, while majority of hydrocarbon source and reservoir rocks were formed during the 1st and 2nd megacycle (Saftić et al., 2003).

The main source rocks are mainly marly limestones and limy marls, while hydrocarbons are found in the Neogene basement, Miocene coarse grained clastics and Upper Miocene sandstone (Lučić et al., 2001). The extensional tectonics and the thinning of the crust and lithosphere within the Pannonian Basin are the cause of the high geothermal gradients and the very pronounced heat flow. The Croatian part of the Pannonian Basin is divided into 4 main depressions (Figure 6): Mura, Sava, Drava and Slavonia - Srijem (Velić et al., 2012). The Mura depression is located in the northernmost part of Croatia and extends from the border with Slovenia and Hungary in the north to a series of Žumberak, Medvednica and Kalnik mountains in the south. The Sava depression extends along the southwestern edge of the Pannonian Basin. The Drava depression covers most of the Basin and extends over the territory of the Drava River and is bounded by the state border with Hungary in the north and reaches the border with the Republic of Serbia in the east. The southern part of the Drava depression borders the mountains from Medvednica to Krndija. Slavonija - Srijem depression is located east of the town of Slavonski Brod and extends to the Serbian and Bosnian - Herzegovina borders and is the smallest of all depressions in the Croatian part of the Pannonian Basin (Malvić and Velić, 2011).

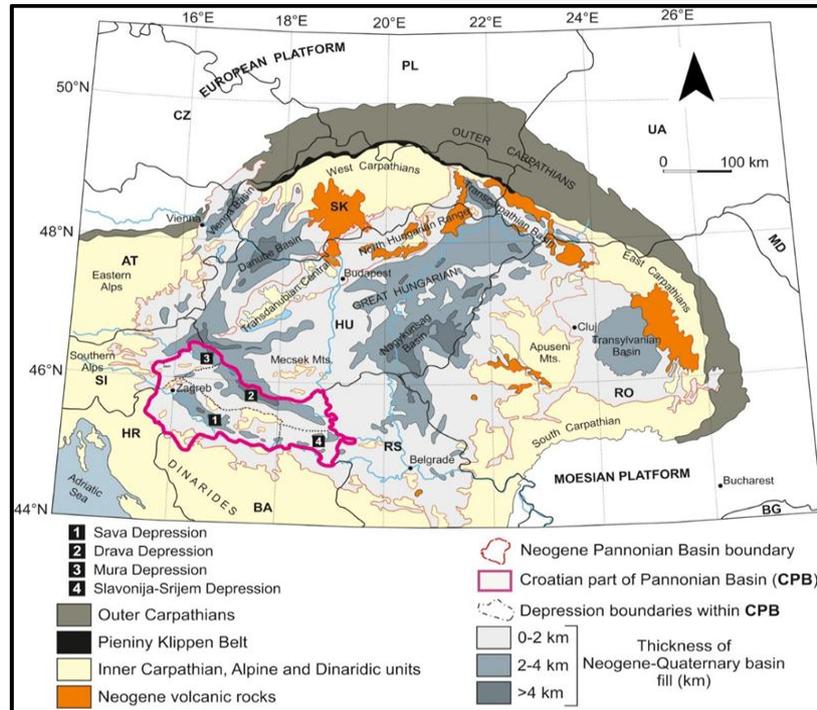


Figure 6: Schematics of the depressions in the Croatian part of the Pannonian Basin

Source: Velić et al., 2012

The geothermal potential in the Croatian Part of the Pannonian Basin is related to the pre - Neogene basement and Lower Neogene deposits (Figure 7). The pre - Neogene basement is the most important correlation unconformity in the Basin and is visible in almost all well and seismic data (Saftić et al., 2003) and is characterised by high temperatures in almost the entire surface of the spreading (Cvetković et al., 2019). According to Royden et al. (1983) the evolution of the Pannonian Basin is subdivided into a syn - rift (Early to Mid - Miocene) and post - rift (Late Miocene to Quaternary) phase. The main geothermal plays are developed in pre - rift and syn - rift phase and considered as plays with high geothermal potential according to the present exploration activities in Croatia. There is a post - rift geothermal clastic play which is usually not a primary target of the geothermal exploration due to the lower geothermal gradient and flow.

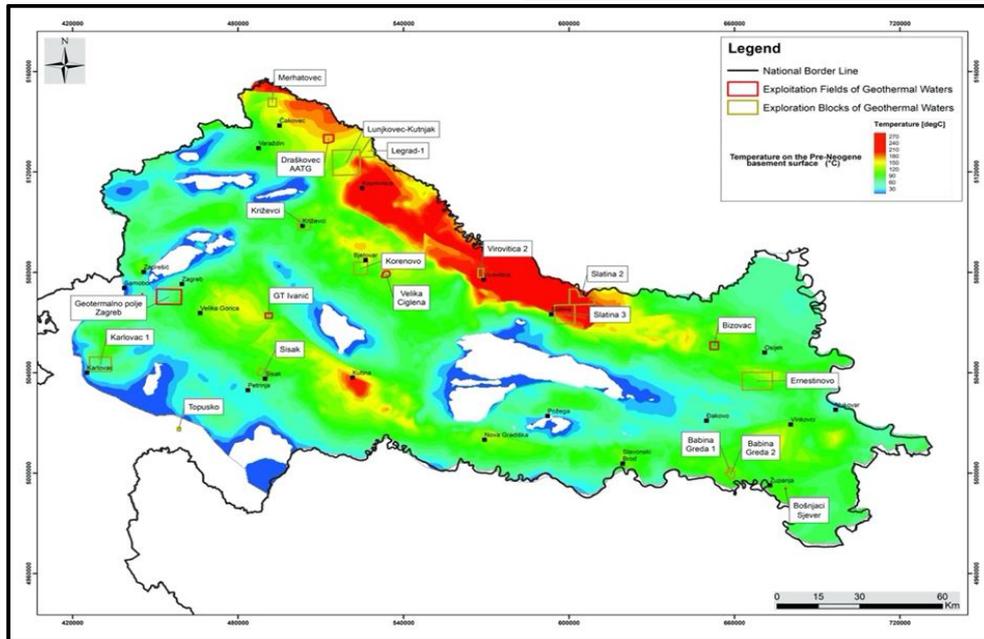


Figure 7: Schematics of the main depressions in the Croatian part of the Pannonian Basin (Temperature of the pre - Neogene basement surface)

Source: Cvetković et al., 2019

Geothermal play developed in the pre - rift phase considers Paleozoic and Mesozoic age deposits and rocks (Sebe et al., 2020). According to the common lithostratigraphic classification, there are two lithological types of the pre - Neogene basement - predominantly Paleozoic magmatic and metamorphic rocks and Mesozoic carbonate deposits (Figure 8). The Paleozoic, in locally accepted nomenclature Crystalline Basement Rock generally consists of granites, gabbro intrusions and fissured and altered metamorphized rocks intrusions. The petrophysical interpretation is based on well data which provides good characterization of weathering zone, almost always located in the uppermost part of the rock, with secondary porosity. The weathering zone can extend from a few metres to several tens of metres from the top of the bedrock and mainly was formed during the Paleogene. (Malvić et al., 2020).

The pre - Neogene deposits consist of carbonate deposits of Mesozoic age, mainly Triassic dolomites, while in the western part of the Pannonian Basin one can also find Jurassic limestones and dolomites as well as Upper Cretaceous Scaglia limestones. Pre - Neogene basement is the log marker Pt (PN) in most of the internal studies of the Croatian part of the Pannonian Basin (Malvić & Cvetković, 2013). The Mesozoic deposits are best preserved in greater thickness in the western part of the Basin. They consist of calcareous dolomite - breccia conglomerates, marly limestones or marbled limestones. It can be concluded that towards the eastern and southern parts of the Basin, they are entirely absent or isolated in the form of blocks or lobes, which may affect the isolation of aquifers. Cracked massive carbonate deposits have been shown to be good aquifers. Geothermal play developed in syn - rift phase refers to the deposits from the Lower to Middle Miocene. They are defined by log markers from Pt to Rs7. They are mostly represented by large clastic deposits in the lower parts of the formations, breccias and breccia conglomerates, which may be polymictic or carbonate. In the upper parts of the formations there can be present sandstones of the lithoarenite or arkose arenite type, siltites, marly and sandy limestones of the biocalcarenite and biocalcrudite type (lithothamnium limestones) and marls (Malvić & Velić, 2011).

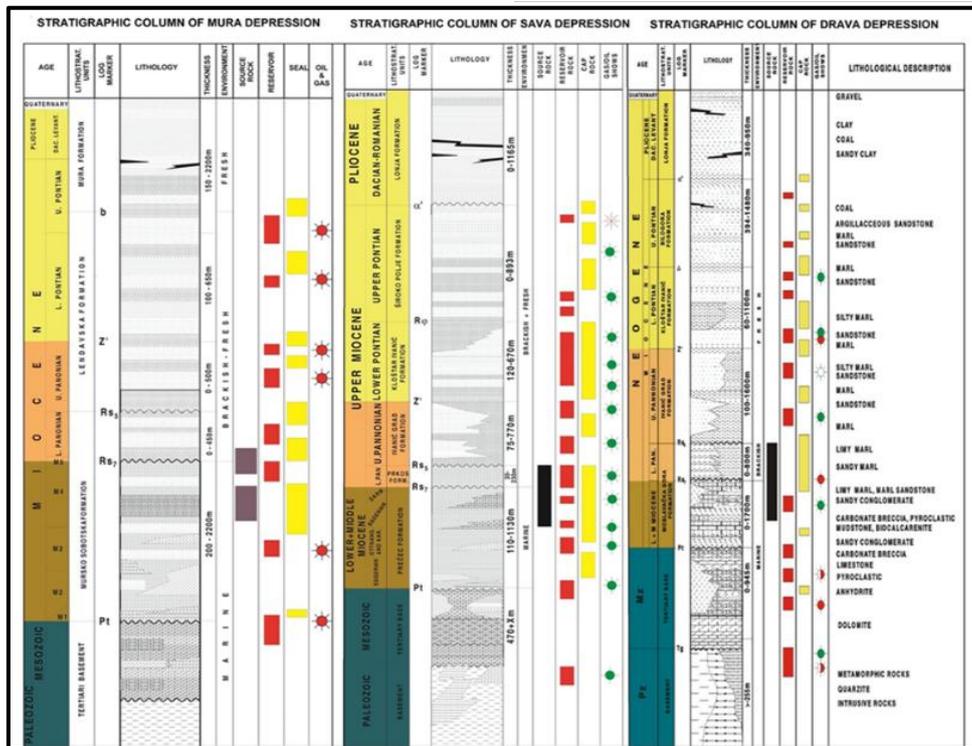


Figure 8: General geological column of the Mura, Drava and Sava depressions

Source: Durn & Krpan, 2016

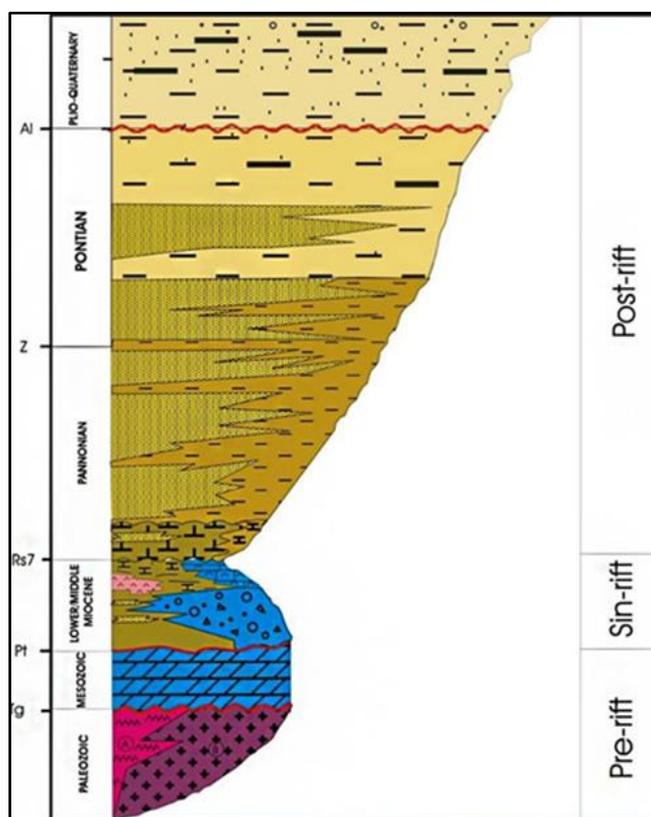


Figure 9: Schematic geological column of the Croatian part of Pannonian Basin

Source: Tuschl & Kurevija, 2023



Geological features of the Mura Depression

The Basin fill sediments of Neogene - Quaternary age within the Mura Depression are distinguished into 3 lithostratigraphic units or formations. The Murska Sobota formation is defined by tectonic - erosive discordance Pt/Tg in the bottom and with EL - marker Rs5 in the top. It is characterized by a heterogeneous lithological composition and chronostratigraphically includes the older, middle Miocene and the oldest part of the younger Miocene (part of the lower Pannonian). The formation lithology consists of: conglomerate, breccia, marly sandstones, calcitic sandstones, lithotamnian limestones, calcitic marls, argillaceous marls and their varieties. The Lendava Formation is bounded by EL - markers Rs5 and b and represents an approximate equivalent to the deposits of Pannonian and lowermost Upper Pontian age. The formation is characterized by sandy and clayey marls and sandstones. The Mura Formation includes deposits from the youngest part of the Miocene (Upper Pontian), Pliocene and Quaternary. The deposits are characterized by a heterogeneous composition, dominated by sandstones and sands, sandy and clayey marls, gravels and clays with occasional occurrences of coal seams. The bottom of the formation is determined by the EL - marker b, while the top of the formation is defined by the surface of the terrain.

Geological features of the Drava Depression

The Basin fill sediments of Neogene - Quaternary age within the Drava Depression are distinguished into 5 formations. The Moslavačka Gora formation is defined by a tectonic - erosive unconformity Pt/Tg in the bottom and with EL - marker Rs5 in the top. It is characterized by a heterogeneous lithological composition, and chronostratigraphical encompasses the older and middle Miocene and the oldest part of the younger Miocene (Lower Pannonian). The formation is lithologically composed of conglomerates, breccias, marly sandstones, calcitic sandstones, lithothamnion limestones, calcitic marls, clayey marls and their varieties. The Ivanić - Grad formation is bounded by EL - markers Rs5 and Z' and represents an approximate equivalent to the Upper Pannonian age deposits. The formation is characterized by sandy, clayey and silty marls and sandstones. Calcite marls often occur in the bottom part of the formation. The Kloštar Ivanić formation is defined by EL - markers Z' and Δ and lithologically it is characterized by sandy and clayey marls and sandstones of Lower Pontian age. The Bilogora Formation comprises a sequence of Upper Pontian deposits bounded by EL - markers Δ and α'. The formation is lithologically defined by the occurrence of sands to weakly bound sandstones, marly clays, clayey or sandy marls with possible coal seams. The Lonja Formation includes Pliocene and Quaternary deposits. The deposits are characterized by a heterogeneous composition, dominated by sands, gravels, and sandy and marly clays with occasional occurrences of coal seams. The bottom of the formation is determined by the EL - marker α', while the top of the formation is defined by the surface of the terrain.

Geological features of the Sava Depression

The Basin - fill sediments of Neogene - Quaternary age within the Sava Depression are distinguished into 6 formations. The Prečec formation is bounded by a tectonic - erosive unconformity Pt/Tg in the bottom and with an EL - marker Rs7 in the top. It is characterized by a heterogeneous lithological composition, and chronostratigraphical it encompasses the older and middle Miocene. The most common rocks are: conglomerates, breccias, marly sandstones, sandy marls, calcitic sandstones, limestones and lithothamnium limestones. The Prkos Formation includes deposits of Lower Pannonian age, and they are related to the so - called white marls. Their lithological composition gradually changes from calcareous marls to sandstones of arkose and subarkose type. The formation is bounded by EL - markers Rs7 and Rs5. The Ivanić - Grad formation is bounded by EL - markers Rs5 and Z' and represents an approximate equivalent of Upper Pannonian deposits. The formation is characterized by alternations of sandy and clayey marls with sandstones and siltstones. The Kloštar - Ivanić formation is limited by EL - markers Z' and Rφ, and lithologically it is characterized by marls with numerous varieties and sands/sandstones of Lower Pontian age. The Široko Polje formation encompasses a sequence of deposits from the uppermost part of the Lower Pontian and the Upper Pontian. The sediments of the Široko Polje formation lie concordantly on older deposits, and consist of sandstones and sands, as well as sandy and clayey marls with layers of coal. The



base of the formation is determined by the EL - marker $R\phi$, while the top is defined by the EL - marker α' . The Lonja Formation includes Pliocene and Quaternary deposits. The deposits are characterized by a heterogeneous composition, dominated by sands, gravels, sandy and marly clays with occasional occurrences of coal seams. The bottom of the formation is determined by the EL - marker α' , and the top of the formation is determined by the surface of the terrain.

Geological features of the Slavonian - Srijem Depression

The Basin - fill sediments of Neogene - Quaternary age within the Slavonian - Srijem Depression are distinguished into 5 lithostratigraphic units or formations. The Vukovar Formation is bounded by a tectonic - erosive unconformity Pt/Tg in the bottom and EL - marker H in the roof. It is characterized by a heterogeneous lithological composition and chronostratigraphical encompasses the older and larger part of the Middle Miocene. The most common rocks are conglomerates, breccias, marly sandstones, sandy sandstones, calcitic sandstones, limestones and lithothamnium limestones. The Valpovac formation encompasses a sequence of deposits of Sarmatian and Pannonian age between the EL - markers H in the floor and EL - marker G in the roof. It is of lithologically homogeneous composition, mainly composed of calcitic marls with less abundant biocalcarenite quartz sandstones and silty marls. The Vinkovci formation is defined by the EL - marker G (or H) in the floor and with an EL - marker B in the roof. The formation is made up of a thick sequence of marl and sandstone deposits from the Upper Pannonian and part of the Lower Pontian. The Vera formation is characterized by the alternation of sandy and marly layers of Lower and Upper Pontian age. The formation is bounded by EL - markers B and A. The Vuka Formation comprises a sequence of deposits of Pliocene and Quaternary age. The formation is characterized by a heterogeneous composition of deposits, such as sands, gravels, sandy and marly clays with occasional coal layers. The bottom of the formation is determined by the EL - marker A, while the top of the formation is defined by the surface of the terrain.

Geothermal sites in Republic of Croatia

In 2018, new legal framework was adopted - Croatia's energy resources have been consolidated in one place, which is the basis for creating a positive investment climate in a country that rationally manages its resources. In this regard, special emphasis was placed on the great potential of geothermal and the exploitation of geothermal water for energy purposes. With the change of this legal framework, the market showed an increase in the number of issued geothermal exploration blocks. The interest in developing geothermal projects is seen in numerous exploration licenses issued in the last years, focusing on mid to deep geothermal potential. The planned use of these granted licenses varies from electricity production to agricultural use. The procedure for assessing the geothermal potential and determining the tender conditions is carried out by the Croatian Hydrocarbon Agency, established by the Government of the Republic of Croatia. Currently, potential investors can use the newly formed Geothermal Virtual Data Room which covers geotechnical data of the Pannonian Basin. Access to reports of 191 potential geothermal wells, seismic data and GIS data are available for the screening process. As of June 2025, 24 exploration licenses (light blue areas) and 11 exploitation licenses (dark blue areas) for geothermal waters are active in Croatia, as seen in Figure 10. All licenses are focused on the exploitation of deep geothermal energy. There are also 7 preliminary exploration areas for district heating systems, as seen in Figure 10 in purple colour. Figure 11 shows active exploitation hydrocarbon fields in Croatia, where the majority of active hydrocarbon wells are located, coloured in yellow, while exploration blocks are coloured light blue.

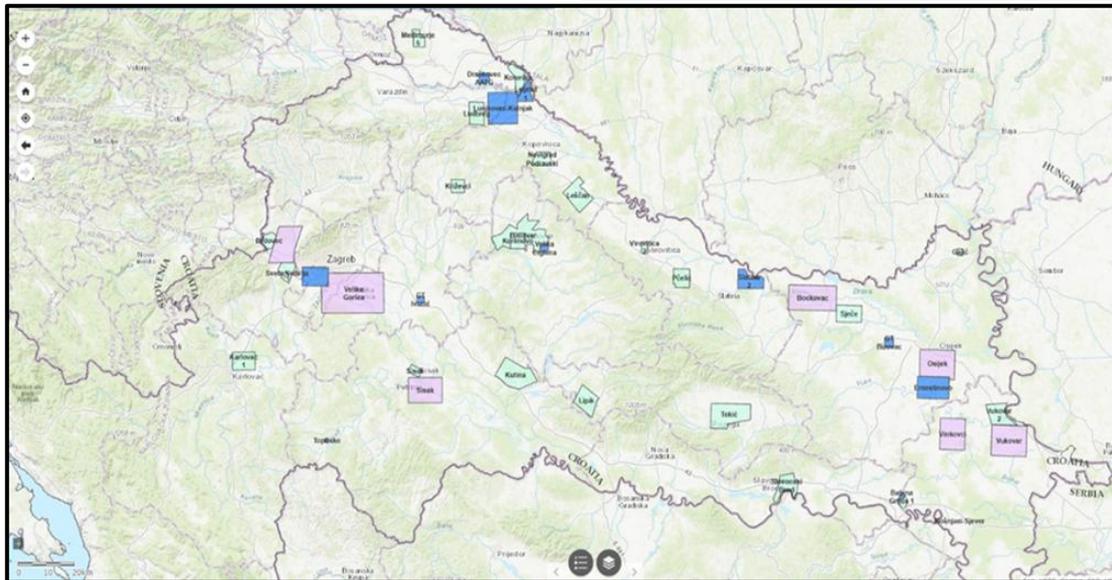


Figure 10: Geothermal exploitation areas (dark blue), exploration areas (light blue) and preliminary exploration areas (purple)

Source: Croatian Hydrocarbon Agency, 2025



Figure 11: Exploitation areas for oil and gas (yellow) and exploration blocks (light blue)

Source: Croatian Hydrocarbon Agency, 2025

Related to the mentioned, Table 3 gives an overview of the currently active exploration licenses for deep geothermal energy in Croatia, the concession holders, area under license and intended utilisation of geothermal energy. The 2 cancelled areas are also shown, since they remain prospective areas. Furthermore, Table 4 gives an overview of the current exploitation licenses, respective holders, area and utilisation intention. It also lists areas with preliminary exploration licenses for deep geothermal energy to be used in urban areas with district heating networks.



Table 3: Current exploration licences for deep geothermal energy (as of June 2025)

Exploration licence	Licence holder	Licence area, m ²	Utilisation
Babina Greda 2	Geotermalni izvori d.o.o.	7,70	ORC
Bjelovar	Terme Bjelovar d.o.o.	99,99	DHS
Brdovec	GeoDa Consulting d.o.o.	18,45	DHS
Gajić	Dalis d.o.o.	4,00	DHS
Karlovac 1	GeotermiKA d.o.o.	45,00	ORC
Korenovo	Terme Bjelovar d.o.o.	25,00	DHS
Kotoriba	Viola Energy Generation d.o.o.	27,14	ORC
Križevci	Komunalno poduzeće d.o.o.	18,45	DHS
Kutina	Razvojna agencija Mrav d.o.o.	84,77	DHS
Lešćan	Ina - Industrija nafte d.d.	55,65	ORC
Lipik	Izvori Lipika d.o.o.	47,53	DHS
Ludbreg	Lukom d.o.o.	34,94	DHS
Međimurje 5	Ina - Industrija nafte d.d.	17,39	ORC
Novigrad Podravski	Geotermal water d.o.o.	24,40	DHS
Pčelić	IGeoPen d.o.o.	32,83	ORC
Sisak	Komunalac Sisak d.o.o.	10,78	DHS
Sječce	IGeoPen d.o.o.	46,84	ORC
Slavonski Brod	Geotermalni izvori Brod d.o.o.	41,22	DHS
Sveta Nedelja 1	Eko plodovi d.o.o.	2,08	GH
Sveta Nedelja 2	Svenkom d.o.o.	22,95	DHS
Sveta Nedelja - Genera	Genera d.d.	0,79	DHS
Tekić	Panonski izvor d.o.o.	91,60	DHS
Virovitica 2	Poslovni park Virovitica d.o.o.	7,00	DHS
Vukovar 2	Vukovarska gospodarska zona d.o.o.	45,63	DHS
Slatina - 3	Cancelled 2025.	/	ORC
Merhatovec	Cancelled 2025.	/	ORC

Source: Croatian Hydrocarbon Agency, 2025



Table 4: Current exploitation and preliminary exploration licences for deep geothermal energy (as of June 2025)

Exploitation licence	Licence holder	Licence area, m ²	Utilisation
Babina Greda 1	Geo Power Babina Greda d.o.o.	2,6	ORC
Bizovac	Ina - Industrija nafte d.d.	9	DHS + B
Bošnjaci - Sjever	Ruris d.o.o. Županja	0,05	GH
Draškovec AATG	AAT Geothermae d.o.o.	11,18	ORC
Ernestinovo	IGeoPen d.o.o.	76,66	ORC
Geotermalno polje Zagreb	GPC Instrumentation Process d.o.o.	54,0	DHS
Geotermalno polje Ivanić	Ina - Industrija nafte d.d.	5,0	DHS + B
Legrad 1	Terra Energy Generation Company d.o.o.	20,89	ORC
Lunjkovec - Kutnjak	Bukotermal d.o.o.	99,97	ORC
Slatina 2	Geo Power Zagocha d.o.o.	38,77	ORC
Sveta Nedelja	Eko plodovi d.o.o.	0,01	GS
Topusko	Top - Terme d.o.o.	1,42	DHS + B
Velika Ciglena	Geoen d.o.o.	5,94	ORC
Preliminary exploration area	Licence holder	Licence area, m ²	Utilisation
Zaprešić	Croatian Hydrocarbon Agency	93,23	DHS
Velika Gorica	Croatian Hydrocarbon Agency	264,55	DHS
Sisak	Croatian Hydrocarbon Agency	95,25	DHS
Bockovac	Croatian Hydrocarbon Agency	131,53	DHS
Osijek	Croatian Hydrocarbon Agency	106,32	DHS
Vinkovci	Croatian Hydrocarbon Agency	87,68	DHS
Vukovar	Croatian Hydrocarbon Agency	121,01	DHS

Source: Croatian Hydrocarbon Agency, 2025

The described prominent geothermal sites are only a small fragment of the entire geothermal potential of the Pannonian Basin. Until now, as part of a broader screening process, drilling data, geophysical exploration data and well testing data from more than 2.000 well sites were initially collected and categorized or are in the process of research. Alongside sites that initially only contained geothermal brine, there is a long history of hydrocarbon exploration and exploitation in the Croatian part of the Pannonian Basin. Therefore, there are high numbers of bottom - type aquifers available for further research on mature natural gas and oil fields. Bottom - type aquifers usually have good potential to be used as geothermal energy resources once the hydrocarbon production is terminated. Such locations have very detailed geological data available, originating from geological exploration works, as well as data obtained from production, injection,



monitoring or exploration wells constructed during the natural gas and oil field exploitation period. Depending on the temperature from such bottom aquifers, geothermal brine could be used for direct heating purposes or in some cases even for power generation. The advantage of using bottom aquifer brine is seen not only in good geological determination but also in already present well assets, which could be converted and used for geothermal brine production. Repurposing of wells, where possible, also has economic benefits, since such projects would have lower investment costs. Bottom aquifer exploitation can have higher certainty of project completion due to lower geological uncertainty and good know-how derived from hydrocarbon exploration and exploitation works, already present at the location. With this tremendous move forward in developing a geothermal data room available for future investors to analyze, an increase of geothermal energy share in the final energy consumption in Croatia would be secured, as part of the green energy transition.

Overall, deep geothermal energy utilisation in Croatia includes electricity production via binary power plants and direct application in heating and balneology, due to its favourable thermogeological conditions. Croatia is actively developing geothermal energy, focusing on electricity generation, district heating, and sustainable agriculture, with several exploration projects confirming high-temperature reservoirs across the country. Croatia's deep geothermal sector is transitioning from exploration to implementation, with several exploitation licenses in the phase of drilling wells and preparatory work for power plants, such as Slatina 2, Legrad 1, Babina Greda 1 and others. The projects, such as Korenovo near Bjelovar city, are showing the way for other urban areas to implement geothermal energy in their development plans for renewable heating solutions. The Korenovo project aims to heat the business zone of the Bjelovar city, as well as utilise it in spas and balneology. In order to minimize the geological risk for prospective investors in district heating, the Croatian Hydrocarbon Agency, with the financing of the National Recovery and Resilience Plan (the NRRP) is drilling 4 wells near cities with existing district heating networks to eliminate a large share of CAPEX. These projects, prepared in such a manner, can be offered to future investors for further development and implementation in district heating systems. Currently, only one small city, Topusko, has an operational district heating network. Furthermore, application in the agricultural sector, where the number of greenhouses should increase in the near future, is of immense importance. Projects such as Sveta Nedelja and Bošnjaci - Sjever, give good practice examples of applications of deep geothermal energy utilisation. Finally, a large number of existing spa and balneology sites, with historical utilisation, such as Varaždinske Toplice, Bizovac, Topusko and others, show that the potential of geothermal energy in Croatia has much to offer.

Even though the thermogeological conditions are favourable in Croatia, it is still an emerging market in utilising its shallow geothermal resources. With under 200 cumulative shallow systems, including open loop and closed loop systems, there is much room in developing such projects. Considering this, there are also currently no active projects in the field of underground thermal energy storage, either shallow or deep. Therefore, there is large potential in implementing shallow systems as well as thermal storage energy solutions and to increase the share of the renewable energy in the energy mix in Croatia.

2.2.3. Germany

Geothermal potentials are commonly divided into shallow and medium to deep. In the following, only medium and deep potentials are considered. These potentials can further be classified to hydrothermal potentials and petrothermal potentials. Based on a study of Schulz et al. (2013) the highest hydrothermal potentials in Germany can be found in the North German Basin, the Upper Rhine Graben and the Molasse Basin. Notable petrothermal potentials can be found in Central and Southern Germany and the North German Basin (Figure 12).

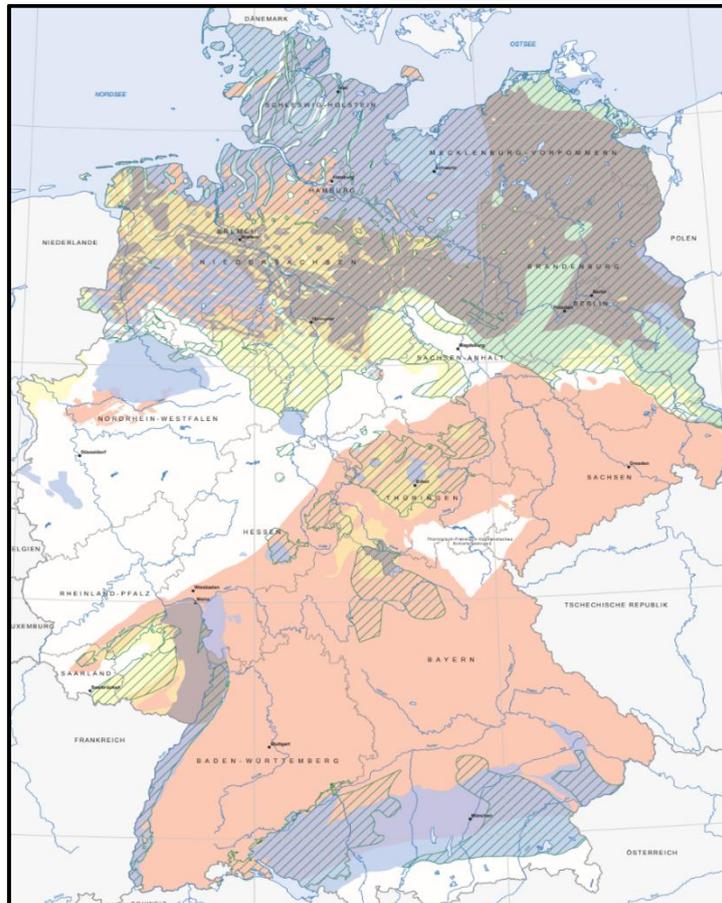


Figure 12: Geothermal regions and potentials in Germany

Source: Schulz et al., 2013

North German Basin

The evolution of the North German Basin began in the Permian about 300 Ma ago and underwent extensive tectonic expansion, subsidence and sedimentation as well as inversion with partial uplifting and erosion (Sattler et al. 2022). The sedimentary cover reaches a maximum thickness of more than 7 km in the centre of the Basin in the border area of Brandenburg and Mecklenburg - West Pomerania. The sedimentary filling is built up by various facies covering marine, shallow water, lacustrine and continental settings. Within the North German Basin hosts 5 Mesozoic aquifers suitable as hydrothermal host rocks (Feldrappe et al. 2008):

- Lower Cretaceous sandstones (Wealden, Hauterive and Barrême)
- Dogger sandstone, predominantly Aalen sandstone
- Rhaetian - Lias complex (Hettang-, Domer- and Exter Formation)
- Schilfsandstein (Keuper)
- Triassic Middle Buntsandstein (Detfurth- and Solling - Formation).

Aquifers within the North German Basin can vary significantly in terms of their thickness, distribution, and diagenesis, making thorough exploration at potential power plant sites essential. Locally other aquifers might be suitable for geothermal exploration such as the sandstones of the Oberrotliegend II or some sandstones of the Paleogene.



- **Lower Cretaceous sandstones**

The Lower Cretaceous sandstones are also widespread and have permeabilities of 250 mD on average with porosities of around 30% (25 - 37%), which enables productivity of over 100 m³ h⁻¹ MPa⁻¹ (Stober et al. 2016). These aquifers are present in Brandenburg, although in some cases their occurrence is limited to local or regionally restricted areas. The Hauterive sandstones are extensively distributed while Sandstones of the Barrême and Valangin are locally distributed.

- **Dogger sandstone**

Sandstone aquifers of the Dogger can be detected both in the Aalen and in the younger layers of the Bajoc/Bathon and the Lower Callov. Especially the Aalen formation usually resembles good reservoir properties and has a widespread distribution. Aalen sandstone can yield 150 to 300 m³ h⁻¹ MPa⁻¹.

- **Rhaetian - Lias complex**

Sandstone aquifers of the Rhaetian - Lias complex is distributed throughout almost the entire eastern part of the North German Basin and usually reaches thicknesses of over 10 m. In Mecklenburg - West Pomerania, these sandstones are predominantly suitable. These aquifers have low binding agent resulting in porosities of 25 - 30% and permeabilities of 500 - 1.000 mD that yield in a productivity of 50 - 150 m³ h⁻¹ MPa⁻¹.

- **Schilfsandstein**

Schilfsandstein within the Keuper can be exploited locally. Depending on their diagenetic history, these sandstones may serve as favourable aquifers.

- **Triassic Middle Buntsandstein**

The quality of the Middle Buntsandstein aquifers can vary within in the North German Basin. In the centre of the North German Basin, the pelitic facies dominates and the sandstone horizons are relatively thin and not suitable for the geothermal use. In the area of the coast to the Baltic sea they are characterized by porosities of predominantly over 20%. A comparison with the yield of the Stralsund and Karlshagen geothermal drillings leads to an expected value of around 100 m³ h⁻¹ MPa⁻¹ in the Detfurth sandstone. While the Buntsandstein might have more favourable permeabilities (due to lower overburden) in the Basin margin, reservoir temperature decreases due to shallower reservoirs.

South German Molasse Basin

Hydrothermal potentials in the German Molasse Basin are mainly focused on the Upper Jurassic and the Upper Muschelkalk. Furthermore, the Molasse Basin can be divided into a western part (mainly Baden - Württemberg) and eastern part (mainly Bavaria). The Upper Jura is the predominant target for exploration in both parts. Nonetheless, there are significant differences.

In the central and eastern part, the most suitable aquifer for hydrothermal exploration are limestones and dolomite of the Malm which can reach more than 600 m in thickness. The sequence in this region is primarily composed of up to 500 m of massive sponge limestone, overlain by porous limestone of coral debris (Meyer & Schmidt - Kaler, 1996). Thickness decreases towards northeast to less than 100 m (Stober et al. 2016).

Overview of the available well data in Brandenburg

The North German Basin is considered well - explored, particularly due to extensive investigations carried out between the 1950s and 1990s focusing on domestic raw materials and the utilisation potential of the deep subsurface. As a result, a dense network of 2D seismic profiles and numerous deep boreholes exceeding 400 meters in depth has been established. The majority of geological data from this region was generated by the hydrocarbon industry. In Brandenburg, well data are stored and accessible in the state's most comprehensive geoscientific database, known as GeoDaB.

According to data from the GeoDaB database, more than 650 of approximately 25.000 natural gas and oil wells in Germany are located in Brandenburg. In addition, the region hosts 159 boreholes for gas storage, 5



for CO₂ storage and around 150 boreholes associated with mineral exploration projects, including 86 for copper ore, 49 for iron ore, 16 for halite and potash salts and 7 for tungsten. Moreover, 14 wells were drilled for hydrogeological studies, and 168 boreholes serve geological mapping purposes (Figure 13).

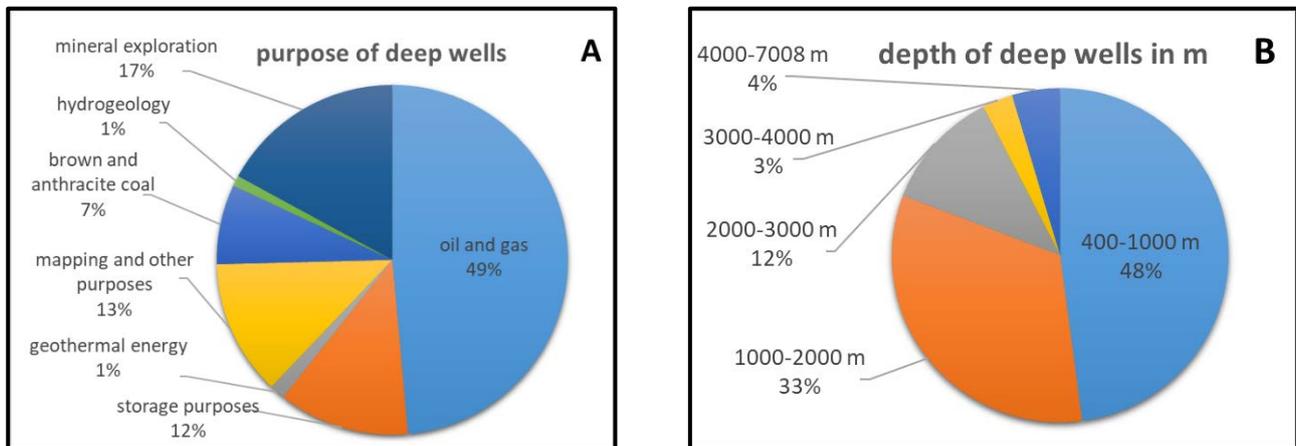


Figure 13: A) Purpose of the 1.127 deep wells in Brandenburg and B) their measured depth

Source: GeoDaB, 2025

Approximately half of the deep boreholes reach depths of less than 1.000 meters, one third range between 1.000 and 2.000 meters and about 210 wells extend beyond 2.000 meters (Figure 14). Notably, around 410 deep wells recorded in the GeoDaB database do not intersect any aquifers. The Rhaetian - Lias complex is reached by approximately 275 wells, while about 135 wells penetrate the Aalenian sandstone. Around 110 boreholes reach the Lower Cretaceous aquifer. The Middle Buntsandstein is intersected by 440 wells, and the Schilfsandstein by 195 (Figure 14). The majority of these deep wells are over 35 years old, with only 58 boreholes drilled after 1990. More than half of the wells were constructed during the 1960s.

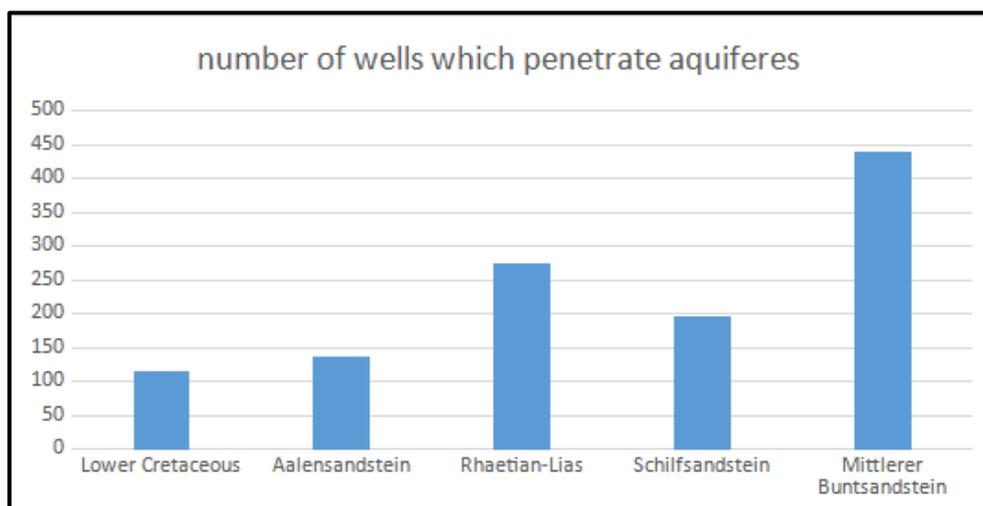


Figure 14: Statistic of deep wells that penetrate characteristic hydrothermal aquifers

Source: GeoDaB, 2025; Diener et al. 1998

Access to the databases of Saxony - Anhalt and Mecklenburg - Western Pomerania is restricted. However, with the help of the final reports from the TUNB project (3D model of the subsurface of the North German Basin), rough estimates can be made regarding the number, spatial distribution, purpose (for Mecklenburg - Western Pomerania only) and depth (for Saxony - Anhalt only) of boreholes in the eastern part of the North German Basin. These estimates are illustrated in Figures 15 and 16.

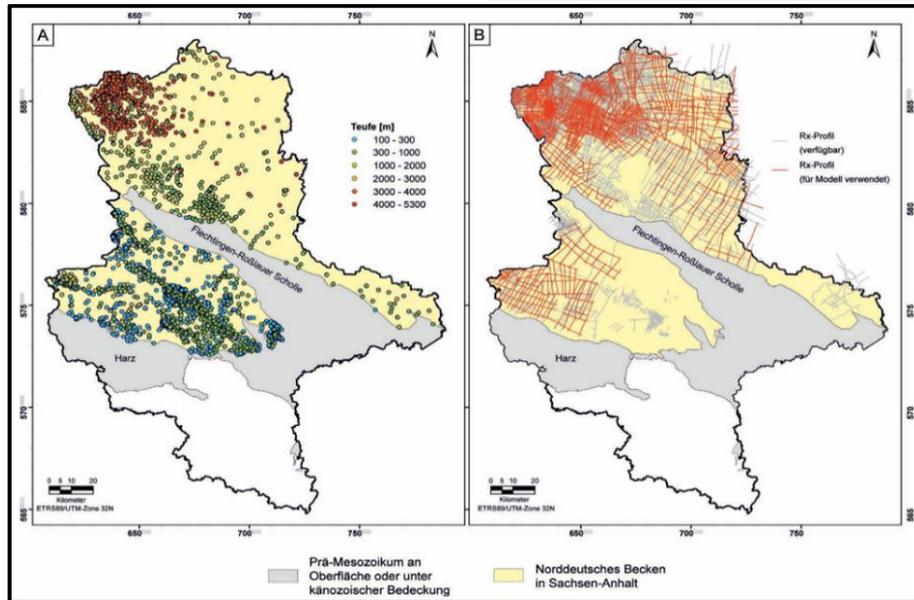


Figure 15: Overview of the boreholes (A) and reflection seismic profiles (B) used for modelling in Saxony - Anhalt

***Note:** For the Subhercynian Basin, only boreholes with depths > 100 m were used and for the Altmark region, only boreholes > 300 m

Source: Obst et al., 2024

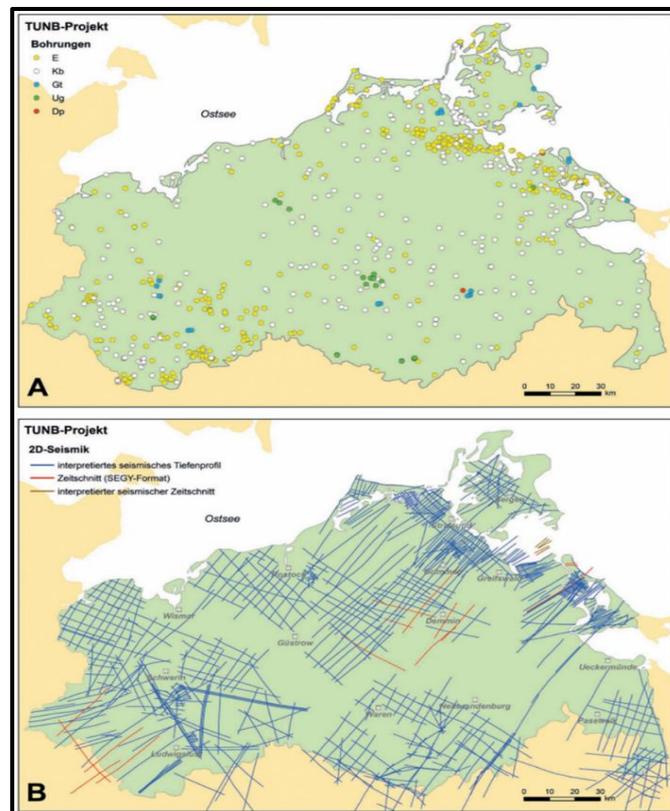


Figure 16: Overview of the boreholes (A) and reflection seismic profiles (B) used for modelling in Mecklenburg - Western Pomerania

Source: Obst et al., 2024



The abbreviations in Figure 16 stand for the following: Dp = Deposition of waste/sewage, E = Natural gas and oil exploration/production, Gt = Geothermal use, Kb = Scientific mapping, Ug = Underground gas storage. Furthermore, in Mecklenburg - Western Pomerania there are 694 deep boreholes, including approximately 450 natural gas and oil wells.

As shown previously, the geothermal potential is substantial and due to the geological variance across Germany, several different reservoir types and potentials can be identified. Most of the activities are currently focused on hydrothermal energy and shallow geothermal applications. Underground thermal energy storage (UTES) is already in use, but not widespread applied yet. Petro thermal potentials are currently under research, but not under significant exploitation. Nevertheless, there is significant effort in establishing new methods, such as Eavor - Loop in Geretsried.

Concluding, the most effort in geothermal applications is currently in shallow geothermal for prominently heating and cooling with borehole heat exchangers, medium deep and deep hydrothermal potentials for district heating, process heat or balneological applications and in geothermal storage systems.

The usage of shallow geothermal systems is widespread throughout Germany and an estimated 480.000 applications are installed and in use. As of 2023 an estimated 15.000 new applications will be installed every year, while as of January 2025, there are 42 geothermal plants in operation. Of these 42 plants, 31 are solely used for heat production, 9 are combine heat and power plants and 2 are dedicated exclusively to electricity generation. In addition to the 42 operational plants, 16 more geothermal power plants are currently under construction, 155 plants are in the planning phase and a total of 8 plants is registered for research purposes. Underground thermal energy storage systems (UTES) are already in use. An estimation of applied systems is quite difficult since only larger systems are registered by the mining authorities. Within the North German Basin, two UTES are currently in use: Berlin (Reichstag) and Neubrandenburg (Bundesverband Geothermie 2025).

Most prominent player in geothermal energy is probably the Greater Munich Area with more than 15 running applications and several projects in planning. The Upper Rhine Graben is furthermore under heavy exploration and approximately more than 30 projects are currently in planning.

2.2.4. Hungary

Hungary's geothermal potential is outstanding, thanks to the petrological and hydrogeological features of the Pannonian Basin. Due to the exceptionally high geothermal gradient in depth (approximately 20 - 30 °C/km), the temperature reaches 55 - 60 °C in many places at 1.000 m and at a depth of 2.000 m it can be as high as 120 - 130 °C (Figure 17). Neogene sediments and mezozoic carbonates are the main aquifers.

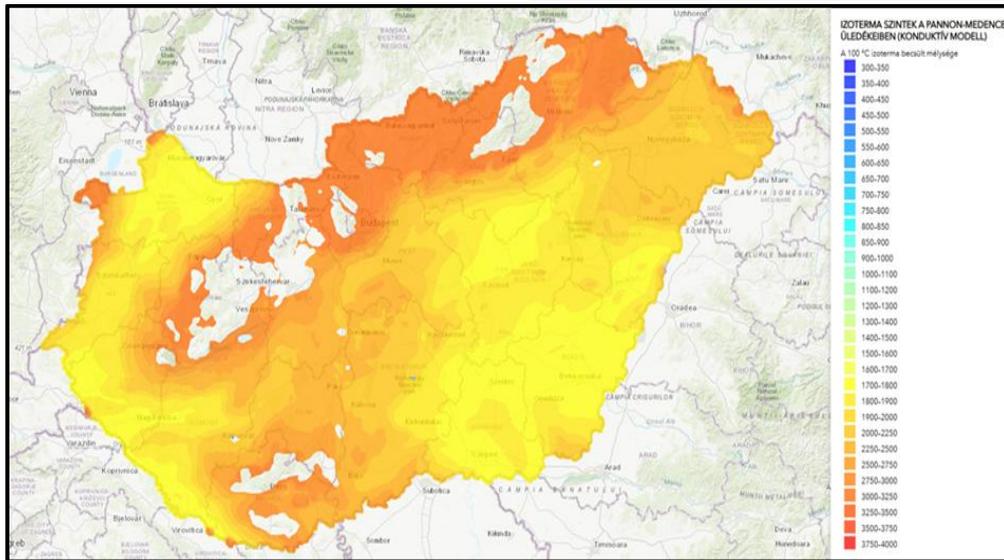


Figure 17: Estimated depth of the 100 °C isotherm

Source: OGRE - Geothermal Information platform of SARA

Based on the geothermal heat isotherms (Figure 18), the Little Hungarian Plain (in the northwest), the Zalai and Drava Basins (in the southeast) and the Hungarian Great Plain and its Sub - basins have the best conditions. These are also the most important hydrocarbon Basins in Hungary.

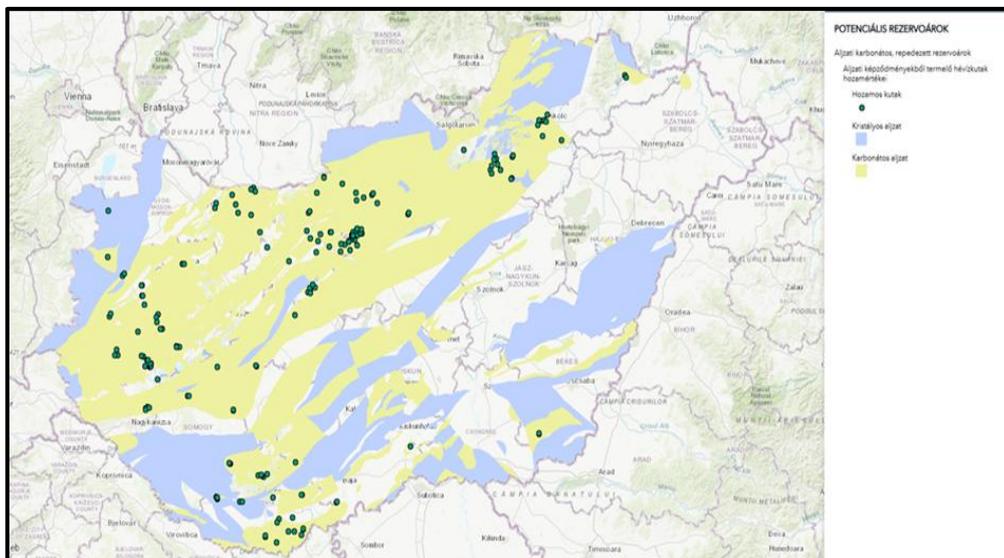


Figure 18: Potential karstified, fractured reservoirs (yellow), crystallin rocks (blue) and wells with water production

Source: OGRE - Geothermal Information platform of SARA

Most karst reservoirs (Figure 19) are connected to the Eurasian Plate, i.e. the Transdanubian Central Mountains, the Sava Unit and the Bükk Unit. The western part of the Transdanubian Central Mountains (Little Hungarian Plain, at the western foot of the Bakony Mountains), the Sava Unit and the Paleogene Basin also contain oil reserves, which means that there is potential for the conversion of abandoned hydrocarbon wells. Despite the presence of karst reservoirs, most of the Transdanubian Central Mountains are not suitable for geothermal heat and power production due to poor geothermal conditions.

The crystalline and carbonate sediments of the Tisza Plate are found deep in the Hungarian Great Plain and are partially explored hydrocarbon reservoirs (e.g., Battonya). Karstic hot water reservoirs can also be found



in Somogy, the Villány Mountains (e.g., Siklós) and the Mecsek Mountains (e.g., Szentlőrinc) in South Hungary, but these are not connected to hydrocarbon deposits.

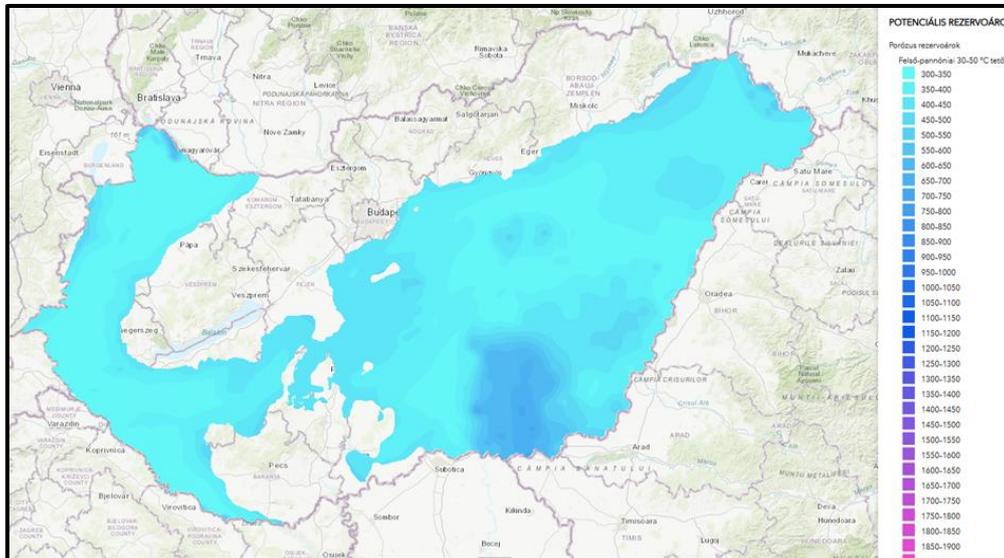


Figure 19: Potential porous reservoirs

Source: Source: OGRE - Geothermal Information platform of SARA

As shown in Figure 19, most of the porous reservoirs belong to the Upper Pannonian Zagyva and Újfalui formations. In the western part of the country (Little Hungarian Plain, Zala and Dráva basins), Middle Miocene sandstones, occasionally volcanics and Lower Pannonian sandstones may be reservoirs at relatively shallow depths (except for Little Hungarian Plain). Some of these are hydrocarbon reservoirs. In the Zala and Drava Basins, Middle Miocene and Lower Pannonian sandstones, as well as volcanic complexes (rhyolite tuff) in strips, may be reservoir rocks, but Upper Pannonian sandstones can also be found here, mainly in the Somogyi hills (e.g. Nagyatád) to the north - northeast of the Basins. In the Hungarian Great Plain, mainly in its southern part, thick Upper Pannonian sediments have accumulated in trenches (e.g., Szeged Basin, Makó Trench, Békés - Gyula Deep Basin, Derecske Trench), as well as in the northern areas of the Hungarian Great Plain (Jászság Basin, Nyírség). In Nyírség, volcanic rocks (rhyolite tuff) can also be good reservoirs, as demonstrated by the Nyíregyházi Legó factory project.

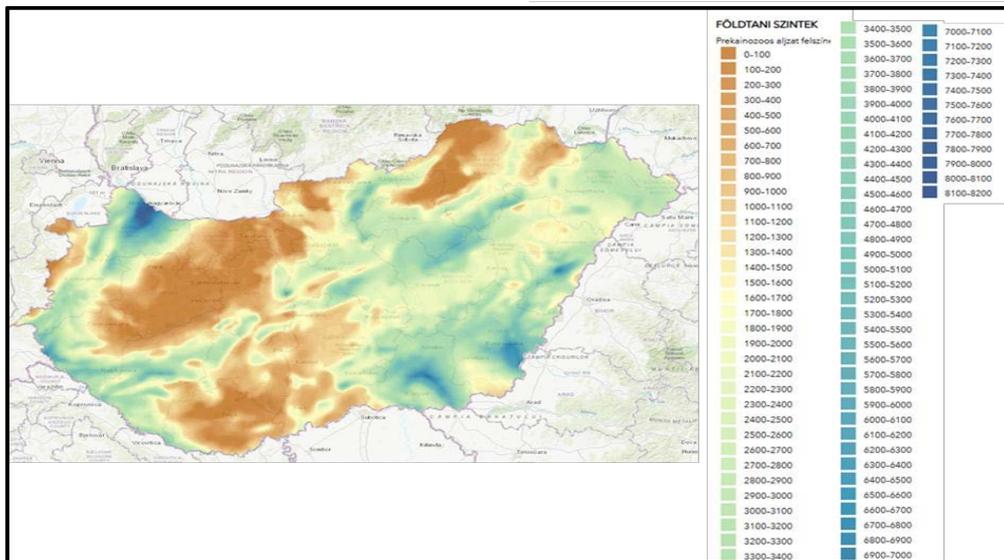


Figure 20: Pre - cenozoic basin surface map

Source: OGRE - Geothermal Information platform of SARA

Figure 20 clearly shows the deep basins and trenches (blue, dark blue) already indicated in Figure 19. All of these were active hydrocarbon exploration areas, meaning that the upper, fractured zone of the Basin floor and the sediments above the Basin floor can be considered as reservoir rocks. The high - temperature waters of the deep Basins may be suitable for energy production, while Zalai Basin and the Battonya area have been actively explored for Enhanced Geothermal System (EGS) power plants.

The Hungarian geological database contains 1.557 geothermal wells for various customer groups, such as municipalities, agricultural companies and industrial users. There are 8.354 natural gas and oil exploration and production wells, mainly operated by MOL, O&GD and a number of smaller companies. There are, also, 2.743 other deep wells (raw material exploration and coal) operated by various companies, as well as 2.334 abandoned wells, of which 2.258 are deeper than 400 m (see Figure 21). A total of 14.912 wells deeper than 400 m can be taken into account, but there may be overlaps within the categorisation (hydrocarbon vs. abandoned vs. water wells; natural gas vs. geothermal wells).

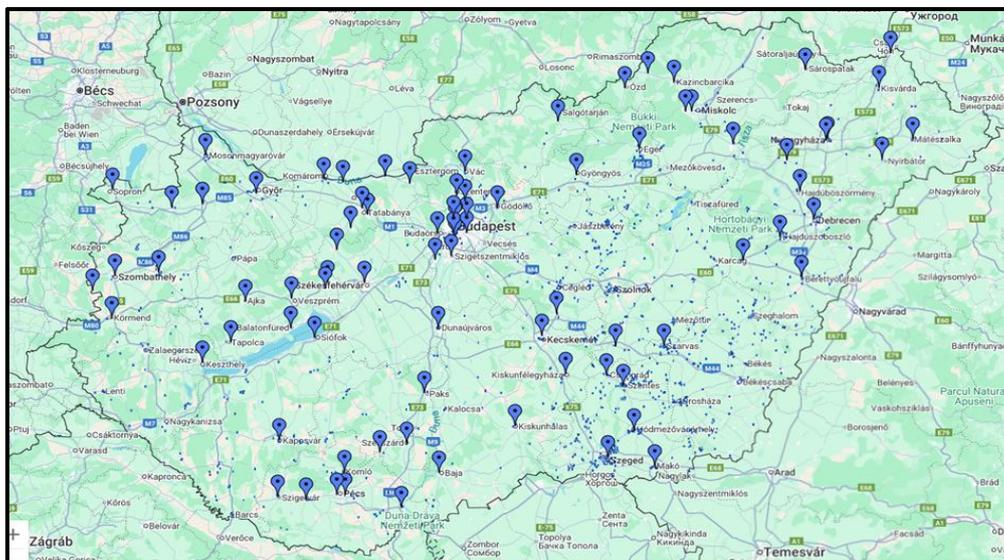


Figure 21: Geothermal wells deeper than 500 m and geothermal district heating providers

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



In 2023, 214 district heating systems in 93 urban areas (Figure 21) provided services to a total of 687.663 paying customers. Out of these, 15 supplied with geothermal heat. According to Figure 21, it would be possible to supply geothermal energy to urban areas that do not currently have geothermal district heating, primarily in the Hungarian Great Plain and the Little Hungarian Plain, as well as and many small and medium - sized urban areas could connect to the geothermal heat market directly or through district heating systems.

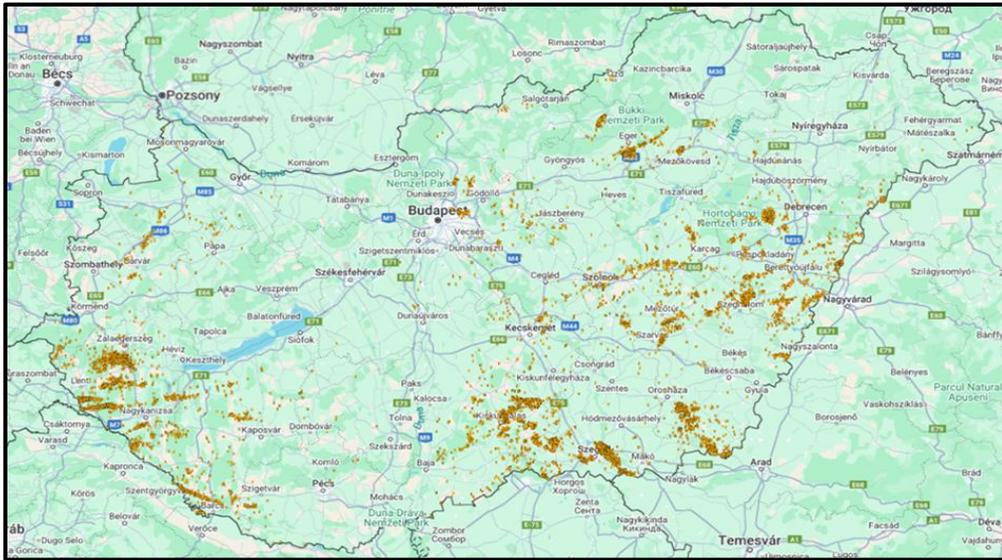


Figure 22: Active oil and natural gas wells deeper than 500 m

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

There are currently more than 6.000 wells (Figure 22) managed by oil companies in Hungary. Some of these could potentially be converted into geothermal wells after they are decommissioned.

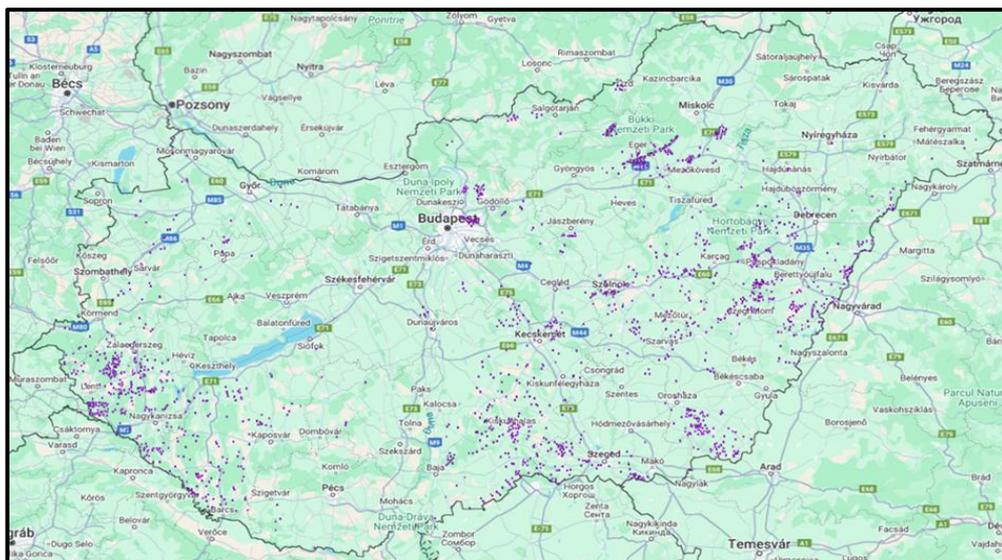


Figure 23: Other (coal and raw material exploration) wells deeper than 500 m

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Other abandoned coal and ore exploration wells (Figure 23) have not been thoroughly investigated for geothermal heat production, but their use as close - loop systems is a potential possibility.

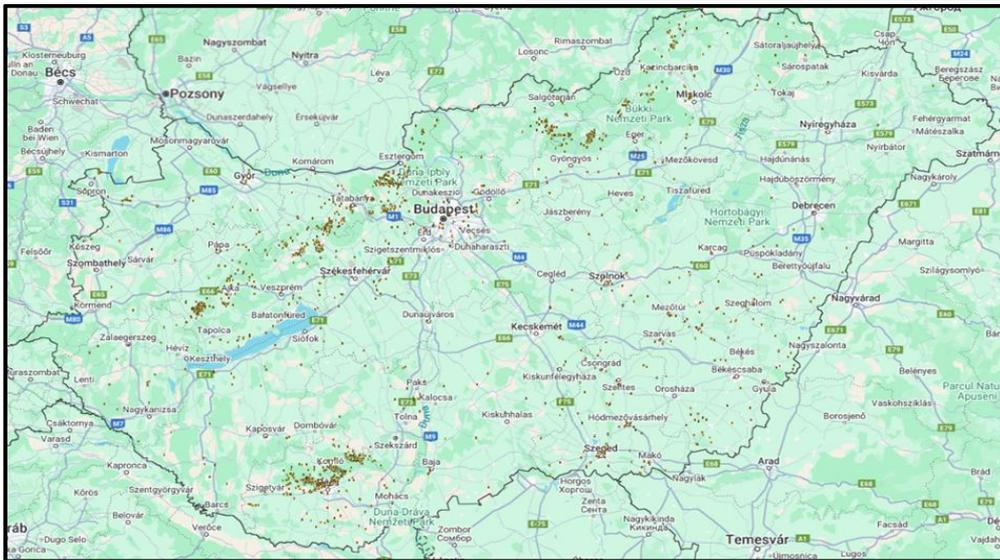


Figure 24: Shut - in and abandoned wells deeper than 500 m

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

The majority of more than 2.300 abandoned wells are no longer usable for geothermal purposes, as they have been permanently abandoned and recultivated, but the information obtained from them is valuable for the installation of geothermal systems in the area. Those wells that are still usable in some form undergo Mining Property Utilization Nonprofit Public Ltd. pre - qualification.

The geological - geophysical - hydrogeological knowledge material is stored in modern digital databases, such as the GeoBank, which contains relevant information about nearly 270.000 shallow and deep boreholes drilled in Hungary. In addition, the unique geological collection consisting of more than 500.000 mineral, rock and fossil items forms an outstanding part of the data assets (the Geological and Geophysical Library, consisting of more than 300.000 units, as well as a core sample collection containing the core material about 8.100 deep boreholes drilled in Hungary). Information is, also, available at SARA (Supervisory Authority of Regulatory Affairs) Directorate of Geology from GeoBank and the Mining Property Utilization Nonprofit Public Ltd. from their databases. The OGRE website run by SARA gives a good overview of the geothermal potential in the country.

The Mining Property Utilization Nonprofit Public Ltd. is responsible for the asset management of the state - owned abandoned wells, which were once drilled for hydrocarbon exploration. The organization reviews the geological and technical condition of these wells and transfers the suitable wells for reutilisation. Based on the available data, it selects certain geologically and technically suitable wells for the assessment of their geothermal potential, their utilisation portfolios and concept studies for reutilisation project plans. At present, the filtered database of suitable wells contains 176 wells that have been reviewed in detail and undergone some form of geothermal qualification (Figure 25). The state - owned wells are transferred for utilisation through public tenders. Based on the State Property Act the state - owned abandoned wells can be transferred for 15 + 5 years.

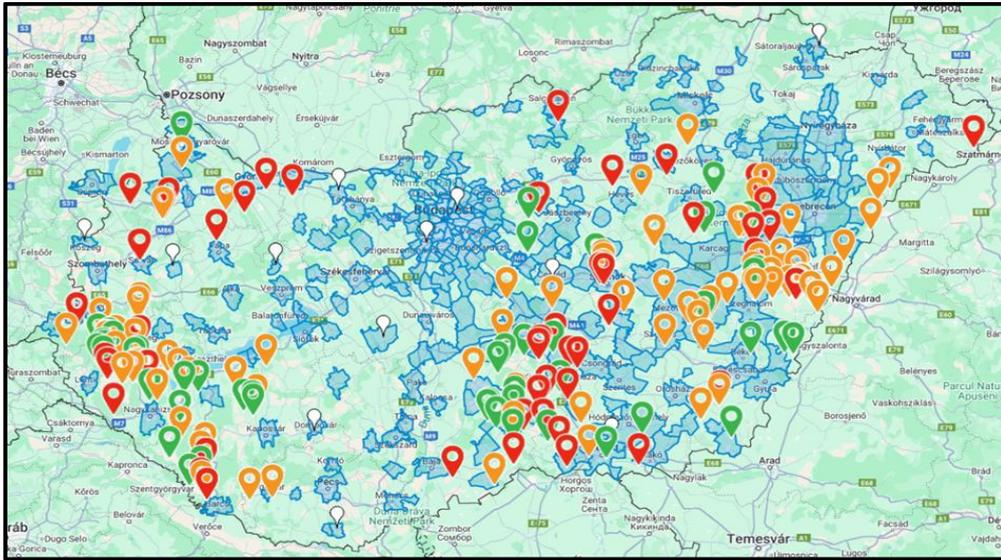


Figure 25: Qualified shut - in and abandoned wells, geothermal district heating providers and municipalities over 5.000 inhabitants

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Of the currently registered geothermal wells, nearly 400 wells were drilled for natural gas and oil exploration, but the exact number is unknown because of lack of exact documentation in the past. The transfer of wells as water or geothermal wells was usually based on a bilateral agreement, often not fully documented. These were generally conventional hydrothermal systems, mainly used in agriculture and to a lesser extent in industry and municipalities (district heating, balneology, spas). Several ongoing reuse projects have been running in Hungary since 2016 for district heating, agricultural, balneological, electric power plant usage (Kiskunhalas - Deep Borehole Heat Exchanger (DBHE), Mezőcsát - Hydrothermal Energy (HE)). In the latter case a successful public tender was conducted for the state - owned well titled Mcsát - 1 and the well was given to the Municipality of Mezőcsát to transform it for geothermal energy production for heating public buildings.

The biggest limitation to use of wells is their technical condition, which in most cases is not known and therefore testing of the wells for geothermal purposes is unavoidable, even at considerable cost. In addition, drilling companies are generally reluctant to take on the risk of a failed test.

The new geothermal law does not prevent the reuse of abandoned hydrocarbon wells, but it does not support it at an adequate level. There are many new scientific articles on the risks of geothermal exploration. The hydrocarbon exploration risk analysis algorithms are being modified and refined, mainly to estimate the risk of hydrothermal projects for power generation, and thus provide decision - makers with a choice of options. The aim is to support individual projects on the basis of a risk analysis, with a particular focus on the use of partly abandoned or shut - in wells.

In Hungary, lower temperature technologies are not yet widespread and the focus is still on the exploitation of high temperature geothermal reservoirs. In the case of hydrothermal systems, injection would be mandatory, but despite this, only a small number of injection wells are operating reliably, only 8% of active thermal wells are injection wells. This may be partly due to technological problems (injection into unconsolidated Upper Pannonian rocks) and partly due to moratorium areas, e.g. agriculture, which for the time being do not have to inject. However, the lack of injection could cause serious problems in the near future, as the pressure in the reservoirs is significantly reduced and the sustainability of the systems is questionable. On the other hand, the extraction of high - temperature water is often not matched by an adequate market, so that the water to be reinjected is also of very high - temperature, which is both wasteful and creates technological problems.



In 2020, 5,6% of Hungary's thermal energy production, 0,03% of domestic gross electricity production, 4,8% of primary renewable energy and 5% of its primary use were provided by geothermal energy. Furthermore, 23% of domestic geothermal utilisation is represented by geothermal district heating and thermal water district heating systems. Geothermal district heating is available in a total of 21 settlements out of the total of 94 district heating systems (Barcs, Bóly, Cserkeszőlő, Csongrád, Gárdony, Győr, Hódmezővásárhely, Kistelek, Makó, Miskolc, Mórahalom, Nagyatád, Orosháza, Szarvas, Szeged, Szentés, Szentlőrinc, Szigetvár, Szolnok, Vasvár, Veresegyház), where thermal water partially replaces natural gas - based heating, depending on local conditions. Despite the 21 geothermal district heating systems, the total share of produced geothermal heating energy is only 2,8%. The thermal water reaches the public buildings (hospital, town hall, kindergarten, school, etc.) through pipes specially established for this purpose.

The largest domestic field of geothermal energy utilisation is agriculture, with a share of about 40%. The heating of the greenhouses and foil tents is particularly outstanding in the area of the Southern Great Plain. Although not for direct energy purposes, the long - standing domestic thermal water spa culture (23% share) is definitely worth mentioning from a national economic point of view. The rest of geothermal energy is used by industrial users which are mainly car manufacturing companies (Audi - Győr, Mercedes - Kecskemét, BMW - Debrecen), chemical industry companies (Procter and Gamble - Unilever), steel and iron manufacturing company (DunaFerr), toy factory company (LEGO), etc.

The current geothermal projects are the Szeged District Heating System, Tótkomlós electricity production project, Nyíregyháza (LEGO factory) and Nyírbátor, Budapest. In addition, 3 agricultural wells are under authorisation in the Southern Great Plain. All of them use new wells. Moreover, many concessions are in progress (Figure 26).

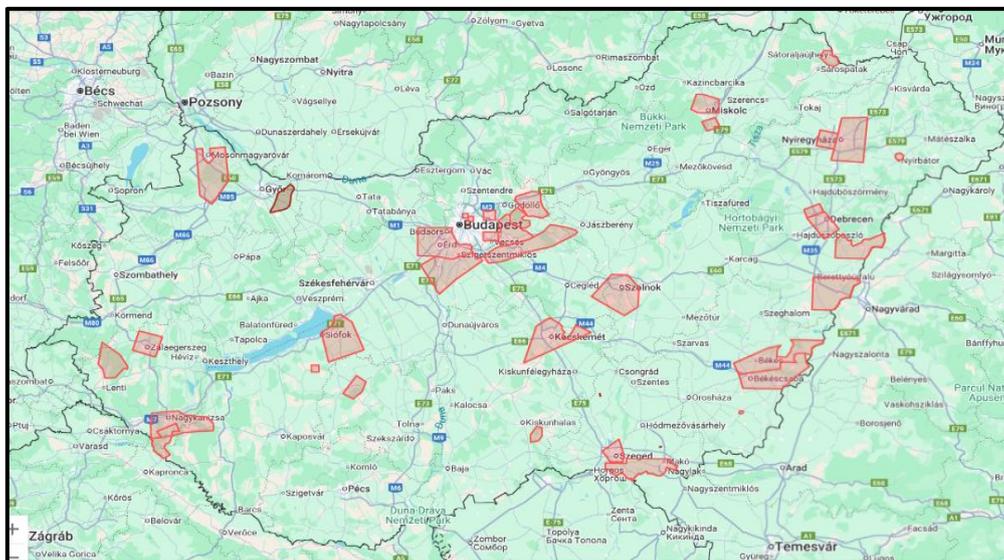


Figure 26: Geothermal concession areas

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

2.2.5. Slovenia

The Slovenian geological map (Figure 27) shows the diversity of the different geological structures dividing the country into several parts. The geological formations which would be interesting for geothermal energy utilisation are in the central, northeastern and southeastern part of the country (white to grey areas). Northeast of Slovenia geothermal gradients typically range from 60 to 80 °C per km, achieving temperatures between 120 and 160 °C at depths of approximately 2 - 3 km. Southeast of Slovenia geothermal gradients



typically range from 10 to 40 °C per km, achieving temperatures between 30 and 80 °C at depths of approximately 2 - 3 km (Rman at al., 2019).

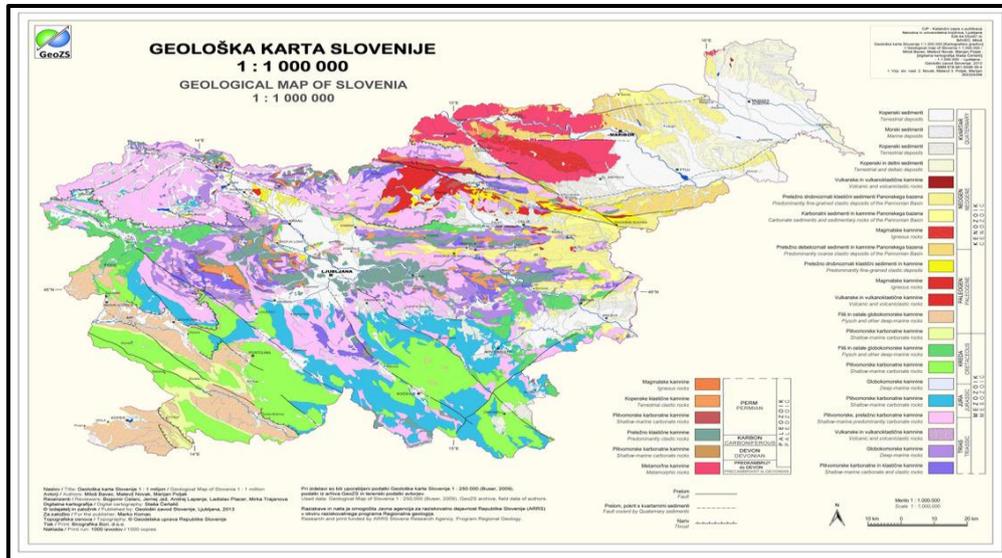


Figure 27: Geothermal geological map of Slovenia

Source: GeoZS, 2013

Generally, in the northeast of Slovenia thermal waters are extracted from low - temperature geothermal systems, also called hydrothermal systems or geothermal aquifers. On the edge of the western part of the Pannonian Basin which connects with eastern and northeastern Slovenia regional high - yield sandy aquifers dominate. In those sedimentary basins, the temperature, content of dissolved minerals and gases in the water increase continuously with depth. In the southeast, coast and other parts of Slovenia, fractured aquifers are found in the basement of sedimentary basins that cover these aquifers. The temperature and chemical composition of the water are very variable with depth due to different fracture systems in the aquifer (Figure 28).

The recharge of both the first and second aquifers is very limited, so excessive water withdrawal can cause a decrease in the groundwater level, and later, intrusions of gases or waters with a different chemical composition and temperature can also occur. In the area of intersections of fault zones, mainly in carbonate rocks, geothermal systems of hot springs are common. Thermal water is only slightly more mineralized than ordinary groundwater and usually has a favorable temperature and chemical composition. The supply is usually good, so changes in the state of the aquifer are not detected by a decrease in the level, but by a change in the water temperature (Rman et al., 2019). Key areas include the Pannonian Basin in the northeastern and eastern part of Slovenia.

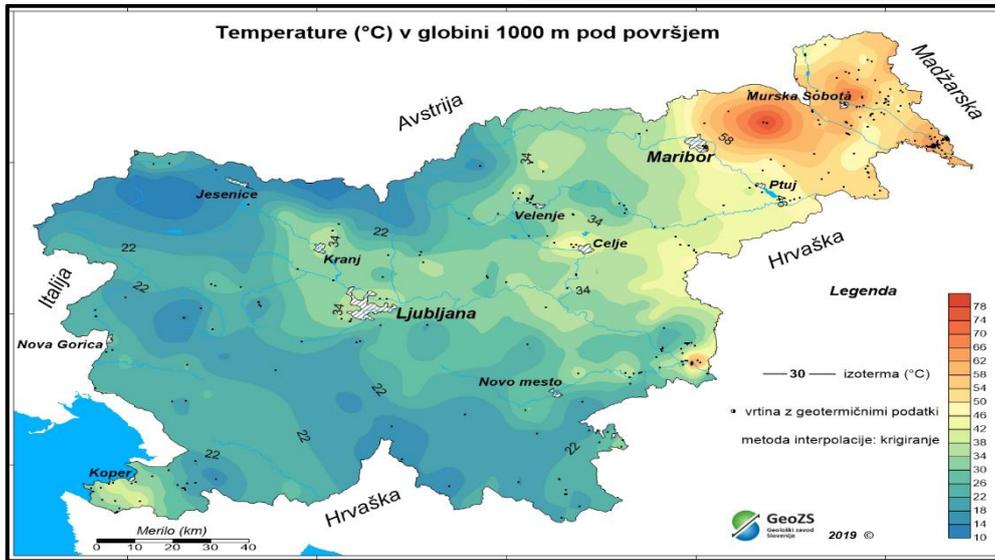


Figure 28: Temperatures in the depth of 1.000 m

Source: GeoZS, 2013

The highest temperatures in wells were measured in the Pannonian Basin in eastern Slovenia. There, a few hundred meters thick package of poorly permeable layers prevents the rapid infiltration of cold precipitation water into the soil, while at the same time, the increased heat flow of the Earth due to the relatively thin crust (only about 30 km) can warm the very slowly flowing groundwater more (Rman et al., 2019).

In the west and Notranjska, due to the deeper circulation of cold infiltrated ancient water, the soil temperature rises significantly slower, so thermal water occurrences are rarer and more local, usually linked to fault structures. The 100 °C isotherm is the approximate limit of economic viability of binary geothermal power plants and is the shallowest (2 - 3 km) in northeastern Slovenia. In many places in northeastern Slovenia, at a depth of 4 km, it is expected at least above 150 °C, which is confirmed by the highest temperature measured in Pomurje (Rman et al., 2019).

The highest water or water vapor temperature measured so far in Slovenia was reached in 1988 during the testing of the deepest well Ljut - 1/88 near Ljutomer, where during the testing of a section at a depth of 4.015 m, the fluid temperature at the wellhead was 148°C. Today, most active wells in eastern Slovenia have thermal water with a temperature between 50 and 59 °C, which is especially typical for the most frequently tapped sandy aquifer in the Mura Formation of the Mura - Zala Basin. The highest temperature of water currently being extracted is approximately 75 °C and was reached in Moravske Toplice. Thermal water from the dolomite aquifer in the Krško - Brežiški Basin, between Dobova and Čatež, also reaches a little over 60 °C (Rman et al., 2019).

All geothermal energy, both shallow systems and thermal water use, accounted for only 0,7% of gross domestic energy consumption at the primary energy supply level in Slovenia in 2022. Direct use of thermal water took place at 29 locations in 2022 with 58,3 MW_t of installed capacity and an annual production of 552 TJ or 153,3 GWh of heat, mostly for heating rooms, greenhouses and swimming pools. This type of use is stagnating, as there are no dedicated incentives. Currently, only one district heating system using geothermal energy is operating, namely in Lendava. It is among the cheaper in Slovenia, so it is not understandable why this solution is not being considered elsewhere, where district heating and cooling systems have to be restructured. Only three geothermal greenhouses are operating in Slovenia. A bigger problem than geological uncertainties for new wells are the long - term procedures for placing industrial greenhouses in space (ESG, 2024).

Due to geological conditions, the potential for obtaining thermal water is greatest in northeastern Slovenia. Here the temperature rises the fastest and is expected to be between 150 and 200 °C at a depth of 4 km.



The calculated achievable base of heat sources reaches 957 EJ at a depth of 3 km and as much as 2.597 EJ at a depth of 5 km. At a depth of up to 2 km, a regional and cross - border geothermal aquifer extends in quartz sands and sandstones, which is shared mainly with Hungary. Its extent is relatively well known, so locating new wells is significantly less risky than elsewhere in Slovenia. However, targeted geophysical surveys are still recommended, which increases the probability of a well being successful. This thermal water is used at 10 locations, so the main limiting factor for use is primarily the current level of resource utilisation. In order to maintain a good regional quantitative situation, new water withdrawals for heating are only possible by constructing a reinjection well, through which the thermally used thermal waste water is returned to the aquifer (ESG, 2024).

Very important, although less well researched and less used, is the Čateč geothermal area between Kostanjevica and Dobova. The stored heat here is estimated at 6,8 EJ. An increased geothermal gradient is also detected in the vicinity of Ljubljana, in the Celje Basin, but the geological structure at depths below 1 km is significantly less well known (ESG, 2024).

The National Energy and Climate Plan of Slovenia (NECP) outlines appropriate steps to promote the use of geothermal energy, but the implementation is not keeping up with the ideas. For many years, there were plans to encourage systematic research into the geothermal potential under major urban areas that need to restructure their district heating systems, but the response has been poor. Only through research can the locations of deep exploration wells (2 - 5 km) be determined, with the aim of capturing temperatures of 100 °C and above, which could also be used for electricity generation. Research could also be carried out with the help of funds from the Climate Fund. In Slovenia, a critical mass of experts still does not work in a coordinated manner, but by establishing a national geothermal association, the cross - sectoral cooperation will strengthen (ESG, 2024).

The geothermal potential of Slovenia is largely associated with the northeastern part of the country, particularly the Pannonian Basin, where thermal gradients are relatively favourable. An assessment of 244 wells indicates significant variation in suitability across different geothermal technologies. Aquifer Thermal Energy Storage (ATES), Deep Borehole Heat Exchangers (DBHE) and Borehole Thermal Energy Storage (BTES) each show a very low share of confirmed suitable wells ($\approx 0,8\%$), though DBHE stands out with a high proportion of uncertain sites ($\approx 67\%$), suggesting that further exploration could yield additional opportunities. Hydrothermal Energy (HE) systems are characterized by complete uncertainty (100%), reflecting a lack of adequate data rather than demonstrated unsuitability. Enhanced Geothermal Systems (EGS) are mostly classified as not suitable ($\approx 70\%$), consistent with the region's limited high - temperature and structurally favourable formations. Current utilisation in Slovenia is, therefore, concentrated on direct uses such as district heating, spa and wellness centres, and greenhouse heating, while advanced concepts remain at the pilot or assessment stage. Expanding geothermal deployment could reduce reliance on fossil fuels, strengthen local energy autonomy and support Slovenia's decarbonization goals, but will require targeted exploration to reduce subsurface uncertainty.

In Slovenia, geothermal energy is widely used for agricultural heating, particularly in greenhouses for tomato production in Renkovci and Moravske Toplice, as well as for flower cultivation in Dobrovnik, enabling stable year - round production and reduced reliance on fossil fuels. It also plays a key role in district heating in Lendava, while spa, wellness, and tourism facilities in Lendava and Moravske Toplice rely heavily on geothermal water for pools, wellness programs and medical treatments. These established systems demonstrate the practical value of moderate - temperature geothermal resources and highlight opportunities for further expansion into industrial process heat, additional greenhouse areas and new municipal heating networks. Beyond direct use, Slovenia is exploring next - generation geothermal technologies, including projects assessing the potential for geothermal electricity production, such as the development initiative led by DEM and the recent concession awarded for deep geothermal exploration, which could unlock future high - temperature applications. Together, these activities indicate strong potential for continued growth, technological diversification and the broader integration of geothermal energy into Slovenia's long - term renewable energy strategy.



2.3. Well repurpose potential of the Central European region

The repurpose potential for existing hydrocarbon well assets is described in detail in the report on the transnational repurpose potential in Central Europe. The report gives an evaluation of the repurposing potential for 5 different technologies of well revitalization and geothermal resource utilisation in sedimentary basins located in the 5 countries of the consortium - North German, Molasse, Vienna and Pannonian Basin. The results of the repurposing potential assessment are shown for each country and the basin located within. For each country the following results present the spatial classification of assessed wells using a traffic light system:

- **Green wells** - suitable for repurposing without restrictions
- **Orange wells** - uncertain, additional data required
- **Red wells** - not suitable for repurposing.

2.3.1. Austria

In Austria, the potential for repurposing existing hydrocarbon wells is concentrated in the Molasse Basin, stretching along the northern margin of the Alps and in the northeastern - southeastern trending Vienna Basin in the eastern part of the country.

Due to the Austrian database structure, the resulting potential is predominantly associated with the location of a well, prevailing market conditions, existence of an aquifer (where necessary) and basic parameters as temperature or total depth of a well. The main limitation is the absence of well status data. This important information, which considerably affects the resulting numbers, is not published and available per well. It has to be requested from the well owner separately. Therefore, the dataset was filtered to include only wells drilled before 1990. This criterion is based on an average well lifespan of 30 - 40 years. While some older wells may still be technically viable, many are likely decommissioned, sealed, or no longer recorded, and thus unsuitable for repurposing. This filtering ensures focus on wells with realistic technical repurposing potential.

Hence, the dataset does not represent the full inventory of active wells. Final decisions on repurposing eligibility require direct consultations with the well owners. For detailed query information, see the deliverables D.1.3.1 Criteria catalogue for well repurposing, D.1.4.1 Beta version of web - based IT tool for well repurposing and D.2.1.1 - D.2.1.4 Regional databases of the Pannonian, Vienna, Molasse and North German Basin.

2.3.1.1. Vienna Basin

The Vienna Basin extends across northeastern Austria into Slovakia and the Czech Republic, including key urban areas such as Vienna, thus representing a strategic region for geothermal energy development. Geologically, it is a deep sedimentary basin formed approximately 20 million years ago, filled with successions of sandstones and siltstones overlying a complex calcareous and crystalline basement (Decker et al., 2005; Salcher et al., 2012). Comparable to the Molasse Basin, the Vienna Basin hosts several aquifers and hydrocarbon reservoirs at varying depths (Wessely, 2006). Historical exploration has led to intensive drilling activities. As of 2024, the Austrian sector contains approximately 3.750 wells (Sachsenhofer et al., 2024). OMV Austria is the primary operator, owning the majority of wells, while ADX holds a minor share (approx. 24 wells). For this study, a dataset of 3.357 OMV - operated wells with publicly available data were used. In all figures the grey outline marks the surface extension of the Vienna Basin, while the black lines represent state borders.



Aquifer Thermal Energy Storage (ATES)

This analysis evaluates the suitability of wells drilled after 1990 in the Vienna Basin for conversion to Aquifer Thermal Energy Storage (ATES), using the beta version of web - based IT tool. Clear clustering in areas with favourable subsurface conditions is seen, indicating localised ATES potential (green wells). Also, conditionally suitable wells are identified in locations where current limitations or missing data must be resolved before confirming reuse potential.

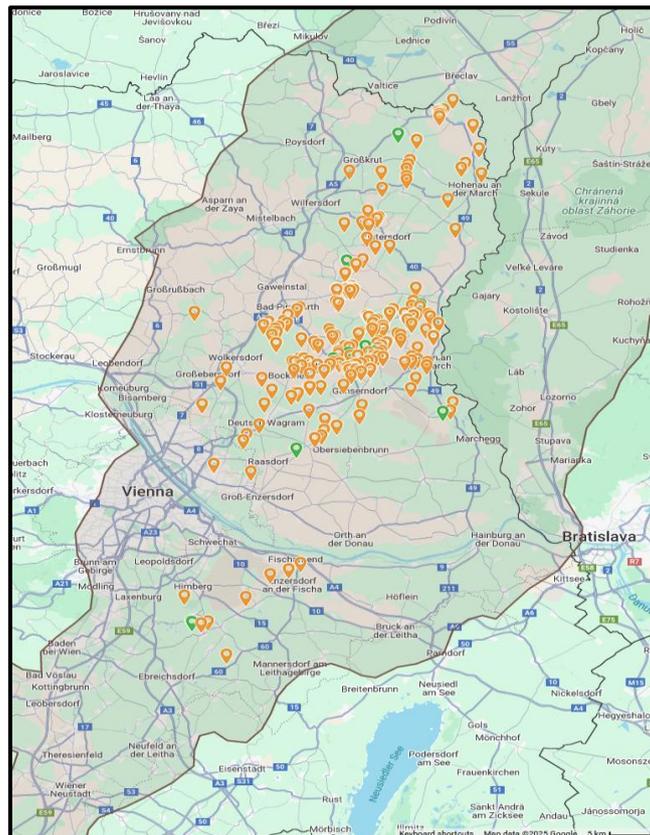


Figure 29: Map of the repurpose potential in the Vienna Basin for ATES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Deep Borehole Heat Exchanger (DBHE)

This analysis evaluates the suitability of wells drilled after 1990 in the Vienna Basin for conversion to Deep Borehole Heat Exchanger (DBHE), using the beta version of web - based IT tool. There is clear clustering in areas with favourable subsurface conditions, indicating localised DBHE potential. Conditionally suitable wells are identified where technical limitations or missing data currently prevent confirmation.

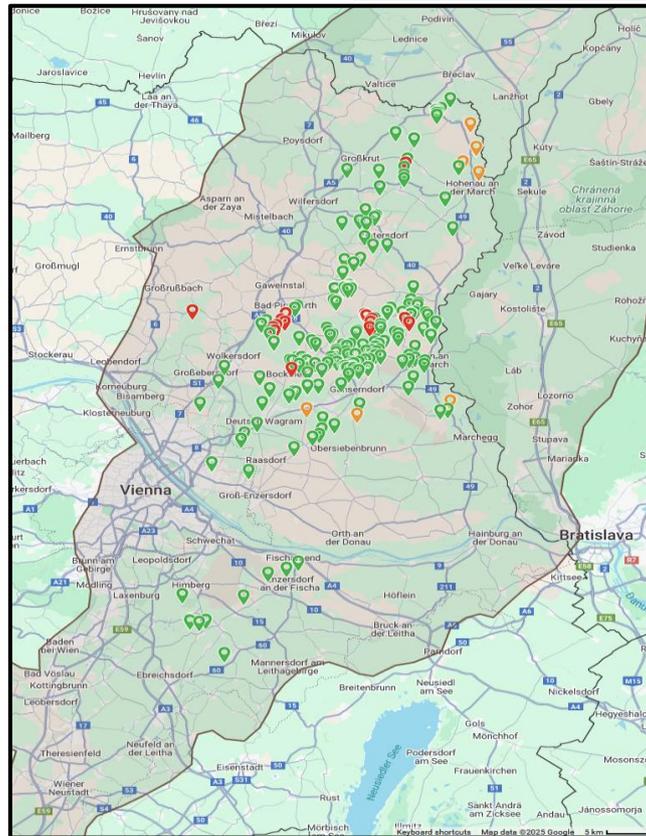


Figure 30: Map of the repurpose potential in the Vienna Basin for DBHE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Borehole Thermal Energy Storage (BTES)

This analysis evaluates the suitability of wells drilled after 1990 in the Vienna Basin for conversion to Borehole Thermal Energy Storage (BTES), using the beta version of web - based IT tool. Suitable wells (green) show clear clustering in zones with favourable subsurface conditions, indicating localised BTES potential. Conditionally suitable wells identify locations with current limitations or missing data that must be addressed to confirm repurposing potential.

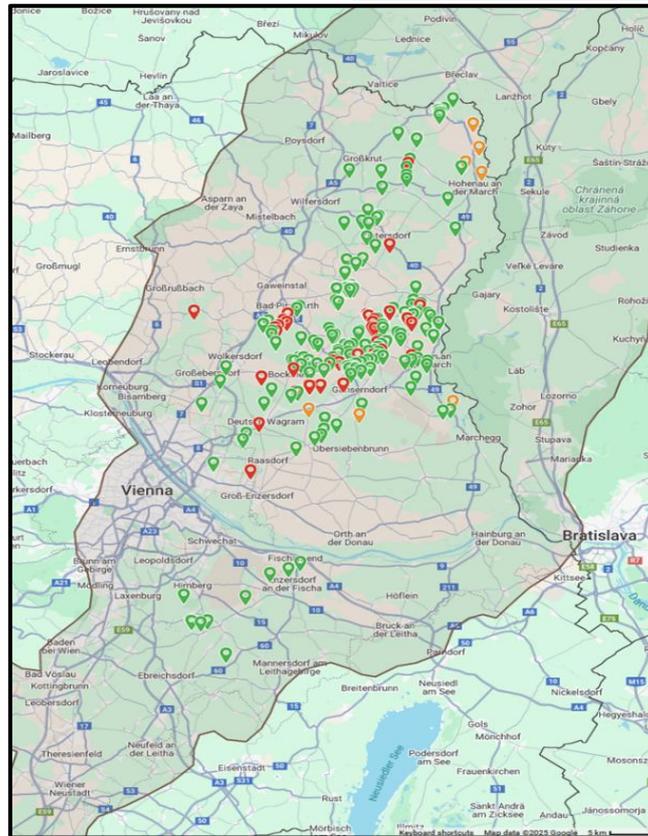


Figure 31: Map of the repurpose potential in the Vienna Basin for BTES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Hydrothermal Energy (HE)

This analysis evaluates the suitability of wells drilled after 1990 in the Vienna Basin for conversion to Hydrothermal Energy (HE), using the beta version of web - based IT tool. Suitable wells reveal distinct clusters in geologically favourable zones, suggesting localised HE potential. Conditionally suitable wells indicate areas where technical limitations or missing data currently hinder confirmation and further investigation is needed.

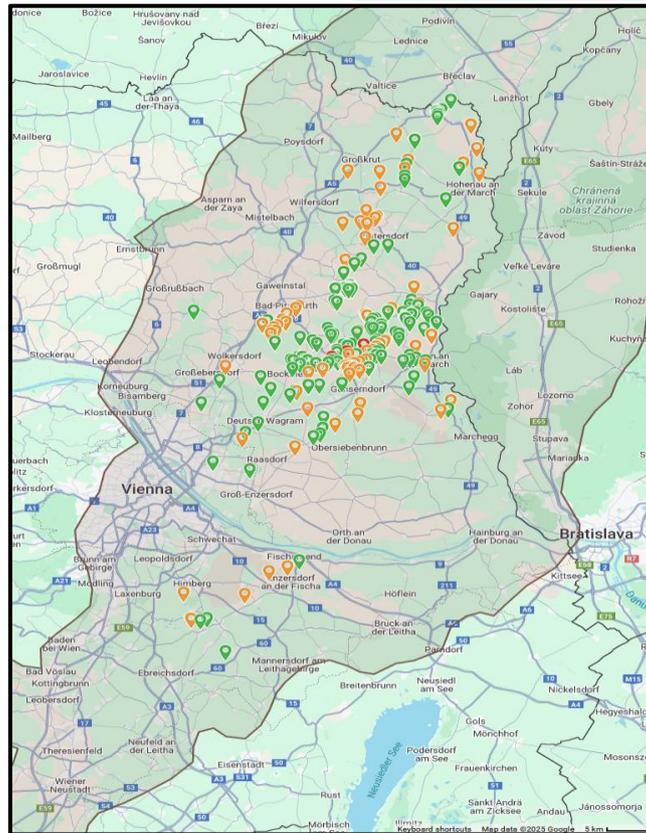


Figure 32: Map of the repurpose potential in the Vienna Basin for HE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Enhanced Geothermal Systems (EGS)

This analysis evaluates the suitability of wells drilled after 1990 in the Vienna Basin for conversion to Enhanced Geothermal Systems (EGS), using the beta version of web - based IT tool. Suitable wells reveal distinct clusters in geologically favourable zones, suggesting localised EGS potential. Conditionally suitable wells indicate areas with missing data or technical constraints, which currently limit repurposing.

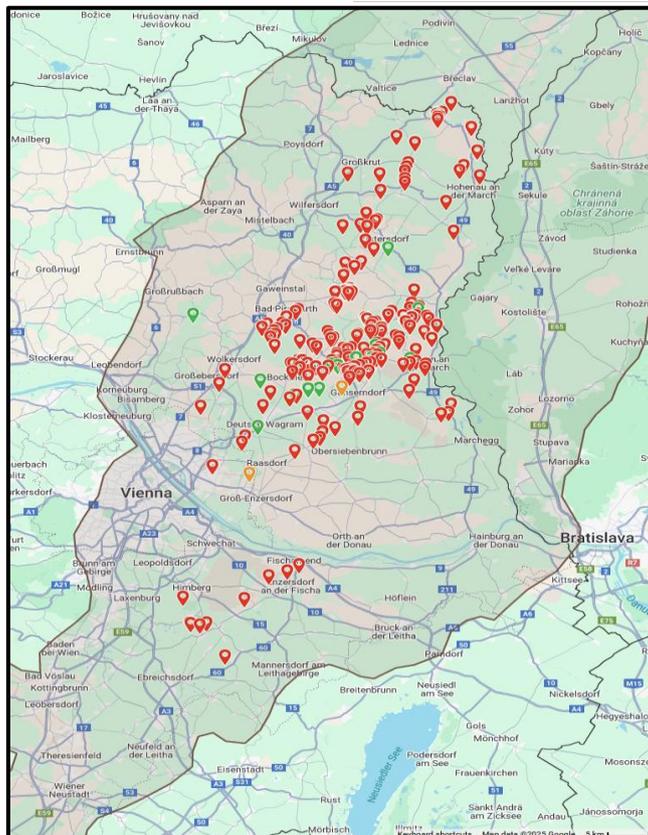


Figure 33: Map of the repurpose potential in the Vienna Basin for EGS

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Summary of the repurposing potential of the Vienna Basin

The Vienna Basin contains a total of 3.357 wells evaluated for their suitability for the 5 geothermal methods: Aquifer Thermal Energy Storage (ATES), Deep Borehole Heat Exchanger (DBHE), Borehole Thermal Energy Storage (BTES), Hydrothermal Energy (HE) and Enhanced Geothermal Systems (EGS). Exact results numbers and percentages are shown in Tables 5 and 6, respectively.

The highest suitability was found for DBHE (7,6%) and BTES (7,0%), followed by HE (5,7%). ATES (0,4%) and EGS (0,6%) demonstrate very limited suitability. A notable proportion of wells fall into the uncertain category for ATES (8,6%) and HE (3,1%), indicating that additional site - specific assessments could uncover further potential. For all methods, most wells (> 90%) are unsuitable, with the highest percentage for EGS (99,3%). The low percentages of suitable wells result from the filtering step in the beta version of web - based IT tool, which only considered wells drilled after 1990. This cutoff aligns with the average lifespan of oil and gas wells ensuring the analysis focuses on wells still viable for geothermal conversion. Despite the small fraction of suitable wells, the potential energy gains are significant: DBHE and BTES can provide 50 - 500 kW of thermal energy per well, HE ranges from 2 - 20 MW thermal, ATES from 1 - 10 MW thermal (storage) and EGS from 5 - 15 MW thermal. This indicates that even a limited number of repurposed wells could make a meaningful contribution to geothermal energy production in the region.

Overall, although only a small percentage of wells in the Vienna Basin are directly suitable for repurposing, DBHE and BTES show the most promising potential for geothermal use and the associated energy yields justify further exploration of repurposing options.



Table 5: Overview of the well assessment results in the Vienna Basin

Vienna Basin	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute / percentage)	3.357/100%	3.357/100%	3.357/100%	3.357/100%	3.357/100%
Suitable	12/0,4%	255/7,6%	234/7,0%	191/5,7%	20/0,6%
Uncertain	288/8,6%	8/0,2%	8/0,2%	104/3,1%	2/0,1%
Not suitable	3.057/91,1%	3.094/92,2%	3.115/92,8%	3.062/91,2%	3.335/99,3%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

2.3.1.2. Eastern Molasse Basin

The Molasse Basin is the foreland basin in the North of the Alps and ranges from France, Switzerland, Germany, Austria, to the Czech Republic. The Basin is filled with sediments that host hydrocarbons at different levels. Hydrocarbon exploration is the reason for the intense exploration and drilling of wells in the area.

In Austria, in the Molasse Basin (Figure 34), approximately 1.200 wells with a greater depth than 300 m have been drilled in the last 100 years, and approximately 300 are still in production, including gas storage wells. The main hydrocarbon operators in Austria are RAG Austria, ADX VIE GmbH and OMV.



Figure 34: Outline of the Molasse Basin

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Aquifer Thermal Energy Storage (ATES)

From the input dataset of 666 wells (Figure 35), 10 (1,5%) are suitable, 75 (11,3%) are suitable with certain restrictions and 581 (87,2%) are not suitable for reuse as Aquifer Thermal Energy Storage (ATES). In Austria the suitability for ATES is mainly restricted to the area of Stadtkirchen (municipality of Dietach, district Steyr - Land, state Upper Austria). The query results in 10 wells, which mainly belong to the former natural gas fields and later gas storages of Thann, Teufelsgraben (both operated by OMV) and Stadtkirchen (RAG



Austria; Kreuzer, 1993). The low percentage of suitable wells (1,5%) and the high percentage (11,3%) of suitable, but uncertain wells for ATES are subject to further investigations, due to the fact that shallow aquifers are not integrated into the database, but they do exist. The main aquifer in the Molasse dataset is the Malmian, which is a target for HE production and too deep for ATES applications.

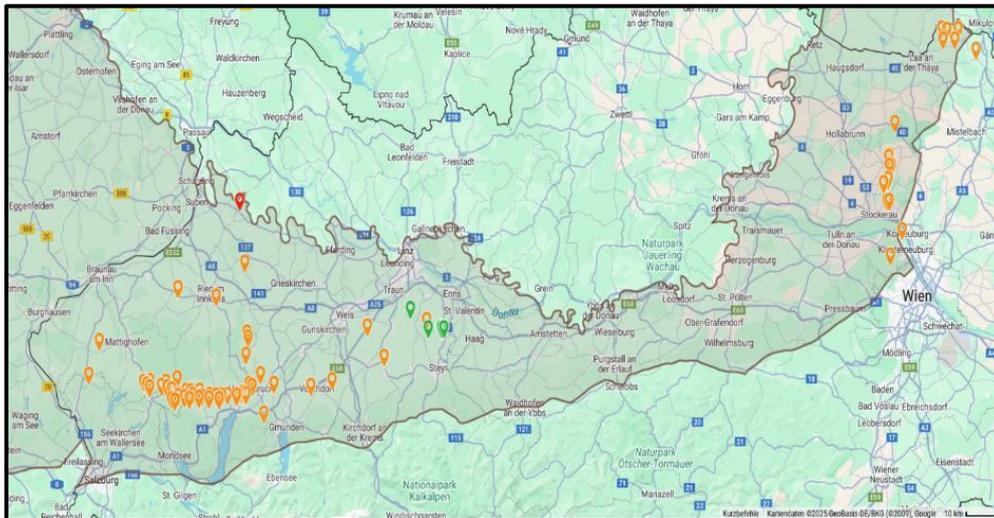


Figure 35: Map of the repurpose potential in the Molasse Basin (Austria) for ATES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Deep Borehole Heat Exchanger (DBHE)

From the input dataset of 666 wells (Figure 36), 73 (11%) are suitable, 2 (0,3%) are suitable with certain restrictions and 591 (88,7 %) are not suitable for reuse as Deep Borehole Heat Exchanger (DBHE). In the Austrian Molasse the highest potential for reuse as DBHE lies in the Molasse of Upper Austria and Salzburg and in the north of Lower Austria, in the Weinviertel region. With 11% of the wells suitable, this method shows high potential for Austria and its geological setting and well conditions. Wells which are suitable but show unknown restrictions are 0,3% for DBHE in Austria.

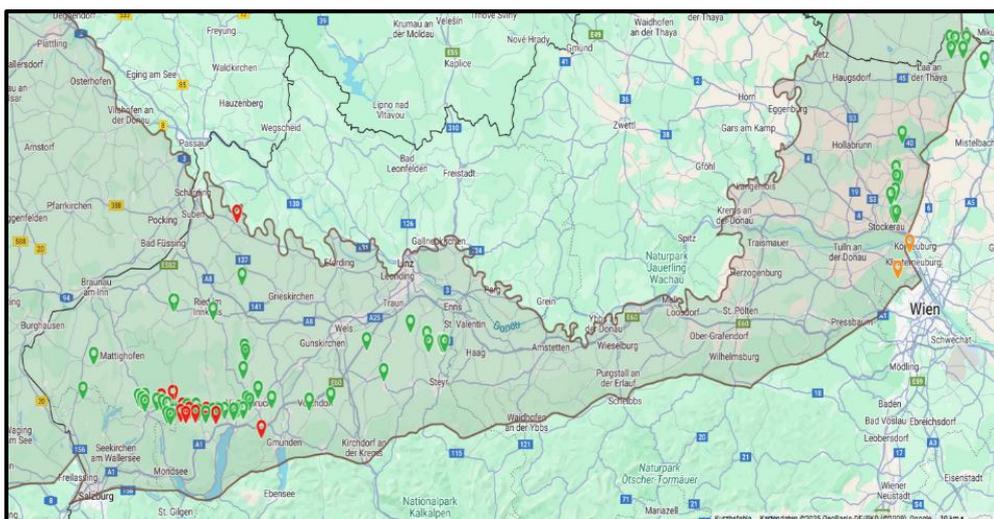


Figure 36: Map of the repurpose potential in the Molasse Basin (Austria) for DBHE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



Borehole Thermal Energy Storage (BTES)

From the input dataset of 666 wells (Figure 37), 64 (9,6%) are suitable, zero are suitable with certain restrictions and 602 (90,4%) are not suitable for reuse as Borehole Thermal Energy Storage (BTES). In the Austrian part of the Molasse Basin, the wells which are suitable are located in the federal states of Salzburg, Upper Austria and the northern part of Lower Austria, the Weinviertel. As the method is applied in rather shallow intervals (up to 1.000 m) and needs moderate temperature levels, the decision for suitability is mainly dependent on the positions of the wells according to the consumers. For BTES there are no wells suitable with certain restrictions for BTES in the Molasse Basin in Austria.

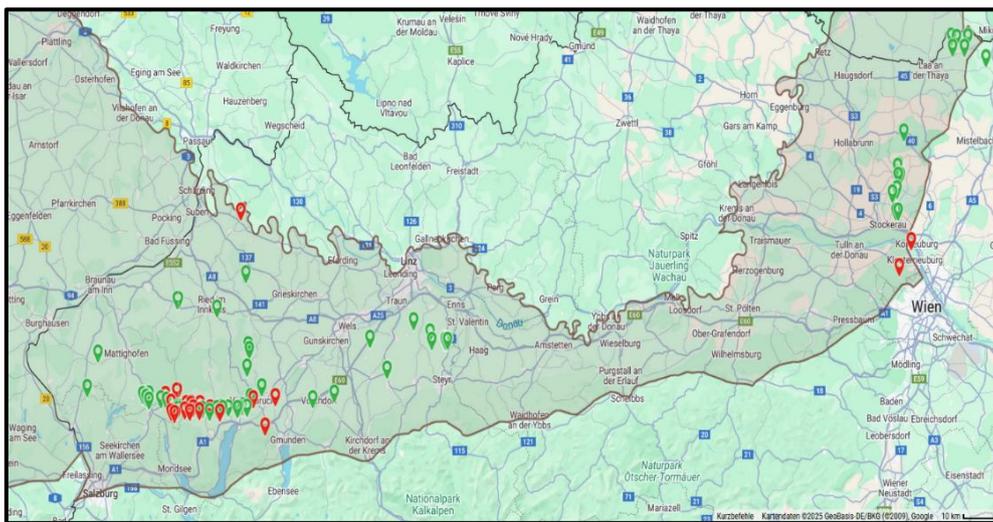


Figure 37: Map of the repurpose potential in the Molasse Basin (Austria) for BTES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Hydrothermal Energy (HE)

From the input dataset of 666 wells (Figure 38), 50 (7,5%) are suitable, 35 (5,3%) are suitable with certain restrictions and 581 (87,2%) are not suitable for reuse as Hydrothermal Energy (HE). In Austria, 50 wells, which represent 7,5% of the total, are suitable for hydrothermal reuse. They are situated in Salzburg and Upper Austria. 5 wells are situated in Lower Austria, north of the city Stockerau. For these wells, the Malmian carbonates act as an aquifer. Note, that for this evaluation the aquifer properties are generalised and have to be evaluated for every well location separately as this lithology is very inhomogeneous and porosity is often linked to fractures, which are not taken into account here. In Austria, with 35 wells (5,3%) there are wells available with uncertainties for the reusage as HE producers. The distribution follows the suitable wells, in Salzburg, Upper and Lower Austria.

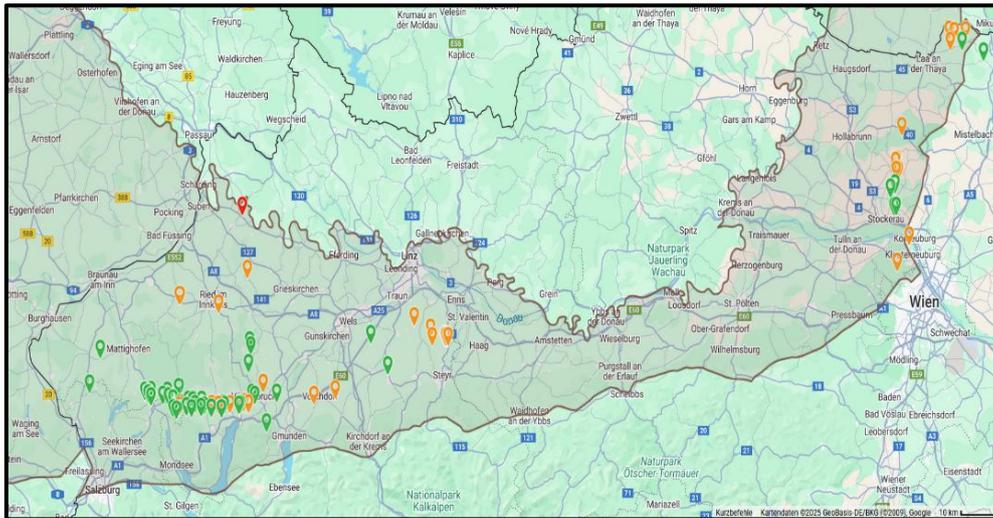


Figure 38: Map of the repurpose potential in the Molasse Basin (Austria) for HE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Enhanced Geothermal Systems (EGS)

From the input dataset of 666 wells (Figure 39), 7 (1,1%) are suitable, 5 (0,8%) are suitable with certain restrictions and 581 (87,2%) are not suitable for reuse as Enhanced Geothermal Systems (EGS). In the Austrian part of the Molasse Basin, 7 wells are reusable as EGS geothermal applications. They are situated in Upper Austria in the region of Attergau. These wells are mainly former exploration wells with a depth greater than 1.000 m.

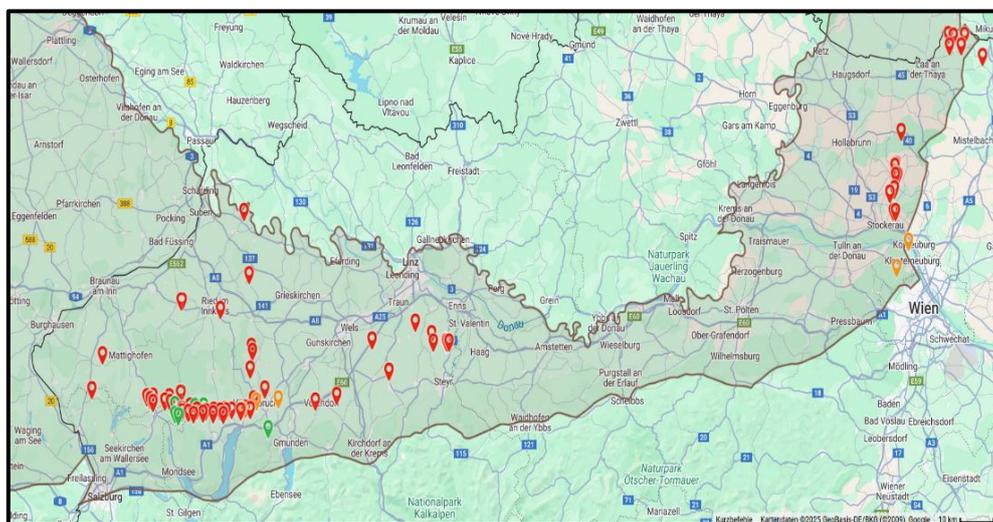


Figure 39: Map of the repurpose potential in the Molasse Basin (Austria) for EGS

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



Summary of the repurposing potential of the Molasse Basin (Austria)

The Molasse Basin contains a total of 666 wells evaluated for their suitability for the 5 geothermal methods: ATEs, DBHE, BTES, HE and EGS. Exact results numbers and percentages are shown in Table 6.

Table 6: Overview of the well assessment results in the Molasse Basin (Austria)

Molasse Basin (Austria)	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute / percentage)	666/100%	666/100%	666/100%	666/100%	666/100%
Suitable	10/1,5%	73/11,0%	64/9,6%	50/7,5%	7/1,1%
Uncertain	75/11,3%	2/0,3%	0/0,0%	35/5,3%	5/0,8%
Not suitable	581/87,2%	591/88,7%	602/90,4%	581/87,2%	654/98,2%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

2.3.1.3. Quantification of land use

To quantify the economic and social situation in the Vienna and Molasse Basins, the CORINE Land Cover (CLC) dataset was extracted (EU Copernicus Land Monitoring Service, 2018). For industrial areas, the category CLC 121, for residential areas the categories CLC 111, 112 and 142 and for agriculture the categories CLC 211, 212, 221, 222, 242 and 243 were extracted and quantified for the Vienna and Molasse Basins. This selection is based on the project reports, where it was found out that the primary “customer” groups for heat energy supply from repurposed abandoned wells are represented by industry, agriculture and municipalities (the service and private sectors). These three sectors represent 60 - 70% of the energy demand. In Austria, the 2 basins cover an area of approximately 16.500 km². Industrial areas represent 208 km² (1,3%) (Figure 41), agricultural areas represent 9.400 km² (57,1%), (Figure 42) and residential areas represent 1.650 km² (10%) (Figure 43).

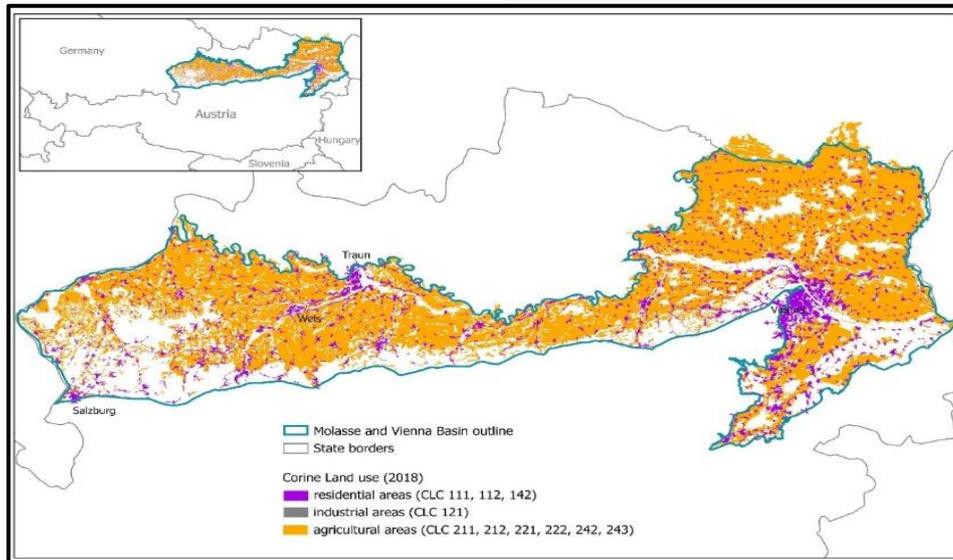


Figure 40: CORINE land use areas (industrial, agriculture, residential) in the Vienna and Molasse Basins (Austria)

Source: Project TRANSCEO, D.1.2.1 Socio - economic analysis report of repurposing abandoned wells for industrial processes

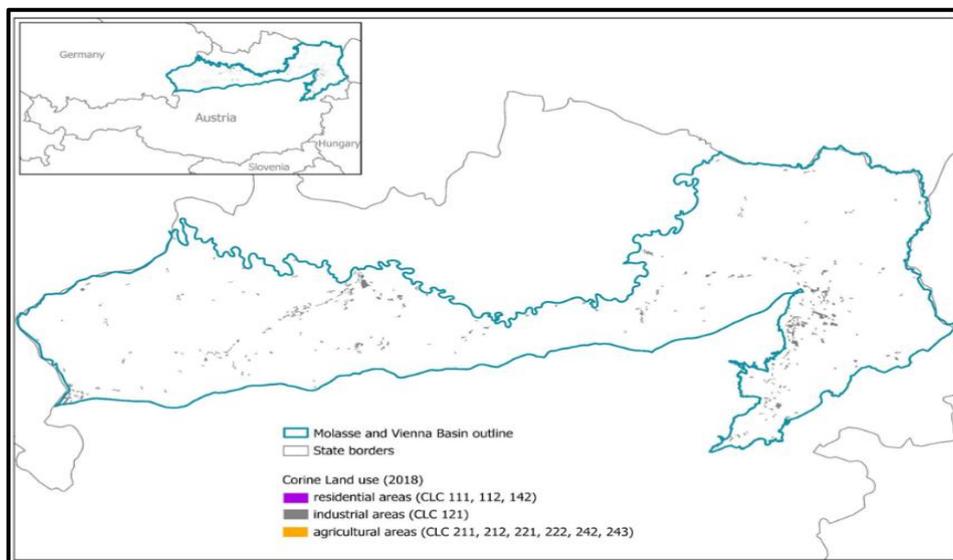


Figure 41: Industrial areas in the Vienna and Molasse Basins in Austria

Source: Project TRANSCEO, D.1.2.1 Socio - economic analysis report of repurposing abandoned wells for industrial processes

According to Figure 41, the industrial sector in Austria has an annual energy consumption/demand of 29% (84,7 TWh) for heat or electricity. This includes the food and beverage, pulp and paper, chemical and petrochemical, and non - ferrous metals industries, as well as the machinery and transport industries. Calculations indicate that higher - capacity geothermal reuse technologies (ATES, EGS and DBHE) will be required for effective application across all industries. Generally, lower - capacity technologies (BTES and DBHE) lack the necessary energy for industrial applications. However, it may be possible to use geothermal energy for space heating or combine multiple wells in a single system to meet the higher temperature and energy requirements of most industries.



Industry areas in the Austrian Vienna and Molasse Basins are sparsely distributed and concentrated in Lower Austria, in the southern Vienna Basin and in the Traisen valley of the Molasse. In Upper Austria, industry is concentrated around the cities of Traun and Wels.

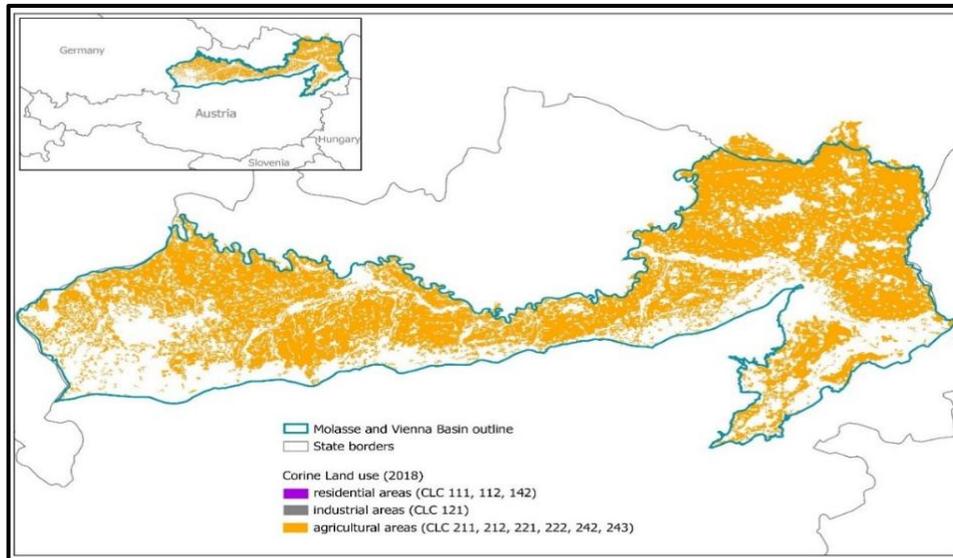


Figure 42: Agriculture areas in the Vienna and Molasse Basins in Austria

Source: Project TRANSCEO, D.1.2.2 Socio - economic analysis report of repurposing abandoned wells for agricultural use

The Figure above states that the agricultural sector could benefit from the redevelopment of abandoned wells for the following reasons:

- The agricultural sector has the lowest heat demand compared to other sectors (industry and municipalities).
- The majority of hydrocarbon wells are located in rural agricultural areas. Therefore, reusing these wells could significantly support the agricultural sector's energy transition.
- Different agricultural applications (e.g. greenhouses for various crops, wood drying and fish farming) require different amounts of energy and temperatures.

These requirements align with the findings on optimal geothermal methods in Austria. The ranking of optimal geothermal applications in Austria is the same as for the Basins separately. The most preferable method is Deep Borehole Heat Exchanger (DBHE), followed by Borehole Thermal Energy Storage (BTES) and Hydrothermal Energy (HE).

Detailed evaluations based on project realisations have shown that, although subsurface workflows are streamlined, surface regulations are very heterogeneous, but essential for the needed redesignation of land. For example, zoning plans are regulated at the federal state level and drawn up by municipalities. Upper Austria has a digital version of its zoning plan, but Lower Austria does not have a comprehensive digital representation. Therefore, there is no comprehensive, unified digital dataset available for Austria.

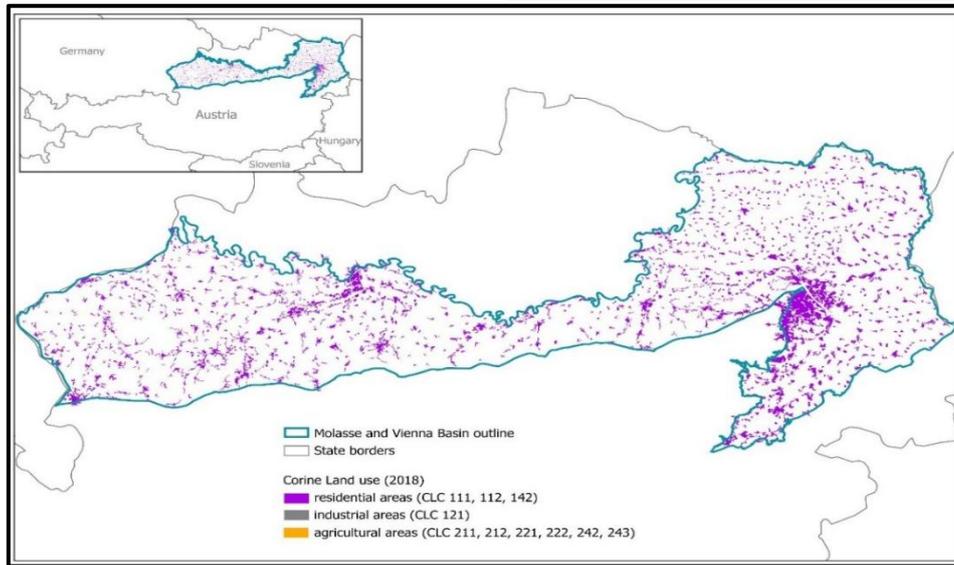


Figure 43: Residential areas in the Vienna and Molasse Basins in Austria

Source: Project TRANSCEO, D.1.2.3 Socio - economic analysis report of repurposing abandoned wells for municipalities

The last Figure shows the following applications in the municipal sector for heat supply from repurposing natural gas and oil wells: communities using district heating systems, small residential communities and balneology and spa centres. The largest concentration of residential areas with a high population density is found in the city of Vienna (population 2 million), where few hydrocarbon wells have been drilled. The rest of the target regions have evenly distributed residential areas where DBHE, BTES or HE applications are suitable.

2.3.2. Croatia

In Croatia the increase in geothermal exploration started with 2018 and continued to 2025, during which period concessions for geothermal exploration areas were given to various companies to develop projects, mainly for power production and lately for heating purposes. Therefore, the existing wells for potential repurpose are currently under concession and are not part of the database for Croatia in the project TRANSCEO. Additionally, a number of exploratory wells were drilled in the Croatian part of the Pannonian Basin whether for hydrocarbon prospection or geological exploration. Since those wells were drilled mainly before 1990 and were abandoned, they present a high risk as a reuse project. Well locations are typically situated on land currently in use, such as agricultural fields or forests, and in some cases, on sites where houses have been constructed. Furthermore, the majority of these wells were drilled during the 1960s, 1970s and 1980s, questioning the condition of the well casings. It is highly likely that the casing is in poor condition, possibly even collapsed. Those wells are deemed not suitable for well reuse and were also not part of the database, however they do present a good information resource for a potential geothermal site.

The remaining areas, which contain a number of wells that could be repurposed in the future, were identified within the oil and gas fields, where bottom - type aquifers are known to exist. These locations have good potential for well reuse, especially from the well status point of view - the majority of these wells are active and not yet abandoned. The selection for the database was made by handpicking those wells that still have active designation, and data from the wells dating back to their respective drilling phase was gathered. The information regarding well completion (both drilling diameters and casing diameters), lithostratigraphic column details, aquifer presence, results from testing of the potential



geothermal reservoirs (permeability, porosity, chemical analysis of water, etc.) and other data, as designated in database flow chart, were inserted in detail.

The resulting well assessment, through the use of the beta version of web - based IT tool, gives a good assessment of the reuse potential of the 115 wells in the Croatian database, for the 5 reuse technologies. The results of the well assessment reuse potential in Croatia are presented as maps of pre - selected wells within hydrocarbon exploitation fields Beničanci, Obod, Kučanci - Kapelna, Molve, Gola, Stari Gradac, Ivanić, Ježevo and Dugo Selo, according to respective reuse technology.

Aquifer Thermal Energy Storage (ATES)

This analysis evaluates the suitability of pre - selected wells in the Croatian part of the Pannonian Basin for conversion to Aquifer Thermal Energy Storage (ATES), using the beta version of web - based IT tool (Figure 44). The majority of the wells are within existing hydrocarbon fields Beničanci, Obod, Kučanci - Kapelna, Molve, Gola, Stari Gradac, Ivanić, Ježevo and Dugo Selo. For ATES, no wells were assessed as suitable ,98 wells assessed as uncertain and 17 assessed as not suitable.

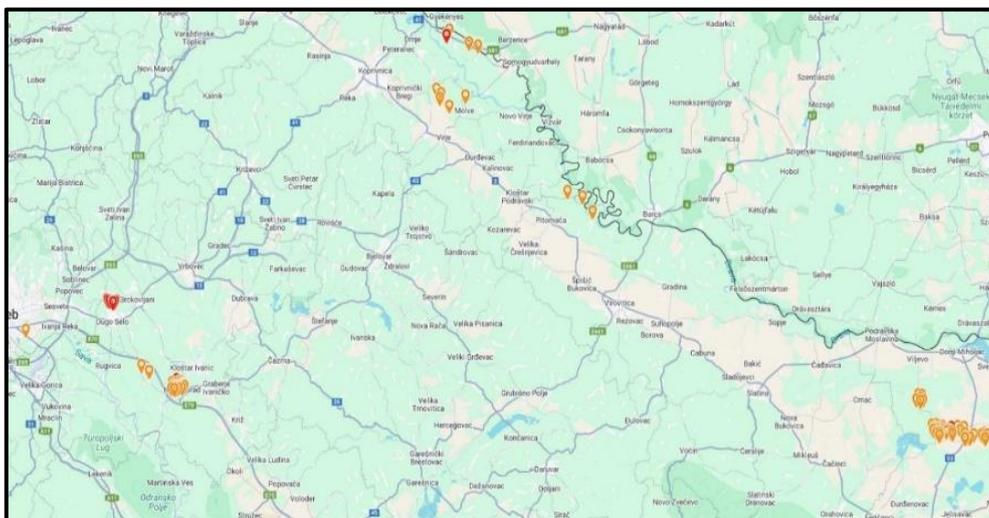


Figure 44: Map of the repurpose potential in the Pannonian Basin (Croatia) for ATES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Deep Borehole Heat Exchanger (DBHE)

This analysis evaluates the suitability of pre - selected wells in the Croatian part of the Pannonian Basin for conversion to Deep Borehole Heat Exchanger (DBHE), using the beta version of web - based IT tool (Figure 45). The majority of the wells are within existing hydrocarbon fields Beničanci, Obod, Kučanci - Kapelna, Molve, Gola, Stari Gradac, Ivanić, Ježevo and Dugo Selo. For DBHE, 24 wells were assessed as suitable, 83 wells assessed as uncertain and 8 assessed as not suitable.

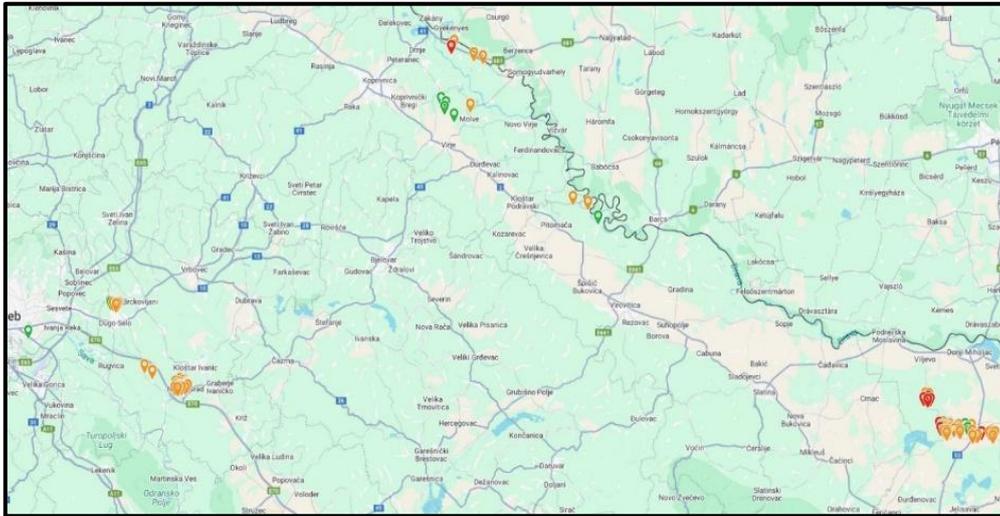


Figure 45: Map of the repurpose potential in the Pannonian Basin (Croatia) for DBHE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Borehole Thermal Energy Storage (BTES)

This analysis evaluates the suitability of pre - selected wells in the Croatian part of the Pannonian Basin for conversion to Borehole Thermal Energy Storage (BTES), using the beta version of web - based IT tool (Figure 46). The majority of the wells are within existing hydrocarbon fields Beničanci, Obod, Kučanci - Kapelna, Molve, Gola, Stari Gradac, Ivanić, Ježevo and Dugo Selo. For BTES, 14 wells were assessed as suitable, 48 wells assessed as uncertain and 53 assessed as not suitable.

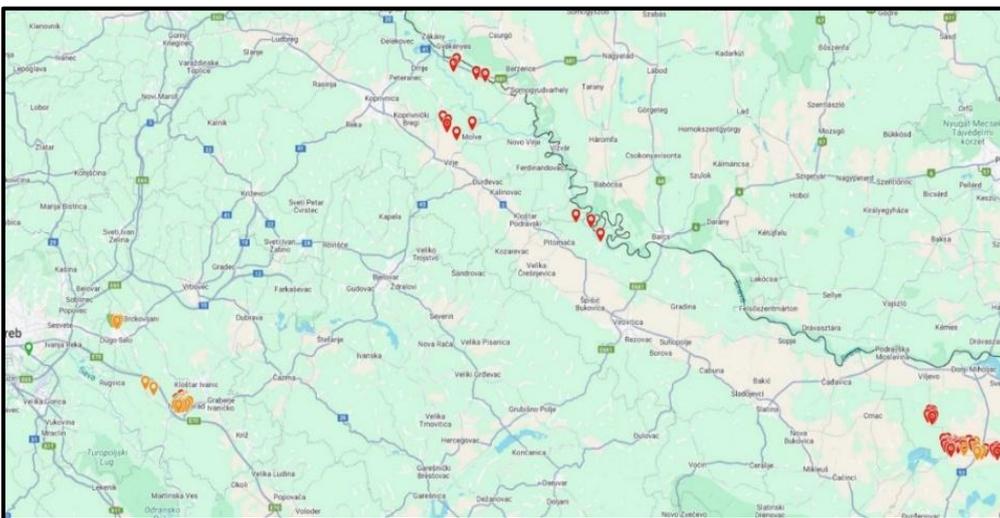


Figure 46: Map of the repurpose potential in the Pannonian Basin (Croatia) for BTES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Hydrothermal Energy (HE)

This analysis evaluates the suitability of pre - selected wells in the Croatian part of the Pannonian Basin for conversion to Hydrothermal Energy (HE), using the beta version of web - based IT tool (Figure 47). The majority of the wells are within existing hydrocarbon fields Beničanci, Obod, Kučanci - Kapelna, Molve, Gola, Stari Gradac, Ivanić, Ježevo and Dugo Selo. For HE, 17 wells were assessed as suitable, 83 wells assessed as uncertain and 15 assessed as not suitable.

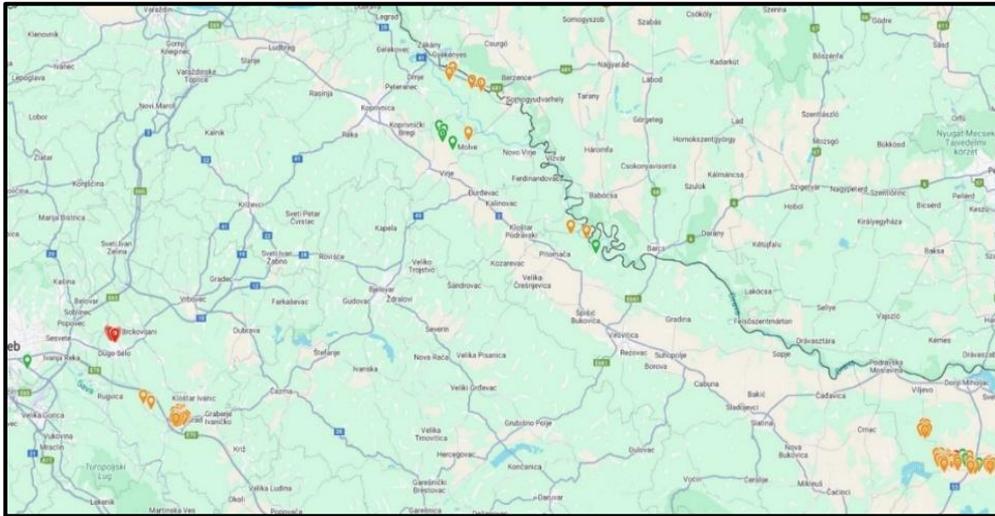


Figure 47: Map of the repurpose potential in the Pannonian Basin (Croatia) for HE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Enhanced Geothermal Systems (EGS)

This analysis evaluates the suitability of pre - selected wells in the Croatian part of the Pannonian Basin for conversion to Enhanced Geothermal System (EGS), using the beta version of web - based IT tool (Figure 48). The majority of the wells are within existing hydrocarbon fields Beničanci, Obod, Kučanci - Kapelna, Molve, Gola, Stari Gradac, Ivanić, Ježevo and Dugo Selo. For EGS, 10 wells were assessed as suitable, 41 wells assessed as uncertain and 64 assessed as not suitable.

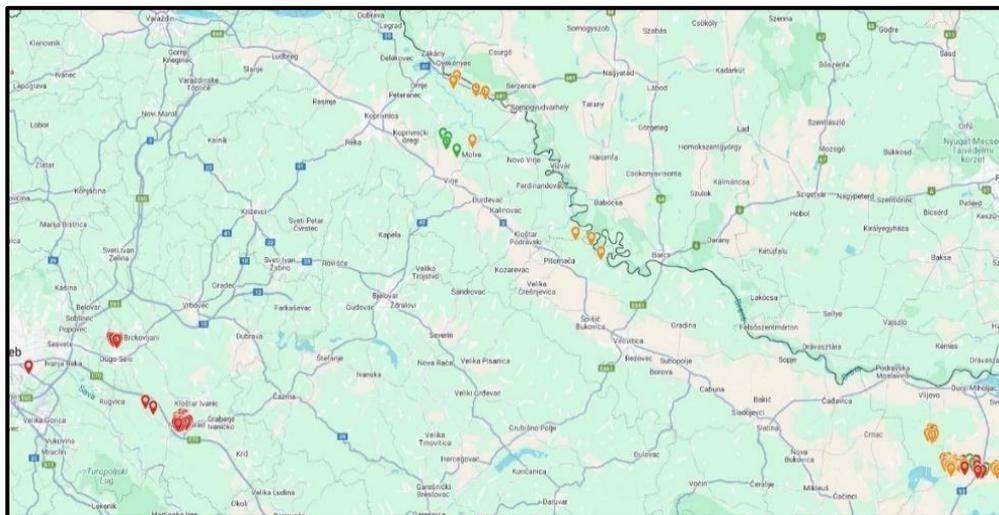


Figure 48: Map of the repurpose potential in the Pannonian Basin (Croatia) for EGS

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Summary of the repurposing potential of the Pannonian Basin (Croatia)

As can be seen from the overview in Table 7, out of 115 wells not one is suitable for ATEs reuse, while the technology with the highest suitable wells for reuse is DBHE, followed by HE with 17 suitable wells. The uncertain category has the highest appraised number of wells. This is due to the criteria set for the well assessment for each technology. Due to those restrictions some wells fall in this category, but if checked carefully could be deemed as suitable. For example, a well that was categorised as uncertain has several aquifer layers. Some of those layers are either below minimum 5 m of reservoir thickness and some are 5 to 10 m thick, prompting the result poor and medium, respectively. However, even though there are reservoirs



with over 10 m of thickness in the same well, the overall rating of this well falls in the category of uncertain. Therefore, the data from uncertain wells should be carefully looked and the final decision should be upon the potential investor.

Table 7: Overview of the well assessment results in the Pannonian Basin (Croatia)

Pannonian Basin (Croatia)	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute / percentage)	115/100%	115/100%	115/100%	115/100%	115/100%
Suitable	0/0,0%	24/20,8%	14/12,2%	17/14,8%	10/8,7%
Uncertain	98/85,2%	83/72,2%	48/41,7%	83/72,2%	41/35,7%
Not suitable	17/14,8%	8/7,0%	53/46,1%	15/13,0%	64/55,6%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

The smallest number of unsuitable wells for reuse is in the DBHE category, followed again by HE, prompting the DBHE and HE technology to the top of the potential technology methods used in Croatia. However, the ATES technology, with 98 wells in the uncertain category also shows good technological solution for existing well repurpose in the future, with restrictions such as depth and corresponding temperatures, as well as reservoir thickness and permeability. The BTES and EGS technologies show the highest numbers in the unsuitable category, 46,1% and 55,6% respectively, even though there are wells where these technologies could be applicable.

2.3.2.1. Quantification of land use

In order to determine the vicinity of the potential heat groups to existing wells in the database, the CORINE Land Cover (CLC) dataset is used as an integral part of the beta version of web - based IT tool. The CORINE Land Cover (CLC) shows a pan - European land cover and land use inventory with 44 thematic classes, ranging from broad forested areas to individual vineyards. Within the beta version of web - based IT tool, it is used to determine the distance between the potential customers in the category of industry, agriculture and municipality and the wells that could be potentially revitalized as geothermal within the Croatian part of the Pannonian Basin. The land use is shown for areas where the wells from the database are grouped.

The category of industry has an annual energy consumption/demand of 16,9% (13,1 TWh) for heat or electricity. Figure 49 shows that significant industry is located in the vicinity of larger cities and only some existing wells have potential to be used for this sector. Of course, there is always the possibility of industrial zones built closer to the wells with potential for revitalization.



Figure 49: Industry areas in the Pannonian Basin in Croatia

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

The category of agriculture has an annual energy consumption/demand of 3,9% (3,1 TWh) for heat or electricity. Figure 50 shows that the wells are clustered in rural areas and could provide significant heating potential for this sector.



Figure 50: Agricultural areas in the Pannonian Basin in Croatia

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Finally, Figure 51 shows that the wells are clustered in areas where the population is over 5.000 inhabitants and the well revitalization could provide significant heating potential for this sector. In municipalities with over 5.000 inhabitants, it can be expected that several buildings or housing estates can be connected to a direct heating system thus creating small scale district heating systems.

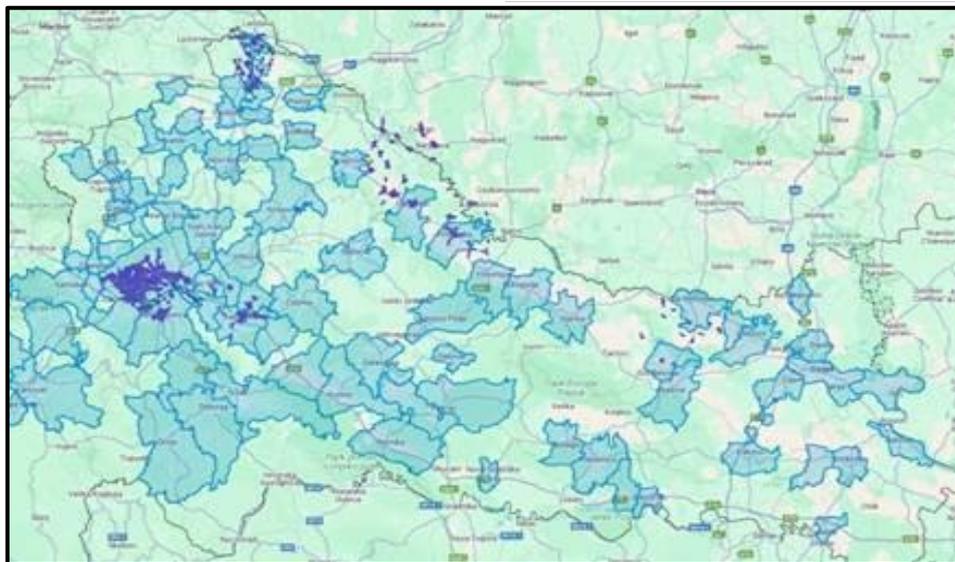


Figure 51: Residential areas in the Pannonian Basin in Croatia

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

2.3.3. Germany

In Germany, geothermal energy can be exploited in the North German Basin, the South German Molasse Basin and the Upper Rhine Graben. In the South German Molasse Basin, mainly the Jurassic carbonates (Malm) are used for deep geothermal, while in the North German Basin in over 5.000 m of sediments/sedimentary rocks, several sandstone formations are used for that purpose. In the database all deep wells have been included, not only natural gas and oil wells. The information available includes site data and formation parameters (temperature and, in some cases, porosity/permeability). But parameters describing the precise status of the wells (abandoned, filled, integrity, etc.) are often unknown. Hence the reuse potential resulting by employing the beta version of web - based IT tool for well repurposing to both Basins is mainly based on the location and the relation of the location to the potential markets, as well as some physical parameters (depth of well, formations available, temperature, and in some cases porosity/permeability). Nevertheless, the status of a well, among other parameters can be retrieved over time and added to the database underlying the beta version of web - based IT tool. The more data becomes digitally available and included in the tool, the more precise the reuse potential of a certain well will become. In Germany DBHE and BTES methods are favoured: over 60% of the wells are suitable for DBHE and 44% for BTES in the North German Basin and 20% in the South German Molasse Basin. The HE technology would follow in importance with over 33% and over 14% for North German Basin and South German Molasse Basin respectively. ATES with approximately 2% and 5% for the North German Basin and South German Molasse Basin respectively and EGS with 15% and 1% for North German Basin and South German Molasse Basin respectively, are less applicable.

2.3.3.1. North German Basin

Aquifer Thermal Energy Storage (ATES)

Figure 52 evaluates the suitability of wells in the North German Basin for conversion to Aquifer Thermal Energy Storage (ATES), using the beta version of web - based IT tool. The map shows all 2.974 wells that appear in the data bases of the geological surveys of the federal states Brandenburg, Saxony - Anhalt and Mecklenburg - Western Pomerania.

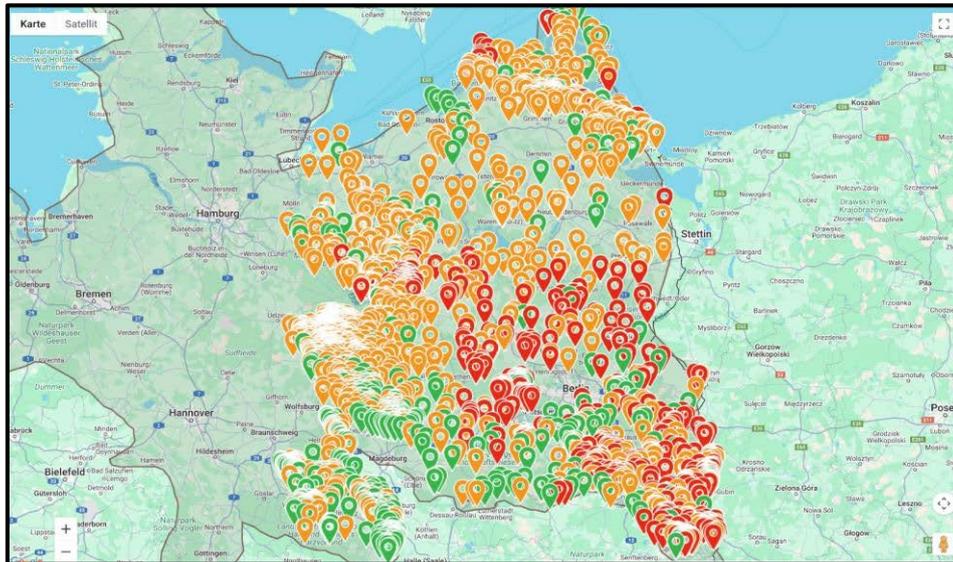


Figure 52: Map of the repurpose potential in the North German Basin for ATES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Deep Borehole Heat Exchanger (DBHE)

Figure 53 evaluates the suitability of wells in the North German Basin for conversion to Deep Borehole Heat Exchanger (DBHE), using the beta version of web - based IT tool. The map shows all 2.974 wells that appear in the data bases of the geological surveys of the federal states Brandenburg, Saxony - Anhalt and Mecklenburg - Western Pomerania.

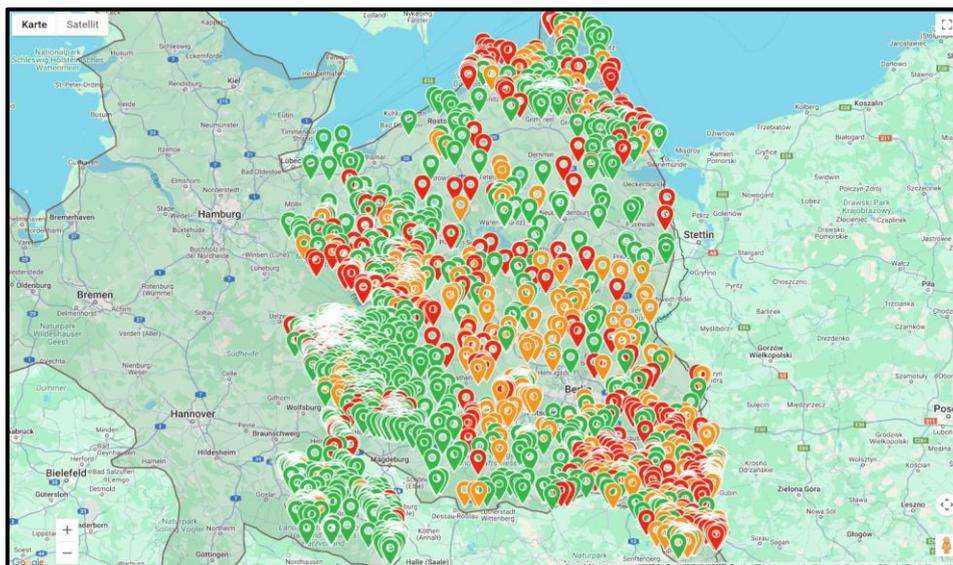


Figure 53: Map of the repurpose potential in the North German Basin for DBHE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



Borehole Thermal Energy Storage (BTES)

Figure 54 evaluates the suitability of wells in the North German Basin for conversion to Thermal Energy Storage (BTES), using the beta version of web - based IT tool. The map shows all 2.974 wells that appear in the data bases of the geological surveys of the federal states Brandenburg, Saxony - Anhalt and Mecklenburg - Western Pomerania.

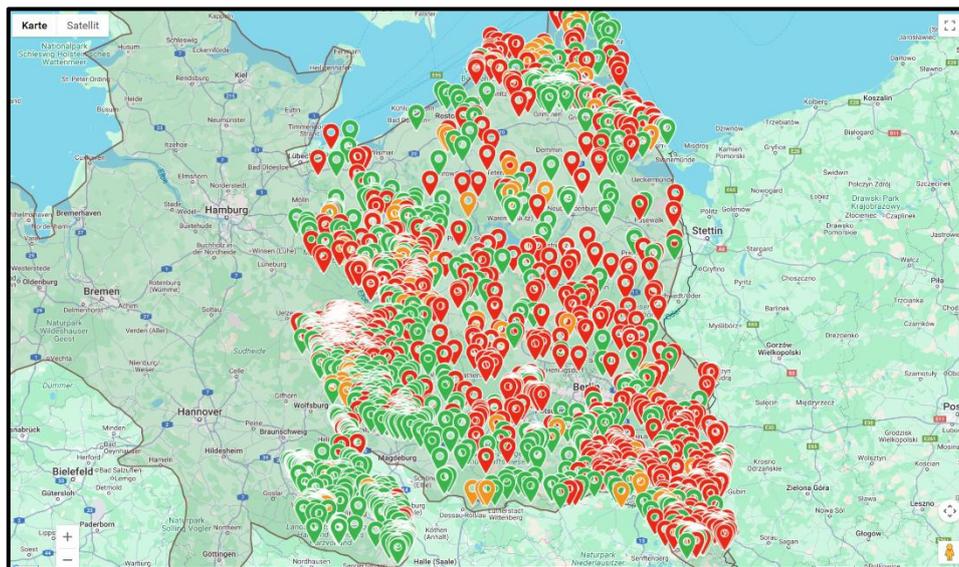


Figure 54: Map of the repurpose potential in the North German Basin for BTES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Hydrothermal Energy (HE)

Figure 55 evaluates the suitability of wells in the North German Basin for conversion to Hydrothermal Energy (HE), using the beta version of web - based IT tool. The map shows all 2.974 wells that appear in the data bases of the geological surveys of the federal states Brandenburg, Saxony - Anhalt and Mecklenburg - Western Pomerania.

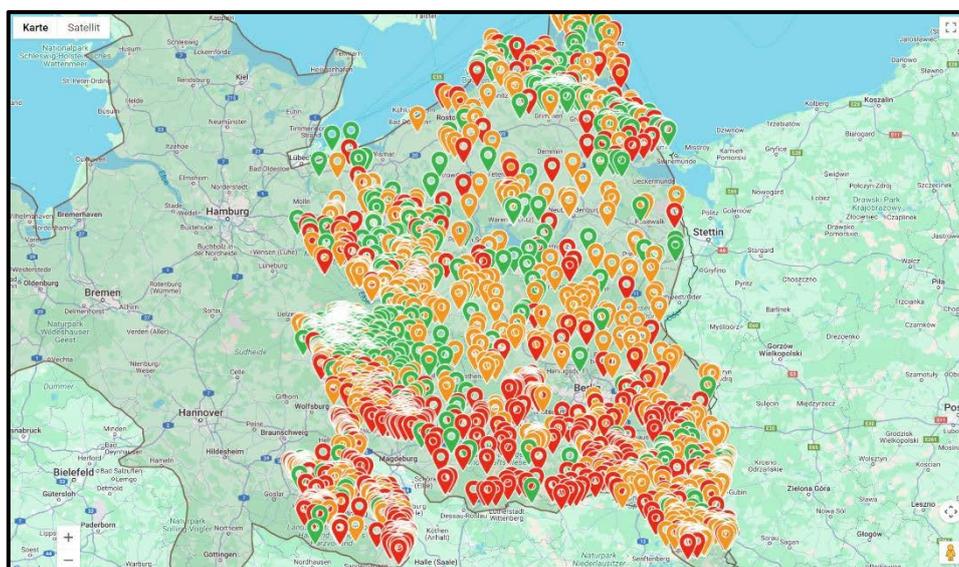


Figure 55: Map of the repurpose potential in the North German Basin for HE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



Enhanced Geothermal Systems (EGS)

Figure 56 evaluates the suitability of wells in the North German Basin for conversion to Enhanced Geothermal Systems (EGS), using the beta version of web - based IT tool. The map shows all 2.974 wells that appear in the data bases of the geological surveys of the federal states Brandenburg, Saxony - Anhalt and Mecklenburg - Western Pomerania.



Figure 56: Map of the repurpose potential in the North German Basin for EGS

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Summary of the repurposing potential of the North German Basin

The North German Basin contains a total of 2.974 wells evaluated for their suitability for the 5 geothermal methods: ATES, DBHE, BTES, HE and EGS. Exact results numbers and percentages are shown in Table 8. Out of 2.974 wells, a high amount seems to be suitable compared to other Basins. Due to lack of data, especially in the federal states of Mecklenburg - Western Pomerania and Saxony - Anhalt (only the master data is available), suitable and uncertain wells should be carefully examined. Furthermore, the majority of the boreholes (~95%) are older than 35 years. The condition of these wells is unclear. Allegedly, almost all of them were sealed, which can lead to misinterpretation of their data.

Table 8: Overview of the well assessment results in the North German Basin

North German Basin	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute / percentage)	2.974/100%	2.974/100%	2.974/100%	2.974/100%	2.974/100%
Suitable	721/24,2%	1.803/60,6%	1.320/44,4%	999/33,6%	462/15,5%
Uncertain	548/18,4%	548/18,4%	179/6,0%	1090/36,7%	222/7,5%
Not suitable	535/18,0%	623/21,0%	1.475/49,6%	855/28,7%	2.290/77,0%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe



2.3.3.2. Western Mollase Basin

Aquifer Thermal Energy Storage (ATES)

Figure 57 evaluates the suitability of pre - selected wells in the German part of the Molasse Basin for conversion to Aquifer Thermal Energy Storage (ATES), using the beta version of web - based IT tool. For ATES, 74 wells were assessed as suitable, 536 wells assessed as uncertain and 744 assessed as not suitable. The majority of the suitable wells are situated in the north of the Basin near the cities of Regensburg, Ingolstadt and Landshut and near the Bodensee lake.

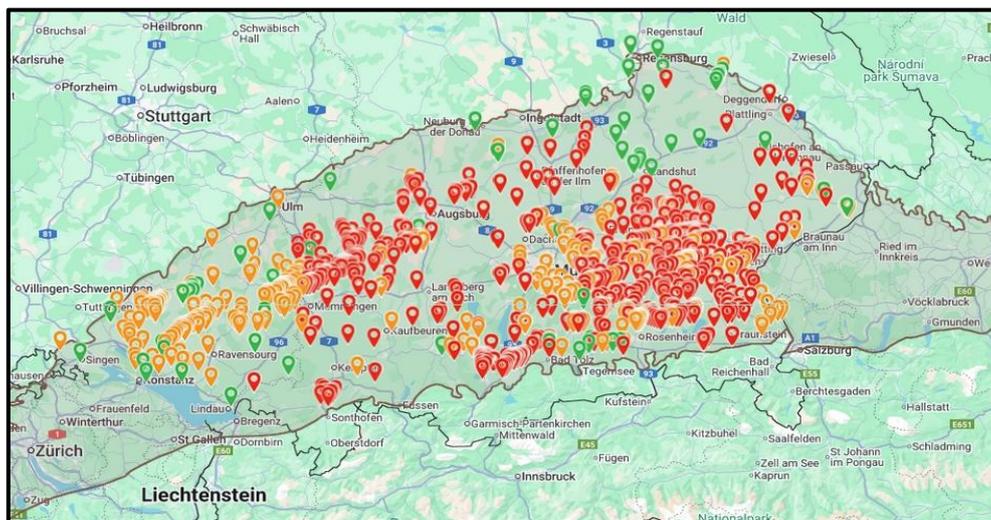


Figure 57: Map of the repurpose potential in the Molasse Basin (Germany) for ATES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Deep Borehole Heat Exchanger (DBHE)

Figure 58 evaluates the suitability of pre - selected wells in the German part of the Molasse Basin for conversion to Deep Borehole Heat Exchanger (DBHE), using the beta version of web - based IT tool. For DBHE, 325 wells were assessed as suitable, 468 wells assessed as uncertain and 561 assessed as not suitable. The majority of the suitable wells are situated in the north of the Basin near the cities of Regensburg, Ingolstadt and Landshut, Munich and near the Bodensee lake.

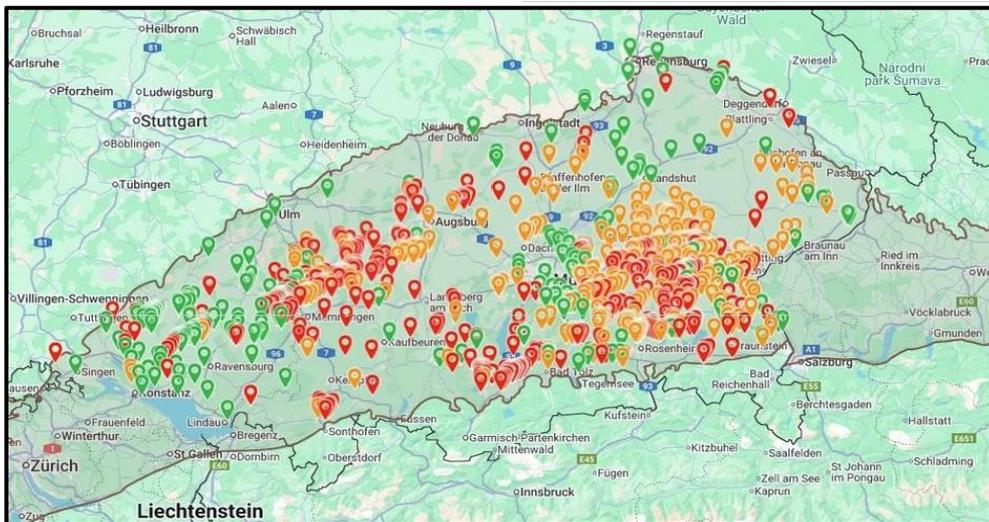


Figure 58: Map of the repurpose potential in the Molasse Basin (Germany) for DBHE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Borehole Thermal Energy Storage (BTES)

Figure 59 evaluates the suitability of pre - selected wells in the German part of the Molasse Basin for conversion to Borehole Thermal Energy Storage (BTES), using the beta version of web - based IT tool. For BTES, 268 wells were assessed as suitable, 84 wells assessed as uncertain and 1.002 assessed as not suitable. The majority of the suitable wells are situated in the north of the Basin near the cities of Regensburg, Ingolstadt and Landshut and near the Bodensee lake.

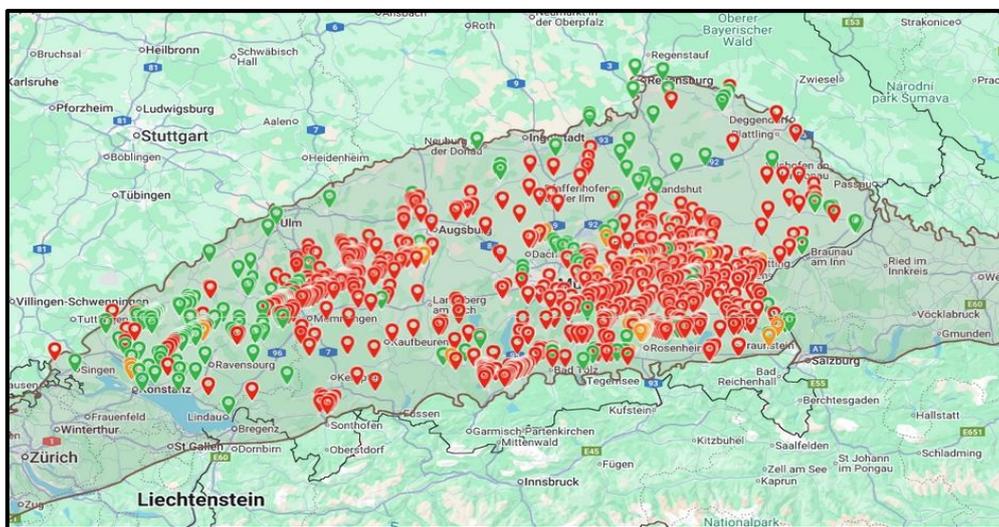


Figure 59: Map of the repurpose potential in the Molasse Basin (Germany) for BTES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Hydrothermal Energy (HE)

Figure 60 evaluates the suitability of pre - selected wells in the German part of the Molasse Basin for conversion to Hydrothermal Energy (HE), using the beta version of web - based IT tool. For HE, 201 wells were assessed as suitable, 904 wells assessed as uncertain and 249 assessed as not suitable. The majority of the suitable wells are situated near the city of Munich and near the Bodensee lake.

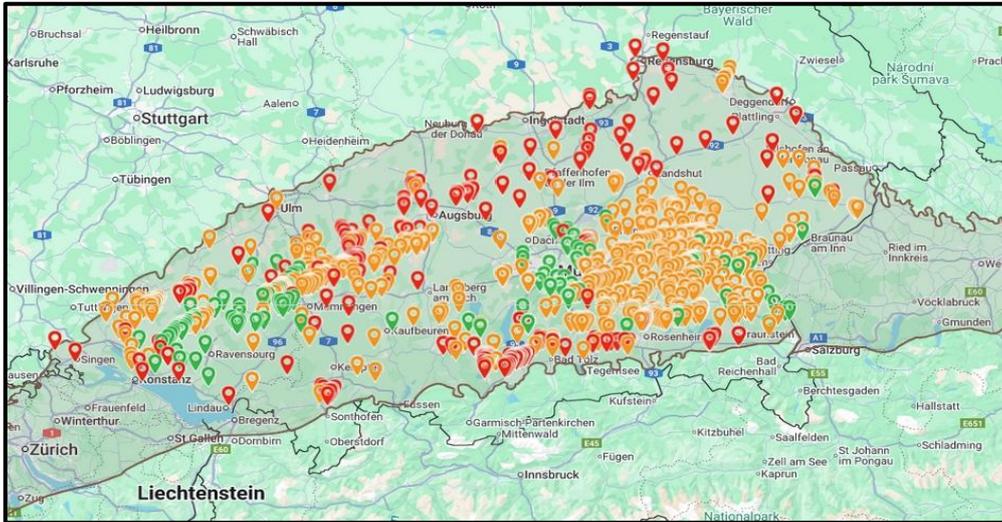


Figure 60: Map of the repurpose potential in the Molasse Basin (Germany) for HE
Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Enhanced Geothermal Systems (EGS)

Figure 61 evaluates the suitability of pre - selected wells in the German part of the Molasse Basin for conversion to Enhanced Geothermal Systems (EGS), using the beta version of web - based IT tool. For EGS, 15 wells were assessed as suitable, 165 wells assessed as uncertain and 1.174 assessed as not suitable. The majority of the suitable wells are situated in the south of the Basin near to the Austrian border and near the Starnberger lake.

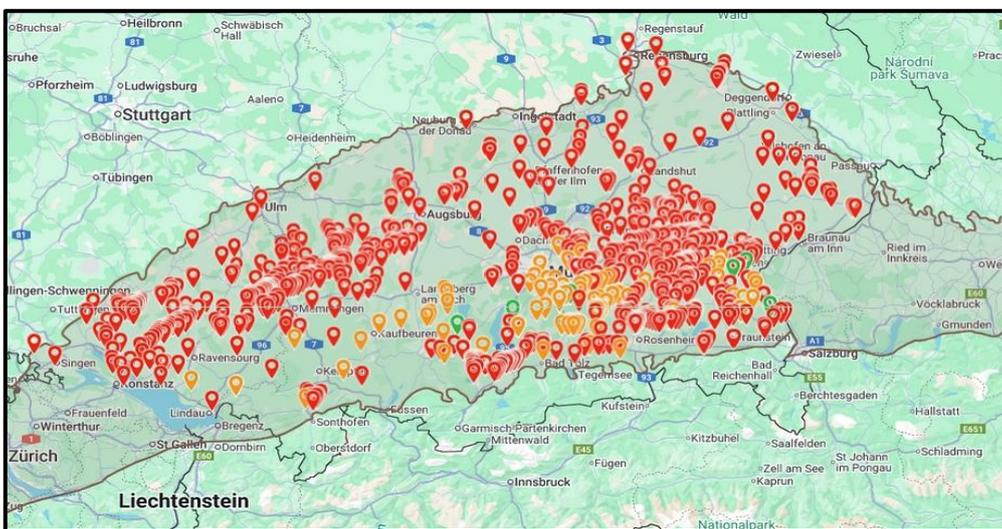


Figure 61: Map of the repurpose potential in the Molasse Basin (Germany) for EGS
Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Summary of the repurposing potential of the Molasse Basin (Germany)

The German part of Molasse Basin contains a total of 1.354 wells evaluated for their suitability for the 5 geothermal methods: ATES, DBHE, BTES, HE and EGS. Exact results numbers and percentages are shown in Table 9. In contrast to the North German Basin, aquifer data (temperature, depth, distribution and permeability) could be generated for the entire Basin. Therefore, the data shown in the beta version of web - based IT tool are more precise compared to the North German Basin. Nevertheless, suitable and uncertain wells should be carefully examined before an investment for a reuse is initiated.



Table 9: Overview of the well assessment results in the Molasse Basin (Germany)

Molasse Basin (Germany)	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute / percentage)	1.354/100%	1.354/100%	1.354/100%	1.354/100%	1.354/100%
Suitable	74/5,5%	325/24%	268/ 19,8%	201/14,8%	15/1,1%
Uncertain	536/39,6%	468/34,6%	84/6,2%	904/66,8%	165/12,2%
Not suitable	744/54,9%	561/41,4%	1.002/74%	249/18,4%	1.174/86,7%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

2.3.3.3. Quantification of land use

CORINE Land Cover (CLC) dataset was used (EU Copernicus Land Monitoring Service, 2018) to determine the spatial relation between the primary customer groups “industry, agriculture and municipality” (together representing 60 - 70% of the energy demand) and the old wells potentially reused for geothermal within the North German Basin and the South German Molasse Basin. The CORINE land use - key for “Industrial or commercial units and public facilities” is CLC - 121. Several land - use categories were jointly used to represent “municipality”: CLC - 111 (continuous urban fabric), CLC - 112 (discontinuous urban fabric), CLC - 123 (port areas), CLC - 124 (airports) and CLC - 142 (sport and leisure facilities). Agriculture is represented by the categories CLC - 211 (non - irrigated arable land), CLC - 221 (vineyards), CLC - 222 (fruit tree and berry plantations), CLC - 242 (complex cultivation patterns) and CLC - 243 (land principally occupied by agriculture, with significant areas of natural vegetation).

The North German Basin covers an area of approximately 108.027 km². Industrial areas represent 1.739 km², agricultural areas represent 67.849 km² and urban fabric (municipality) represents 7.532 km². This represents 1,6% for industrial areas, 62,8% for agricultural areas and 7,0% for residential areas. For the South German Molasse Basin, which extends over an area of 21.746 km², 355 km² (1,6%) are industrial, 12.608 km² (58,0 %) are agricultural and 1.623 km² (7,5%) are urban areas.

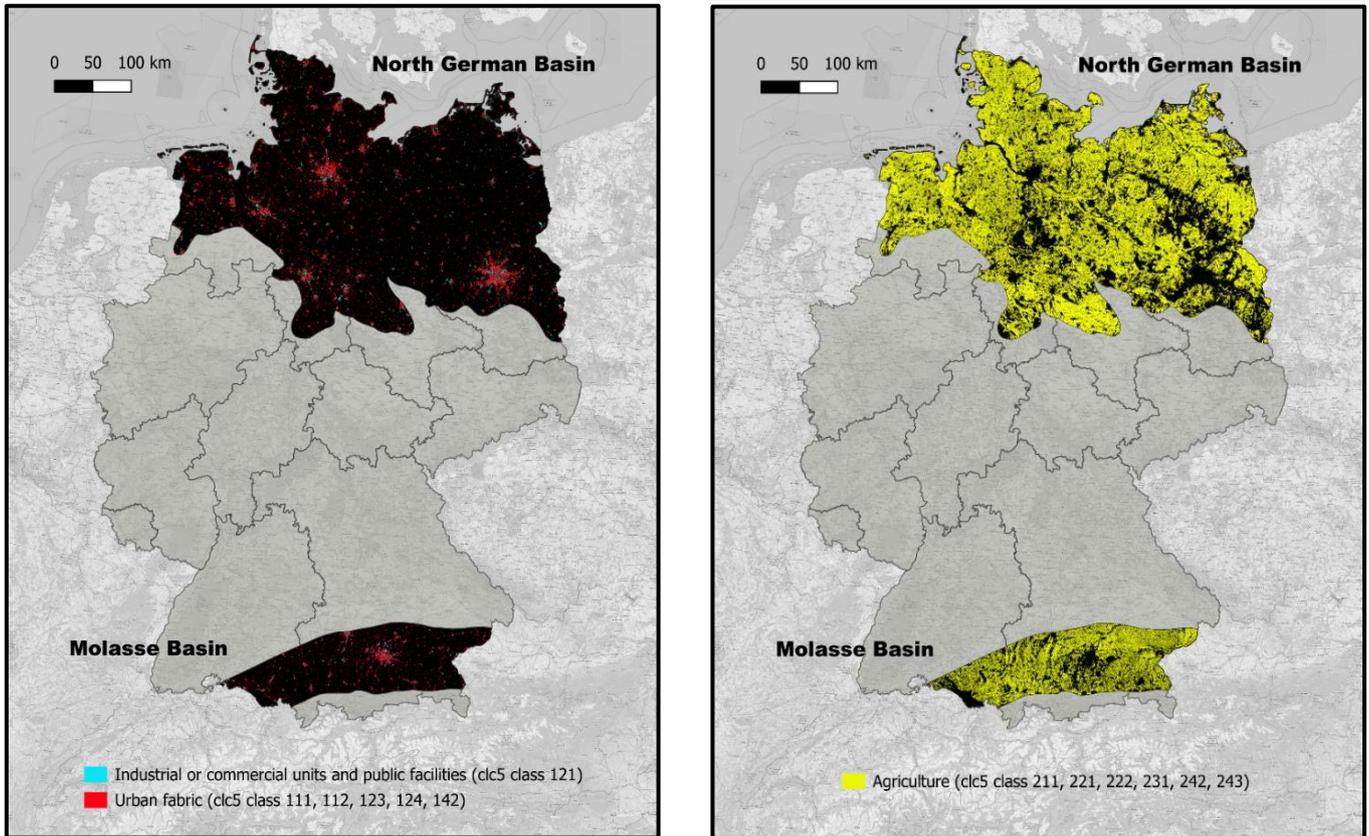


Figure 62: Industrial and residential, as well as agricultural areas of the North German Basin and Molasse Basin in Germany

Source: CORINE Land Cover, 2025

2.3.4. Hungary

The Pannonian Basin is surrounded by the Alpine - Carpathian - Dinaridic orogens in Central Europe. The retreat of subduction along the Carpathians led to Miocene back - arc extension, resulting in a reduction in crustal thickness in the Pannonian Basin to 22 - 25 km (Horváth et al., 2015; Kalmár et al., 2021). This region has a lithospheric thickness of approximately 50 - 60 km and exhibits a high average surface heat flow of 90 - 120 MW m⁻² (Lenkey et al., 2002; Kalmár et al., 2023). Initially, Lake Pannon consisted of interconnected shallow basins, separated by islands and peninsulas. Due to rapid post - rift subsidence, these basins were eventually flooded, leading to the formation of a wide, open water body around 10 million years ago (Magyar et al., 1999). Despite this flooding, the lakebed maintained an uneven surface, characterized by both raised areas and trenches (Sztanó et al., 2013, 2026).

Lake Pannon existed for approximately 8 million years within the Pannonian Basin. Lacustrine sedimentation began with a condensed layer that included calcareous marls, marls, and clayey marls (Juhász et al., 2006), deposited at water depths ranging from 200 to 1.000 m (Magyar et al., 1999). The ongoing uplift and erosion of the surrounding mountain ranges contributed a significant amount of sediment to the Basin, which gradually filled despite the relatively rapid subsidence. The first modern process - based sedimentary reconstructions of deltaic deposits were conducted using hundreds of cores from the Algyó hydrocarbon field (Révész, 1980). Researchers identified the cyclicity and repetition of delta lobes, which were 10 to 30 m thick and observed the progradation of the delta system. They also noted the heterochronous nature of the lithological boundaries. The integration of well - log and seismic data, particularly the identification of clinoforms several hundred meters high and their progradation, contributed to a better understanding of



the basin - fill geometry (Mattick et al., 1994). Studies of the deepest well in Hungary (Hód - I, with a total depth of 5.842 meters) (Bérczi, 1988) and a dozen other deep wells, along with the identification of gravity - flow deposits, laid the groundwork for a complex source - to - sink sedimentological model. This model encompasses the fluvial feeder system, deltas, and turbidites within the lake (Bérczi and Phillips, 1985; Phillips et al., 1994).

The Lake Pannon successions in the Pannonian Basin can be divided into 6 major depositional environments (I - VI) and 7 related formations (Sztanó et al., 2026). The formations from the 'transgressive phase' include sandstones and conglomerates that originate from cliffed coasts, locally fed coarse - grained deltas, or wave - dominated nearshore zones (I). Open - water mudstones indicate transgression and deepening of the lake, forming in varying water depths. In the deepest basins (II.a), these mudstones contain profundal fossils and show a decreasing carbonate content, often interfingering with low - volume mass - gravity flow deposits. Laminated black shales, which are proven source rocks (Tari et al. 2023), are also part of the open - water marls. Additionally, mudstones with sublittoral fossils, which accumulated on underwater highs (II.b), are likely the most homogeneous lacustrine deposits. The 'regressive phase' is characterized by shallowing - upward successions that consist of turbidite systems (III), progradations of the shelf - slope (IV), and deltas (V), all sourced from distal orogenic areas. The most sand - rich deposits are found in the Basin - centre turbidite systems (Sztanó et al. 2013; Vlček et al., 2024), although slope - toe turbidites and deltas are also predominantly sandy. These 3 units are significant because they form reservoirs, making them targets for hydrocarbon or geothermal exploration (Bagoly Árgyelán et al., 2024). The successions are capped by deposits from the fluvial feeder systems (VI). The slope and the sediments of the alluvial plain are primarily mud - rich. In specific areas, particularly near the Basin margins, coarse - grained Pliocene alluvial systems can also be identified (Šujan et al., 2021; Subová et al., 2022).

The geothermal reservoirs of the Pannonian Basin offer an excellent potential for the utilisation of thermal energy and, where appropriate, for the production of electricity due to their favourable geological conditions. A particular advantage is that high temperatures can be reached at relatively shallow depths in the Basin areas.

With the exception of mountainous areas, the country's surface is covered by Neogene sediments ranging in thickness from 100 m to 8 km. The thickness of the sediments is the greatest in the Little Hungarian Plain (8 km), the Drava trench (4 km) and in certain areas of the Hungarian Great Plain (Makó trench, 7 km and Békés depression, 7 km). The upper part of the Neogene reservoir, the Quaternary and Upper Pannonian aquifer system, consists of alternating layers of gravel, sand, sandstone, silt, clay and marl, which form a hydraulically coherent reservoir. The reservoir is characterised by regional water flow, with the higher hills and mountains, the Nyírség and the Danube - Tisza Basin as recharge areas and the lower areas as discharge areas. Reservoir productivity is a function of regional permeability. The productivity of the reservoir depends on regional permeability. The Upper Pannonian sands and sandstones, which are among the rocks with the highest geothermal potential, have a hydraulic conductivity of 10^{-5} m/s and a flow rate of 10 - 100 m³/h.

The Lower Pannonian sediments are mainly marls and clays. These rocks are predominantly aquitards, although sandstone bodies are also found among the aquitards (e.g. Szolnok). Overpressure is very common in Lower Pannonian sediments, but varies from area to area. However, the production of overpressure reservoirs, being considered closed systems, always requires water reinjection. In the case of Lower Pannonian formations, faults can play an extremely important role in ensuring upward water flow and reducing pressure in overpressured systems. In the Neogene reservoir, the temperature at a depth of 2.000 - 2.500 m is 90 - 110 °C.

Thick layers of Miocene rhyolite tuff (e.g., Nyírség, Tokaj - hills' foothills (Fejes, 2021)) can also act as aquifers, which led to a successful project at the LEGO factory in Nyíregyháza. The water conductivity of carbonate reservoirs is due to faults and karstification. Carbonate Mesozoic rocks can be found on the surface in the karst areas of the Transdanubian Mountains, Mecsek, Villány, Bükk, and Aggtelek. Due to the



faults in the rock, rainwater easily seeps into the rocks and then, after heating up deep underground, reaches the surface in the form of hot springs at the foot of the mountains (Hévíz, Budapest, Eger). The water temperature is also below 100 °C, so these reservoirs can also be classified as low - enthalpy systems. The carbonate rocks are covered by Neogene sediments at the bases. In these places, the hot water that emerges seeps into the sediments and creates a temperature anomaly.

Most of the Mesozoic carbonates found in the bedrock covered by Neogene sediments are not in contact with open karsts (South - Western Transdanubia, South - Eastern Great Plain). They form a closed system (higher salt content, saline water, probable overpressure), the depth extent of which is unknown or only partially known. The medium - high enthalpy reservoirs (120 - 200 °C) found in the fractured, fragmented carbonate rocks in the Neogene sedimentary bedrock are therefore already suitable for electricity generation. The main obstacle to extraction is the high overpressure.

In summary, most hydrocarbon exploration drilling is directed at the Lower Pannonian and deeper layers, so the Neogene aquifers have been penetrated in these layers. From a geological point of view, abandoned wells in these areas may be suitable for conversion into geothermal wells, but the main concerns are the condition of the wells, integrity problems, sand production, gas and salt content. Carbonate rocks are also target areas and are often reached by drilling for oil (e.g., Andrásida - Nagylengyel, Mélykút - Pusztamértes, and Nagyszénás - Fábiansébestyén areas) (Mádlné et al., 2008). The main problems in deeper carbonates are salt content, hydrocarbon content and overpressure. There is great potential for the repurpose of abandoned hydrocarbon wells, especially if preparations for the process begin before the hydrocarbon production ends (conscious planning). The key to future development is sustainable production, reinjection, and the design of complex, multi - purpose geothermal systems.

There are 1.557 geothermal wells operated by various users, such as municipalities, agricultural companies, and industrial users. There are 8.354 natural gas and oil exploration and production wells, mainly operated by MOL, O&GD, and a number of smaller companies. There are 2.743 other deep wells (raw material exploration and coal) operated by various users, as well as 2.334 abandoned wells, of which 2.258 are deeper than 400 m, operated by Mining Property Utilization Nonprofit Public Ltd. in the Pannonian Basin (see Figure 63.) A total of 14.912 wells deeper than 400 m can be taken into account, but there may be overlaps (HC wells - abandoned wells - water wells; CH wells - geothermal wells). Therefore, the actual number of wells is approximately 10.000.

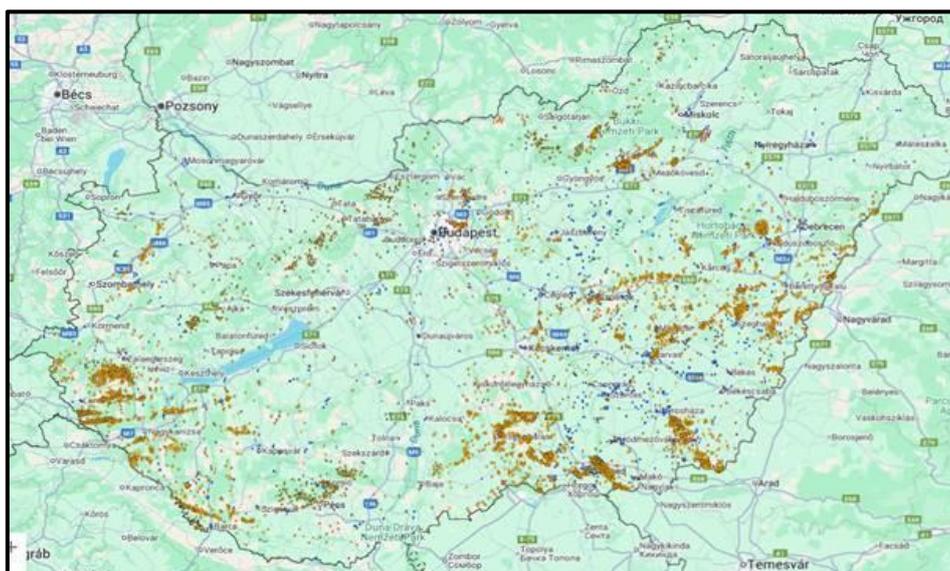


Figure 63: Wells deeper than 400 m in the Pannonian Basin (Hungary)

*Note: orange - hydrocarbon, brown - other exploration and coal, blue - thermal, purple - abandoned wells

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



Aquifer Thermal Energy Storage (ATES)

The Figure 64 shows the well assessment results in the Hungarian part of the Pannonian Basin for ATES technology. From the input dataset of 177 wells, 2 (1,1%) are suitable, 65 (36,7%) are suitable with certain restrictions and 110 (62,2%) are not suitable for reuse as Aquifer Thermal Energy Storage (ATES). The low percentage of suitable wells (1,1%) and the high percentage of suitable, but uncertain wells (36,7%) for ATES are subject to further investigation, as shallow aquifers are not currently integrated into the database, despite their existence. The main aquifers in the Pannonian Basin dataset are the Upper Pannonian sandstones in the Hungarian Great Plain and the Zala Basin’s sediments.

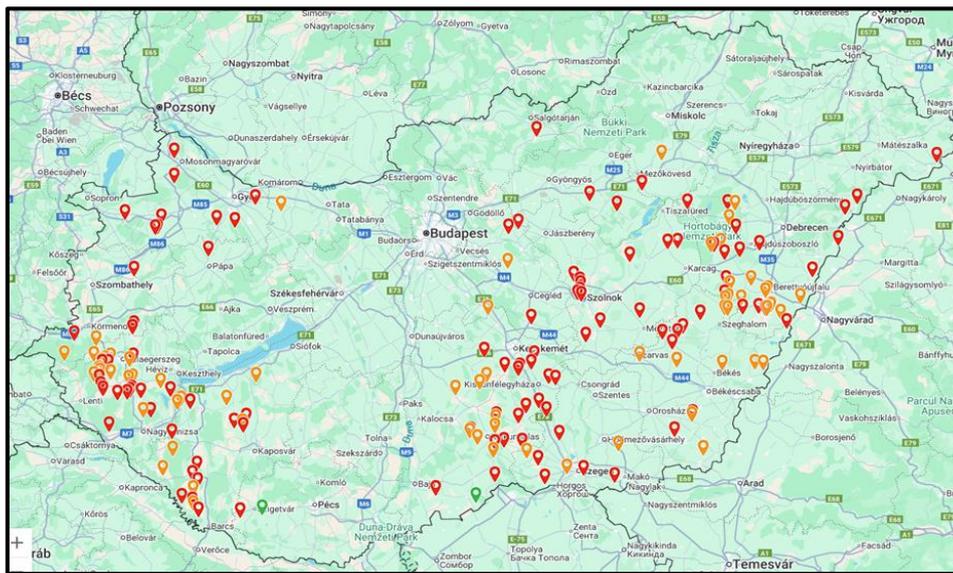


Figure 64: Map of the repurpose potential in the Pannonian Basin (Hungary) for ATES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Deep Borehole Heat Exchanger (DBHE)

The Figure 65 shows the well assessment results in the Hungarian part of the Pannonian Basin for DBHE technology. From the input dataset of 177 wells, 63 are suitable (35,6%), 66 (37,3%) are suitable with certain restrictions and 48 (27,1%) are not suitable for reuse as Deep Borehole Heat Exchanger (DBHE). By calculating the heating capacity of a DBHE well at 250 kW and considering only those wells found to be suitable, a heating capacity of 15,75 MW can be calculated. Theoretically, taking into account the similar usability ratio of all wells deeper than 400 m, a potential heating capacity of almost 1.070 MW could be obtained.

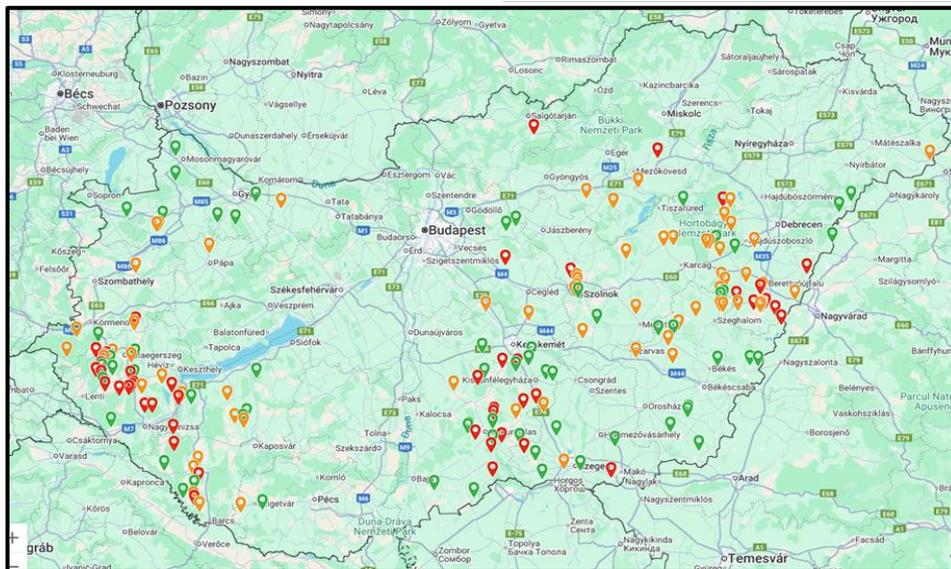


Figure 65: Map of the repurpose potential in the Pannonian Basin (Hungary) for DBHE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Borehole Thermal Energy Storage (BTES)

The Figure 66 shows the well assessment results in the Hungarian part of the Pannonian Basin for BTES technology. From the input dataset of 177 wells, 18 (10,2%) are suitable, 27 (15,2%) are suitable with certain restrictions and 132 (74,6%) are not suitable for reuse as Borehole Thermal Energy Storage (BTES). In most cases, BTES cannot be considered due to excessively high temperatures.

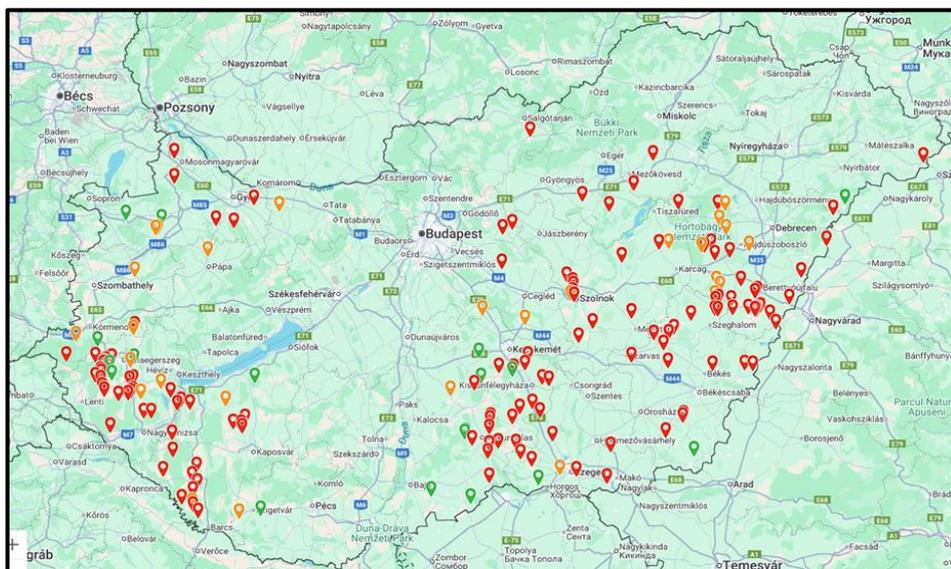


Figure 66: Map of the repurpose potential in the Pannonian Basin (Hungary) for BTES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Hydrothermal Energy (HE)

The Figure 67 shows the well assessment results in the Hungarian part of the Pannonian Basin for HE technology. From the input dataset of 177 wells, 26 (14,7%) are suitable, 40 (22,6%) are suitable with certain restrictions and 111 (62,7%) are not suitable for reuse as Hydrothermal Energy (HE) applications. Calculating the heating capacity of a HE well (doublet) at 1,5 MW, and considering only those wells deemed suitable,



yields a heating capacity of 39 MW. Theoretically, considering the similar usability ratio of all wells deeper than 400 m, a potential heating capacity of almost 2.650 MW could be achieved.

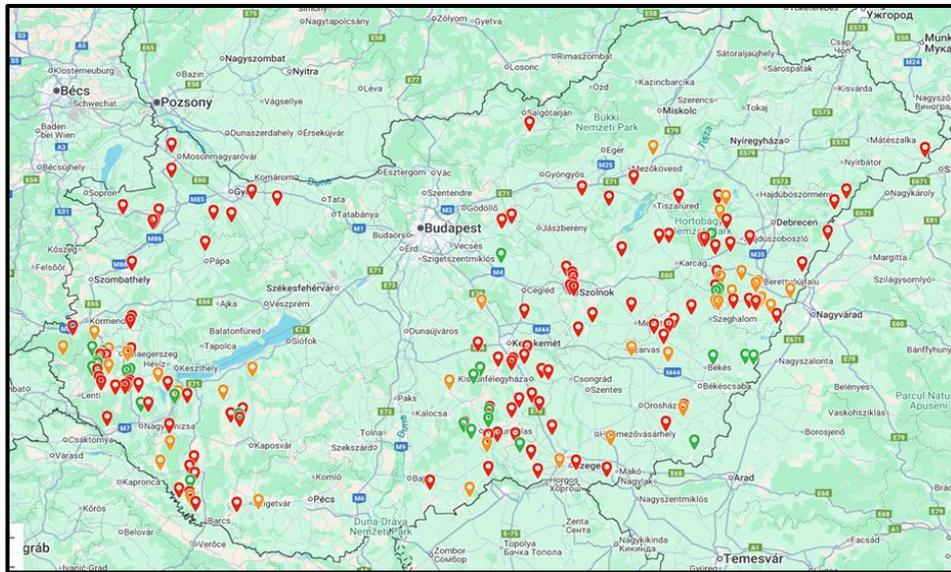


Figure 67: Map of the repurpose potential in the Pannonian Basin (Hungary) for HE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Enhanced Geothermal Systems (EGS)

The Figure 68 shows the well assessment results in the Hungarian part of the Pannonian Basin for EGS technology. From the input dataset of 177 wells, 48 (27,1%) are suitable, 61 (34,5%) are suitable with certain restrictions and 68 (38,4%) are not suitable for reuse as Enhanced Geothermal Systems (EGS). Calculating the heating capacity of an EGS well at 3 MW and taking into account only those wells found to be suitable, a heating capacity of 144 MW can be calculated. Theoretically, considering the similar usability ratio of all wells deeper than 1.000 m, a potential heating capacity of almost 9.760 MW could be achieved.

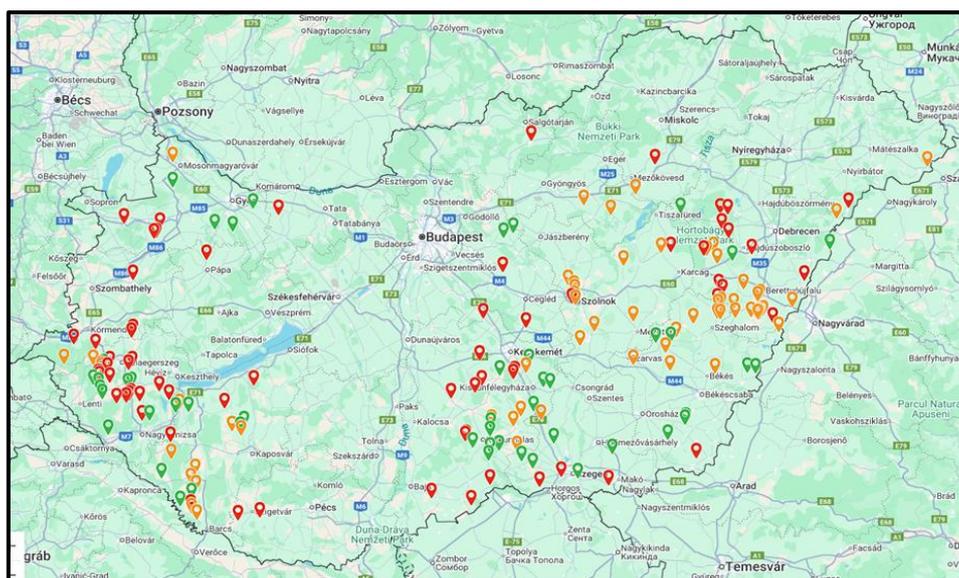


Figure 68: Map of the repurpose potential in the Pannonian Basin (Hungary) for EGS

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



Summary of the repurposing potential of the Pannonian Basin (Hungary)

A total of 624 wells were evaluated after which 177 wells were selected as potentially suitable and inserted to the database and thus into the beta version of web - based IT tool. The preliminary assessment of the 177 wells yielded the following results (Table 10).

Table 10: Overview of the well assessment results in the Pannonian Basin (Hungary)

Pannonian Basin (Hungary)	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute / percentage)	177/100%	177/100%	177/100%	177/100%	177/100%
Suitable	2/1,1%	63/35,6%	18/10,2%	26/14,7%	48/27,1%
Uncertain	65/36,7%	66/37,3%	27/15,2%	40/22,6%	61/34,5%
Not suitable	110/62,2%	48/27,1%	132/74,6%	111/62,7%	68/38,4%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

2.3.4.1. An estimation of the repurposing potential

The Mining Property Utilization Nonprofit Public Ltd. carried out 743 technical condition assessments and 937 geological evaluations on the 2.334 wells it manages and compiled 62 utility portfolios. Of the abandoned wells, 1.710 were abandoned and recultivated, meaning that they can no longer be used for other purposes. Of the remaining 624 wells, all of which are deeper than 400 m, 32 converted into water wells (partially used), 325 have been technically abandoned, and 267 have been sealed.

In the case of HE projects, the flow rate range between 10 l/s and 100 l/s is marked as uncertain, although well production falling within this range may be perfectly suitable for smaller geothermal heat production projects. It is therefore advisable to consider these as potentially good wells in the calculations.

Of course, there are overlaps between these wells. Taking into account the table of 177 wells, 63 wells were suitable for DBHE, 66 for HE and 48 for EGS. Of course, there are overlaps between these wells. Of the 177 wells, a total of 114 wells were suitable for DBHE, HE or EGS projects. In 9 cases, the well was classified as suitable for all three projects, in another 12 cases the well was suitable for DBHE and HE, in another 25 cases it was suitable for DBHE and EGS and in 8 cases it was suitable for HE and EGS. In order to filter out overlaps, a feasibility order must be established, i.e., it is easiest to implement DBHE, then HE and finally EGS. Based on this, the overlaps can now be managed, meaning it cannot be counted on 63 DBHE, 45 HE, and 6 EGS projects. The modified assessment of the 177 wells yielded the following results, shown in Table 11.

Table 11: Modified assessment of the 177 wells

Pannonian Basin (Hungary)	DBHE	HE	EGS
Total of wells (absolute/percentage)	177/100%	177/100%	177/100%
Suitable	63/10,1%	45/7,2%	6/1%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe



In Hungary, the greatest potential has traditionally been found in HE projects, but the possibilities of DBHE and EGS projects should not be overlooked either. In the latter case, ORCs operating at lower temperatures ($T < 150\text{ }^{\circ}\text{C}$) offer significant potential. Such temperatures occur even at depths of 2.500 - 3.000 m in most of the Pannonian Basin, as well as in Mesozoic carbonates as bedrock.

The following average values can be used to calculate the heat production potential of wells: DBHE: 250 kW_{th}; HE: 1,5 MW_{th}, EGS: 3 MW_{th}. There was insufficient experience available to calculate the heat production potential of ATES and BTES. The electricity production potential is relevant in the case of HE and EGS. Based on experience to date with the Tura power plant and EGS, electricity production of 2,7 MW_e and 5 MW_e can be expected.

Assume that all suitable wells are indeed suitable and calculate ratios. In this case, the following maximum heat and electricity production values are obtained, on the basis of which the annual heat and electricity production can be calculated (Table 12). In the case of heat production, the heating period should be taken into account. In total, let's calculate a heating period of 1.500 hours. For electricity production, the hours where the price of the electricity produced exceeds 90 EUR/MWh are taken into account. In 2024, according to the historic data downloaded from the Hungarian Power Exchange (HPEX) portal, this was 4.257 hours.

Table 12: Potential annual heat/power production and energy in Hungary from wells suitable for repurposing

Pannonian Basin (Hungary)	DBHE	HE	EGS
Total of wells (absolute/percentage)	177/100%	177/100%	177/100%
Suitable	63/35,6%	45/25,4%	6/3,4%
Potential max. annual heat production	23,6 GWth	101,3 GWth	27 GWth
Potential max. annual electric production	-	172,4 GWe	127,7 GWe
Potential annual max. heat energy	0,085 PJ/y	0,365 PJ	0,097 PJ
Potential annual max. electric energy	-	0,621 PJ	0,460 PJ

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

However, since the ratios calculated in this way are derived from a database that has already been filtered by the Mining Property Utilization Nonprofit Public Ltd., they probably significantly overestimate the actual possibilities. It is advisable to project the number of wells deemed suitable onto the entire database of 624 wells and calculate the success rate in this way. A further assumption is that, in the case of HE and EGS projects, half of the projects can be implemented, taking into account various risks, like lack of well pair, reinjection problems, etc. This results in the following ratios for the 624 wells as shown in Table 13.



Table 13: Modified assessment of the 624 wells

Pannonian Basin (Hungary)	DBHE	HE	EGS
Total of wells (absolute/percentage)	624/100%	624/100%	624/100%
Suitable	63/10,1%	45/7,2%	6/1%
Reasonable	63/10,1 %	23/3,2%	3/0,5%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

There is a total of 8.354 hydrocarbon exploration and production wells deeper than 400 m. Assuming that these overlap with abandoned oil wells (2.258 wells), there is believe that this well number, as well as 6.096 wells, represents the total stock of geothermal wells that could potentially be converted.

The Upper Pannonian reservoirs should be considered as suitable only for heat production. Reservoirs older than the Upper Pannonian (Triassic and Jurassic limestones) are suitable for both heat and energy production. When selecting the pilot areas, a filtered database was used, which only included those wells from the 624 wells pre - qualified for which a portfolio had been created. From the portfolio of 62 wells, 50 wells and 62 aquifers were analysed in detail, taking into account the previous activities and assessments in this area, supplemented by the possibilities offered by the beta version of web - based IT tool, primarily in terms of the market.

A total of 27 reservoirs was excluded from further analysis based on various technical criteria. Of the remaining 35 reservoirs, 2 reservoirs remained promising for 4 wells, one of which had to be excluded to avoid overlap. The most suitable reservoir was considered for each of the 4 wells. Finally, 31 reservoirs were evaluated and recommended for 31 wells, taking into account the various technological feasibility options. Of the proposals, 1 was for ATES implementation, 6 for DBHE implementation, 1 for BTES implementation, 20 for HE implementation and 3 for EGS implementation. If the reservoirs that can only be used for agricultural purposes, as well as those that are clearly unsuitable due to lack of data or technical obstacles to implementation are excluded, then 0 ATES, 3 DBHE, 0 BTES, 12 HE and 3 EGS remain. Of the 12 potential HE, 8 would produce from the Upper Pannonian layers and 4 from Miocene and older formations (Cretaceous, Triassic). The latter 4 wells are located in Zala County, while the rest are in the Hungarian Great Plain. Of the wells suitable for DBHE, 2 are located in the Hungarian Great Plain and 1 in the Little Hungarian Plain. There are two potential EGS systems in the Hungarian Great Plain and 1 in Zala County. Based on this, one - third of HE - suitable wells could be implemented in carbonate reservoirs. This means that HE projects can be expected to generate 100% heat, but only 33,3% electricity. The following estimates are shown in Table 14.



Table 14: Estimation of hydrocarbon wells suitable for geothermal use and potential annual electric and heat production

Pannonian Basin (Hungary)	DBHE	HE	EGS
HC wells	6.096/100%	6.096/100%	6.096/100%
From them suitable for geothermal	616/10,1%	226/3,7%	30/0,5%
Already abandoned wells suitable for geothermal (reasonable)	63	23	3
Sum of suitable wells	679	249	33
Potential max. annual heat production	0,255 TW _{th}	0,560 TW _{th}	0,149 TW _{th}
Potential max. annual electric production	-	0,954 TW _e	0,702 TW _e
Potential annual max. heat production	0,917 PJ	2,017 PJ	0,535 PJ
Potential annual max. electric production	-	3,434 PJ	2,529 PJ

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

This would give a total annual heat production of 3,469 PJ/y and electricity production of 5,963 PJ/y. However, it is worth noting that in the case of EGS systems, the heat produced is practically unsaleable and in the case of HE systems with combined heat and power generation, heat consumption is also questionable in many cases. For comparison, Hungary's electricity production in 2023 and 2024 (preliminary data) is shown in Table 15. Annual heat consumption from district heating systems in 2022 is around 26 PJ.

Table 15: Hungary's electricity production in 2023 and 2024 (preliminary data)

Electricity	2023	2024
Production	35.516 GWh/y (127,9 PJ/y)	37,437 GWh/y (134,8 PJ/y)
Nuclear	45,6%	42,8%
Fossil (mainly gas)	28,8 %	26,2%
Renewable	25,5% (18,7% solar)	31,1% (24% solar)
Import	11.100 GWh/y (39,96 PJ/y)	10.729 GWh/y (38,62 PJ/y)

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

Based on the above calculations, it can be said that by converting hydrocarbon wells that are potentially suitable for this technology into geothermal wells, nearly half of Hungary's annual heating demand could be covered, taking into account current geothermal production (≈ 6 PJ/year), and 10% of electricity imports could also be replaceable.



In Hungary, nearly 400 abandoned hydrocarbon production and exploration wells have been converted and retrained for geothermal and water well purposes. Many municipalities, agricultural and industrial players use such wells, and more and more technological and combined technological solutions are emerging. The examples of Nagyatád and Szeged can be highlighted as good practices, although there are still tasks to be solved in both cases. In addition, Hungary has commitments related to EU climate targets for the 2030s, 2040s, and 2050s, some of which could be solved by converting hydrocarbon wells into geothermal wells, as shown in the above calculations. At the same time, drilling companies, most of which are behind geothermal projects, have a strong interest in preventing the conversion of used hydrocarbon wells into geothermal wells. Similarly, agricultural companies have an interest in this as long as they have a privileged role in terms of reinjection. The latter requires a change in the regulatory environment. In order to exploit the potential of geothermal energy, it would be advisable to introduce measures to support the reopening of shut - in or temporarily abandoned wells, which would facilitate the process (grant funding, risk reduction, but also more severe penalties for environmental pollution).

2.3.4.2. Quantification of land use

The CORINE Land Cover (CLC) of geothermally affected areas dataset was used to determine the distance between potential industrial, agricultural and municipal heat markets and existing wells in the database. The heat market is defined as the nearest boundary point from the wells. In addition, the boundaries of municipalities with a population of more than 5.000 people and other thematic maps are also given a prominent role. The category of agriculture has an annual energy consumption/demand of 3,9% (3,1 TWh) for heat or electricity.

The CORINE Land COVER nomenclature (CLC) was used to identify industries, covering the areas defined under CLC Urban fabric 121, which are defined under industrial or commercial units. Geothermal objectives played a primary role in the selection of areas, i.e., geothermal projects that can be implemented in connection with industrial areas. The industrial areas were defined as follows:

- 121: Buildings, other built - up structures and artificial surfaces (with concrete, asphalt, tarmacadam, or stabilised like e.g. beaten earth) occupy most of the area. It can also contain vegetation (most likely grass) or other non - sealed surfaces. This class is assigned for land units that are under industrial or commercial use or serve for public service facilities.

The category of industry has an annual energy consumption/demand of 24,2% (166,7 PJ) for heat or electricity. Figure 69 shows that significant industry is located in the vicinity of larger cities, and only some existing wells have potential to be used for this sector. At the same time, the construction of industrial parks is very significant in Hungary and larger companies (e.g. car factories, Lego factories, etc.) are constantly looking for the possibility of heating with geothermal energy.

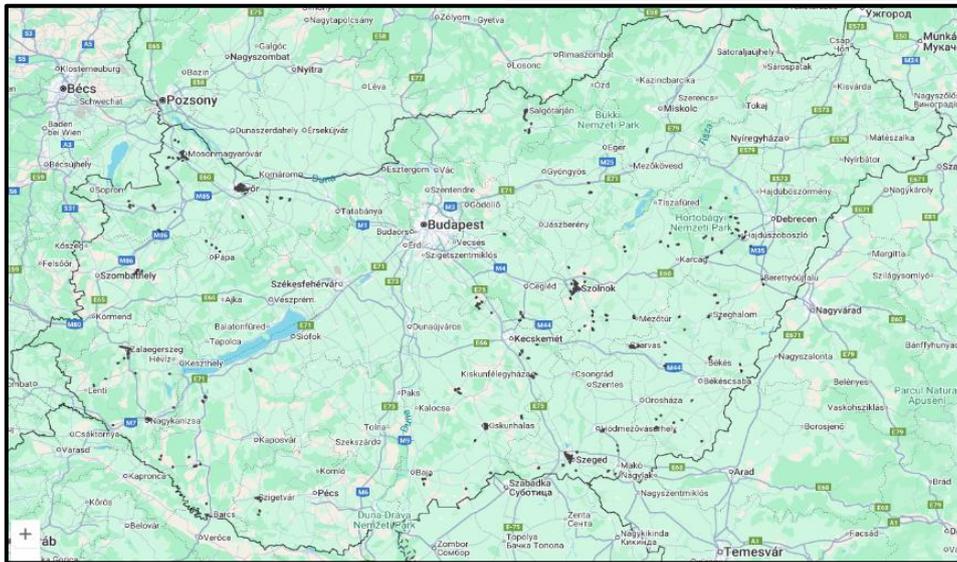


Figure 69: Industry areas in the Pannonian Basin in Hungary

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

The agricultural areas within 10 km of the wells are shown on the Figure 70. Based on the CLC, the following areas are affected from an agricultural perspective:

- 211: Cultivated land parcels under rainfed agricultural use for annually harvested non - permanent crops, normally under a crop rotation system, including fallow lands within such crop rotation. Fields with sporadic sprinkler - irrigation with non - permanent devices to support dominant rainfed cultivation are included.
- 212: Cultivated land parcels under agricultural use for arable crops that are permanently or periodically irrigated, using a permanent infrastructure (irrigation channels, drainage network and additional irrigation facilities). Most of these crops cannot be cultivated without artificial water supply. Does not include sporadically irrigated land.
- 221: Areas planted with vines, vineyard parcels covering > 50% and determining the land use of the area.
- 222: Cultivated parcels planted with fruit trees and shrubs, intended for fruit production, including nuts. The planting pattern can be by single or mixed fruit species, both in association with permanently grassy surfaces.
- 242: Mosaic of small cultivated land parcels with different cultivation types - annual crops, pasture and/or permanent crops, eventually with scattered houses or gardens.
- 243: Areas principally occupied by agriculture, interspersed with significant natural or semi-natural areas (including forests, shrubs, wetlands, water bodies, mineral outcrops) in a mosaic pattern.

In Hungary, there is no adequate information available regarding agricultural primary and secondary heat and electricity consumption. Overall, the combined energy and heat consumption of agriculture is 23,7 PJ, which is 3,4% of total consumption. In Hungary, the most significant agricultural use of geothermal energy is greenhouse vegetable production.

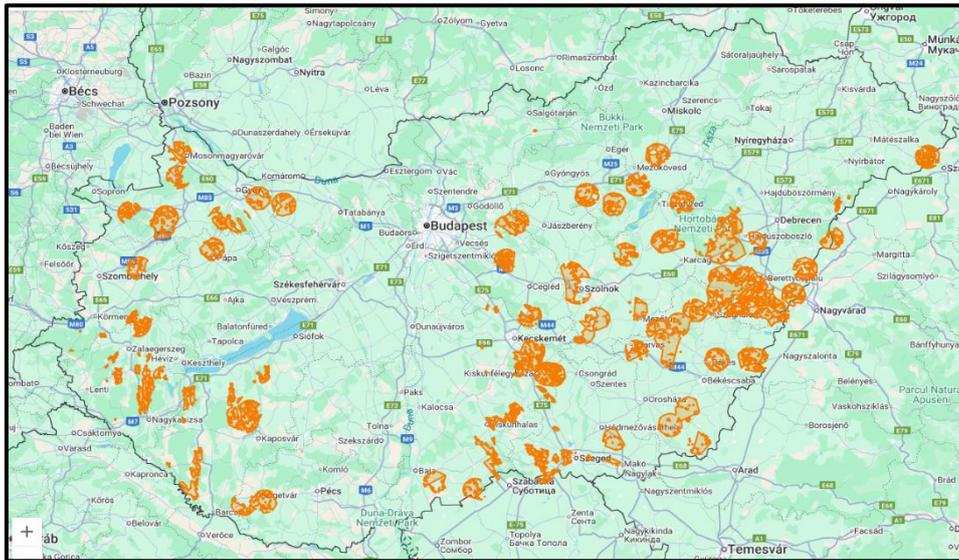


Figure 70: Agricultural areas in the Pannonian Basin in Hungary

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Finally, it is important to present the most important user layer, the population. The CORINE Land COVER nomenclature (CLC) was used to identify municipalities, covering the areas defined under CLC Artificial surfaces 111, 112 and 142, which are continuous urban fabric, discontinuous urban fabric and sport and leisure facilities, respectively. Geothermal objectives played a primary role in the selection of areas, i.e., geothermal projects that could be implemented in connection with municipal areas. Residential areas is a collective name for all areas belonging to municipalities. Population size is additional information regarding the scale of the project.

- 111: The continuous urban fabric class is assigned when urban structures and transport networks are dominating the surface area. > 80% of the land surface is covered by impermeable features like buildings, roads and artificially surfaced areas. Non - linear areas of vegetation and bare soil are exceptional.
- 112: The discontinuous urban fabric class is assigned when urban structures and transport networks associated with vegetated areas and bare surfaces are present and occupy significant surfaces in a discontinuous spatial pattern. The impermeable features like buildings, roads and artificially surfaced areas range from 30 to 80% land coverage.
- 142: This class is assigned for areas used for sports, leisure and recreation purposes. Camping grounds, sports grounds, leisure parks, golf courses, racecourses etc. belong to this class, as well as formal parks not surrounded by urban areas.

Due to their size, municipalities with more than 5.000 inhabitants play a key role in geothermal projects from an economic perspective. In settlements with more than 5.000 inhabitants, it is expected that more buildings and housing estates can be connected to a direct heating system or to an existing district heating system.

Figure 71 clearly shows that there are many small towns with a population of more than 5.000, mainly in the Hungarian Great Plain, which represent a potential market. The use of geothermal energy is particularly interesting in places where district heating systems already exist. Most of these do not currently use geothermal energy. In addition, the implementation of individual heating systems in small towns is also significant, where many public and private buildings can be connected to one system.

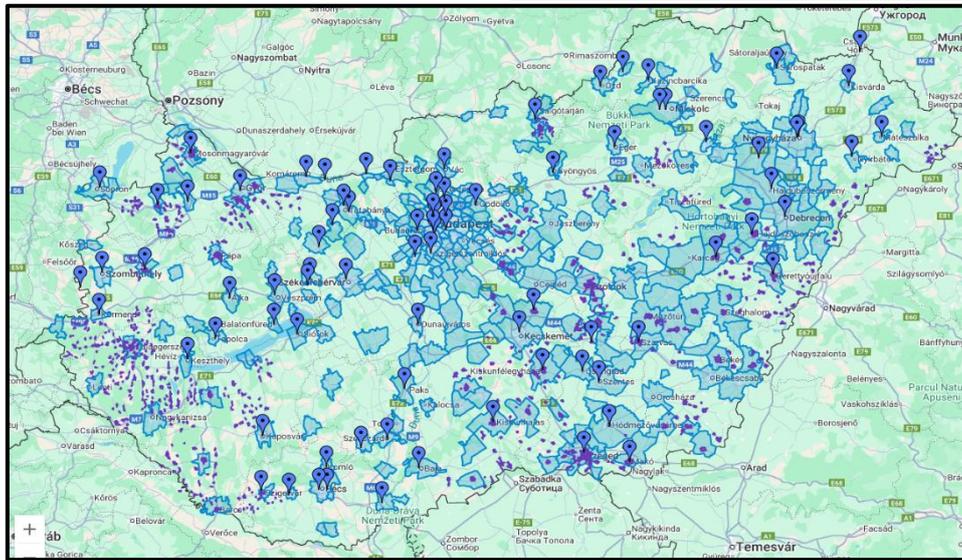


Figure 71: Residential areas in the Pannonian Basin in Hungary

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

2.3.5. Slovenia

In Slovenia, thermal waters are extracted from low - temperature geothermal systems, which are also referred to as hydrothermal systems or geothermal aquifers. In the northeastern part of Slovenia, high - yield intergranular regional sandy aquifers dominate within the Pannonian sedimentary basin. In these aquifers, temperature, as well as the content of dissolved minerals and gases in the water, increase fairly continuously with depth. Map of the contour of the Pannonian Basin with the Slovenian wells is shown in Figure 72 (Rman et al., 2019).

In the southeastern region, along the coast, and in other parts of Slovenia, fissured aquifers are tapped in the bedrock beneath sedimentary basins that cover these aquifers. Due to the varying fracture systems within the aquifer, the temperature and chemical composition of the water are highly variable with depth. Recharge of both types of aquifers is very limited, meaning that excessive water extraction can lead to a drop in the groundwater level and later even to the intrusion of gases or waters with different chemical compositions and temperatures (Rman et al., 2019).

In areas where fault zones intersect - mostly in carbonate rocks - geothermal systems with warm springs are common. Thermal water in these cases is only slightly more mineralized than regular groundwater and usually has a favourable temperature and chemical composition. Recharge is typically good, so changes in aquifer conditions are not observed as a drop in water level, but rather as a change in water temperature. In the Pannonian Basin, the most widespread and productive aquifers are intergranular aquifers located in sedimentary basins, which are mostly transboundary. These aquifers are accessed by 87% of all wells, which together provide approximately 70% of all extracted thermal water. One such example is the transboundary aquifer found in the poorly consolidated Pontian and Upper Pannonian sandstones of the Mura Formation in the Mura - Zala Basin, which is shared with Hungary and Croatia (Rman et al., 2019).

The highest temperatures in wells have been measured in the area of the Pannonian Basin in eastern Slovenia. There, a several hundred - meter - thick layer of poorly permeable strata prevents rapid infiltration of cold precipitation into the ground, while the elevated geothermal heat flow from the Earth - due to the relatively thin crust (only about 30 km thick) - can more effectively heat the very slowly flowing groundwater (Rman et al., 2019).

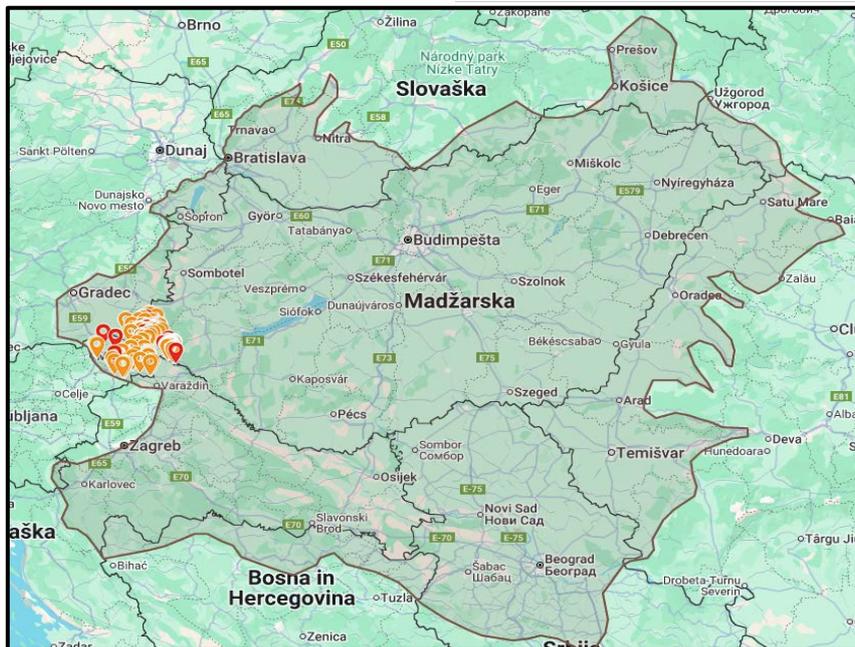


Figure 72: Map of the contour of the Pannonian basin with the Slovenian wells

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Aquifer Thermal Energy Storage (ATES)

This analysis evaluates the suitability of existing wells in the Slovenian Part of the Pannonian Basin for conversion to Aquifer Thermal Energy Storage (ATES), using the beta version of web - based IT tool. Figure 73 presents the spatial classification of the assessed wells, dividing them to wells with favourable subsurface conditions, indicating localised ATES potential. Also, it identifies locations with current limitations or missing data that must be addressed to confirm repurposing potential.



Figure 73: Map of the repurpose potential in the Pannonian Basin (Slovenia) for ATES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



Deep Borehole Heat Exchanger (DBHE)

This analysis evaluates the suitability of existing wells in the Slovenian Part of the Pannonian Basin for conversion to Deep Borehole Heat Exchanger (DBHE), using the beta version of web - based IT tool. Figure 74 shows clear clustering in areas with favourable subsurface conditions, indicating localized DBHE potential, as well as identifies wells where technical limitations or missing data currently prevent confirmation.

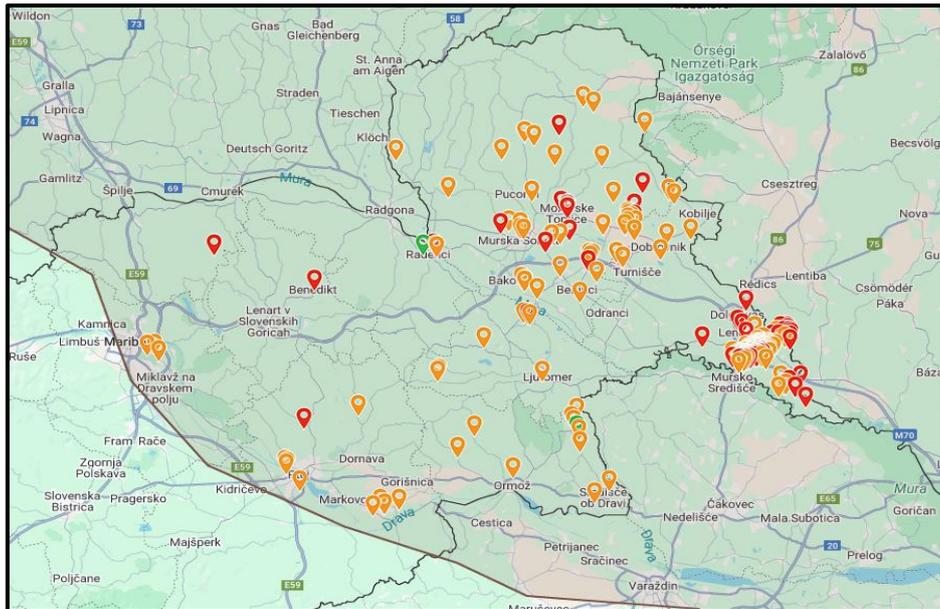


Figure 74: Map of the repurpose potential in the Pannonian Basin (Slovenia) for DBHE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Borehole Thermal Energy Storage (BTES)

This analysis evaluates the suitability of existing wells in the Slovenian Part of the Pannonian Basin for conversion to Borehole Thermal Energy Storage (BTES), using the beta version of web - based IT tool. Figure 75 presents the spatial classification of assessed wells and shows clear clustering in zones with favourable subsurface conditions, indicating localised BTES potential. It, also, identifies locations with current limitations or missing data that must be addressed to confirm repurposing potential.

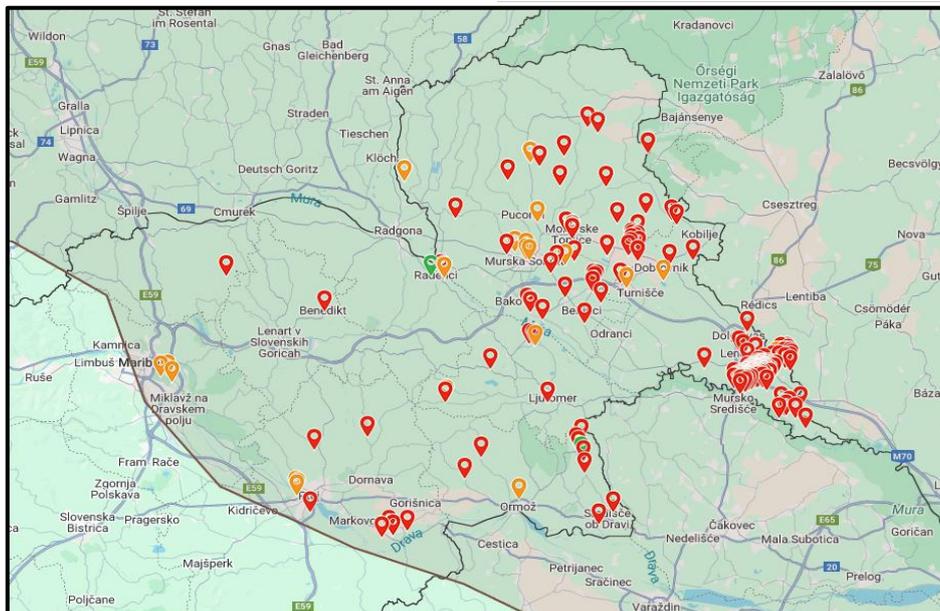


Figure 75: Map of the repurpose potential in the Pannonian Basin (Slovenia) for BTES

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Hydrothermal Energy (HE)

This analysis evaluates the suitability of existing wells in the Slovenian Part of the Pannonian Basin for conversion to Hydrothermal Energy (HE), using the beta version of web - based IT tool. Figure 76 presents the spatial classification of assessed wells and the fact that only wells with certain restrictions are available for HE technology. This indicates areas, where technical limitations or missing data currently hinder confirmation.

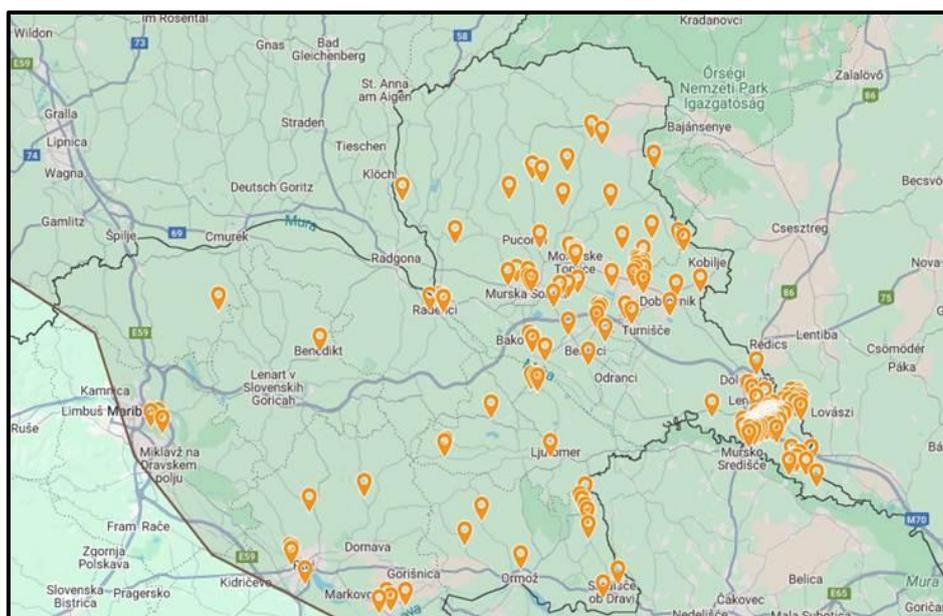


Figure 76: Map of the repurpose potential in the Pannonian Basin (Slovenia) for HE

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing



Enhanced Geothermal Systems (EGS)

This analysis evaluates the suitability of existing wells in the Slovenian Part of the Pannonian Basin for conversion to Enhanced Geothermal Systems (EGS), based on the beta version of web - based IT tool. Figure 77 presents the spatial distribution of assessed wells, as well as identifies locations where missing data or technical constraints currently limit repurposing.



Figure 77: Map of the repurpose potential in the Pannonian Basin (Slovenia) for EGS

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

Summary of the repurposing potential of the Pannonian Basin (Slovenia)

The assessment of the 244 wells across 5 geothermal technology options (ATES, DBHE, BTES, HE and EGS) shows considerable variation in suitability.

- **Storage/Exchanger technologies (ATES, DBHE, BTES):** Each of these has 2 wells classified as suitable, indicating only limited confirmed potential.
 - ATES: Most wells are not suitable (164), with 78 uncertain, suggesting that favourable hydrogeological conditions (aquifer availability, transmissivity) are rare.
 - DBHE: Shows a more optimistic balance, with 163 uncertain wells and only 79 not suitable, implying that borehole heat exchangers could be more widely deployable if further studies confirm feasibility.
 - BTES: Dominated by not suitable classifications (208 wells), leaving little potential beyond the two suitable sites.
- **Hydrothermal Energy (HE):** None of the wells are currently classified as suitable or unsuitable. Instead, all 244 wells are uncertain. This reflects a lack of sufficient subsurface data to confirm hydrothermal potential. It highlights the need for additional exploration (e.g., geophysical surveys, flow testing).
- **Enhanced Geothermal Systems (EGS):** The dataset indicates 0 suitable wells, with 171 not suitable and 73 uncertain. This suggests that the required geological conditions (sufficient depth, temperature, and fracturability) are generally absent or poorly characterized in this region.



Analytical summary of the 244 wells across 5 geothermal technology options (ATES, DBHE, BTES, HE and EGS) shows the considerable variation in suitability and is summarized in Table 16.

- **(Aquifer Thermal Energy Storage (ATES):** Only 0,8% of wells are suitable, with the majority not being suitable (67,2%). Around one - third (32%) are uncertain, indicating limited potential tied to the rarity of appropriate aquifers.
- **Deep Borehole Heat Exchanger (DBHE):** Like ATES, only 0,8% of the wells are suitable, but the dominant category is uncertain (66,8%). This suggests DBHE has the highest exploration potential, as many wells could still prove to be usable with further study.
- **Borehole Thermal Energy Storage (BTES):** Again 0,8% wells are suitable, but here 85,2% are not suitable, making this the least promising of the storage/exchanger technologies.
- **Hydrothermal Energy (HE):** No wells are confirmed suitable or unsuitable - 100% are uncertain. This reflects a major knowledge gap (insufficient subsurface data rather than demonstrated unsuitability).
- **Enhanced Geothermal Systems (EGS):** No suitable wells identified, with 70% not suitable and 30% uncertain. This confirms that geological conditions (high heat flow, suitable stress regime, permeability enhancement potential) are generally absent.

Table 16: Overview of the well assessment results in the Pannonian Basin (Slovenia)

Pannonian Basin (Slovenia)	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute / percentage)	244/100%	244/100%	244/100%	244/100%	244/100%
Suitable	2/0,8%	2/0,8%	2/0,8%	0/0,0%	0/0,0%
Uncertain	78/32%	163/67,2%	34/14%	244/100%	73/30%
Not suitable	164/67,2%	79/32%	208/85,2%	0/0,0%	171/70%

Source: Project TRANSCEO, D.2.2.1 Report on the transnational repurpose potential in Central Europe

2.3.5.1. Quantification of land use

The following section analyses target areas within the Slovenian part of the Pannonian Basin, focusing on the potential reuse of wells for industrial, agricultural or inhabited areas (Figure 78). Based on the search capabilities of the beta version of web - based IT tool, data and locations were filtered to identify zones potentially suitable for the reuse of abandoned wells, tailored to specific sectors. These sectors represented as industry, agriculture and municipalities were defined as the primary “customer” groups for heat energy supply and the repurpose potential of abandoned wells was assessed in relation to their proximity and relevance to these end users.

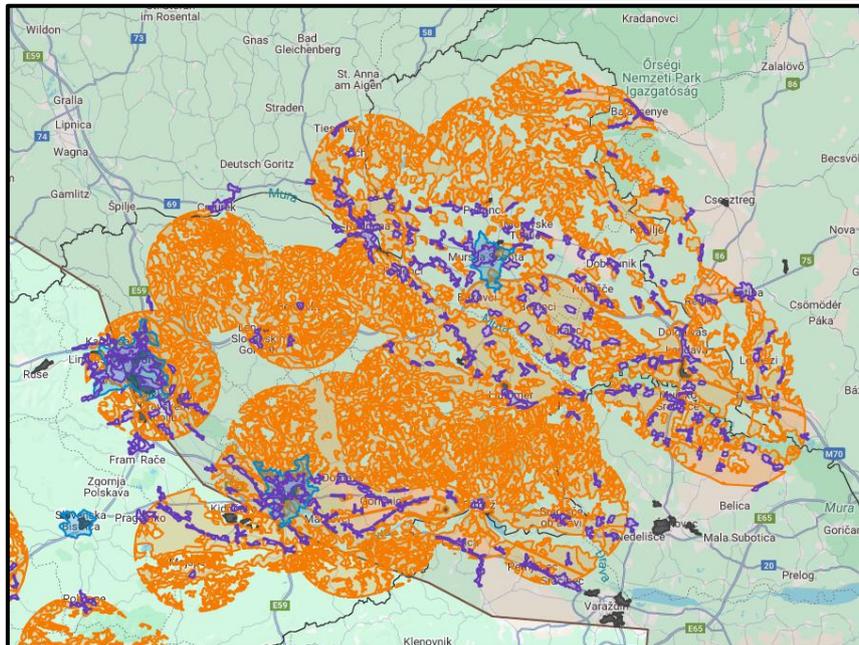


Figure 78: Land use areas in the Pannonian Basin (Slovenia)

Source: Project TRANSCEO, D.1.4.1 Beta version of web - based IT tool for well repurposing

The industrial sector in Slovenia has an annual energy consumption/demand of 27% (15 TWh) for heat or electricity. This includes the food and beverage, pulp and paper, chemical and petrochemical, and non - ferrous metals industries, as well as the machinery and transport industries. Industry areas in the Slovenian part of the Pannonian Basin are concentrated in the location of bigger inhabited areas (Figure 79).

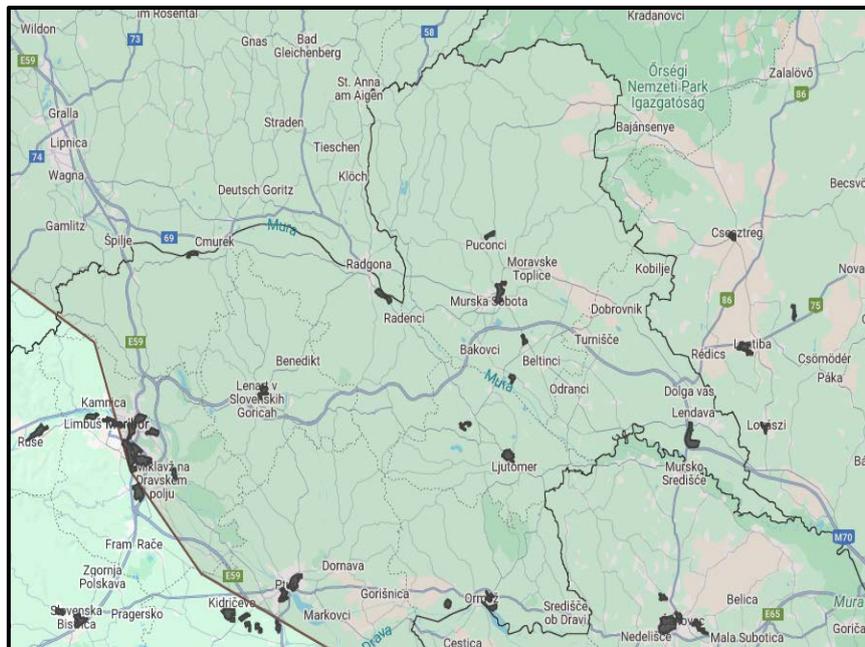


Figure 79: Industrial areas in the Pannonian Basin (Slovenia)

Source: Project TRANSCEO, D.1.2.1 Socio - economic analysis report of repurposing abandoned wells for industrial processes



The agricultural sector could benefit from the redevelopment of abandoned wells for the following reasons:

- The agricultural sector has the lowest heat demand compared to other sectors (industry and municipalities).
- The majority of hydrocarbon wells are located in rural agricultural areas. Therefore, reusing these wells could significantly support the agricultural sector's energy transition.
- Different agricultural applications (e.g. greenhouses for various crops, wood drying and fish farming) require different amounts of energy and temperatures.

The most preferable method for agricultural use is Deep Borehole Heat Exchanger (DBHE) followed by Borehole Temperature Storage (BTES) and Hydrothermal Energy (HE).

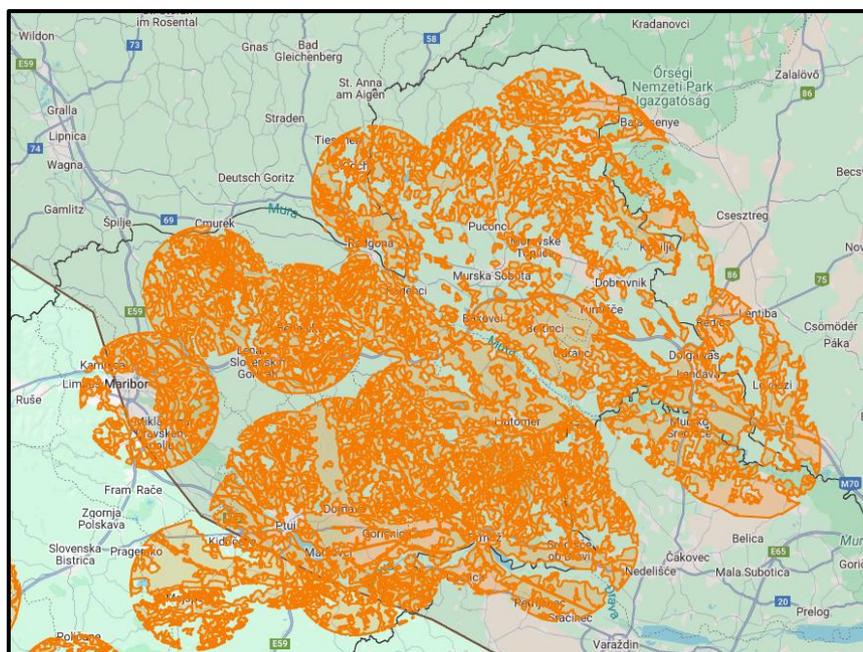


Figure 80: Agricultural areas in the Pannonian Basin (Slovenia)

Source: Project TRANSCEO, D.1.2.2 Socio - economic analysis report of repurposing abandoned wells for agricultural use

Finally, the following applications in the municipal sector for heat supply from repurposing natural gas and oil wells are recognized: communities using district heating systems, small residential communities, and balneology and spa centres. The residential areas are spread and there are 3 areas populated with more than 5.000 inhabitants (Murska Sobota, Ptuj and Maribor). Near those areas only few hydrocarbon wells have been drilled. The rest of the investigated area has more or less evenly distributed residential areas where DBHE, BTES or HE applications are suitable.

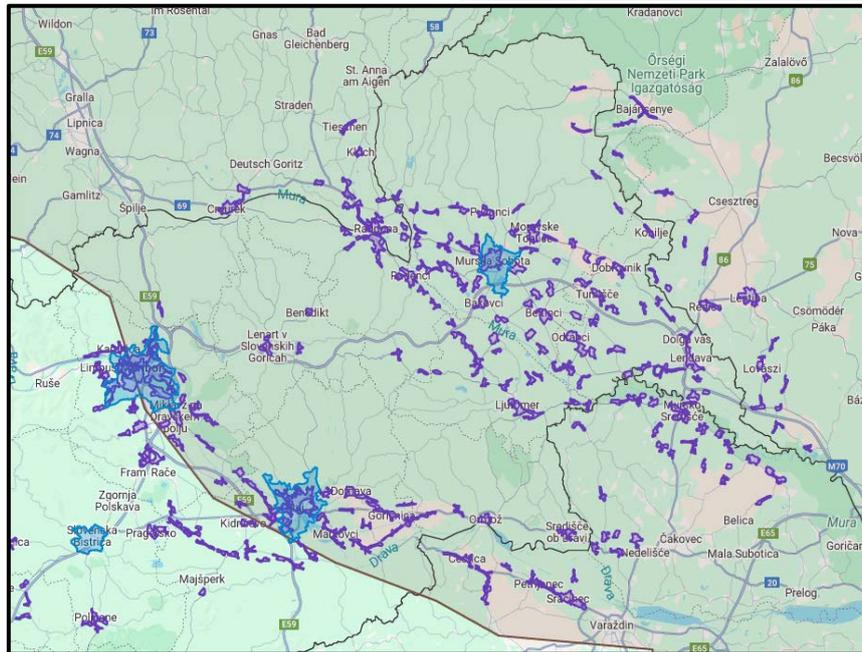


Figure 81: Residential areas in the Pannonian Basin (Slovenia)

Source: Project TRANSCEO, D.1.2.3 Socio - economic analysis report of repurposing abandoned wells for municipalities

Apart from the described features, geothermal energy and, especially, its utilisation from abandoned wells has high impact on the environment. Exploration and exploitation of the mentioned energy source leave footprints on environmental components such as soil, land, underground waters, air, biodiversity, and even, the surrounding settlements. Therefore, the next Chapter examines the positive and negative effects of geothermal energy utilisation, with special focus on repurposing abandoned hydrocarbon wells into geothermal ones.



3. Environmental impact of geothermal energy use and well repurposing

Application of any energy technology has an environmental impact that should be considered as a part of project development. While the risk can never be reduced to zero, reusing existing wells almost always has lower environmental impacts and thus significant advantages over drilling new wells, due to reduced drilling operations, land clearance and use, greenhouse gas (GHG) emissions and other aspects, as detailed below. Specific environmental challenges are related to potential integrity problems of old borehole infrastructure and equipment, geological conditions and the actual repurposing technology applied and its associated operational considerations. However, when compared with hydrocarbon production and high - enthalpy geothermal systems, the environmental impact of repurposing old wells with the low - enthalpy geothermal systems present in Central Europe is relatively small. Most risks can be reduced or even eliminated through proper testing and logging before use, repair as needed and monitoring through the life of the project.

3.1. Environmental impacts of deep geothermal energy use and mitigation strategies

Below is a list of potential environmental impacts, accompanied by their related mitigation strategies, of geothermal energy production and storage in low - enthalpy geothermal systems (Hunt, 2001; Dhar et al., 2020; Soltani, 2021; Nkinyam, 2025). These potential risks are addressed and regulated by legislation in most countries and are not specific to well repurposing, but to geothermal development in general.

- **Land use and ecosystem impacts due to land clearance and infrastructure required for drill site access and preparation**
 - Directional drilling of multiple wells from one well pad can be used to minimise land use and surface/habitat disturbance during drilling or retrofit operations. Careful planning, including restoring any impacted areas after construction and implementing biodiversity offsets, where appropriate, can be used to minimise and mitigate this impact.
- **Surface disturbances such as noise and bright lights during drilling/workover operations**
 - Noise disturbance can be reduced through the use of electric drilling motors, noise protection walls, site vegetation, water cooling, muffling, constraining loud operations to daytime and proper pipe handling.
 - Light pollution can be reduced via temporary screens and careful placement of lamps on the site, as well as avoiding night - time operation.
- **Groundwater contamination by drilling mud, pathways between aquifers, improper borehole cementation and handling of fluids at surface**
 - Groundwater contamination is negligible if proper drilling, casing and cementing are performed, the drill site at the surface is properly contained and if spills on the surface are prevented or cleaned up promptly and completely. Casing and cementing should be done immediately after finishing a drill section and the driller must adhere to regulations on composition of the drilling mud and closing of drill sections.
- **Water for drilling may be taken from nearby surface or groundwater bodies, potentially disturbing the local ecology**
 - To avoid local ecological disturbance, availability of sufficient water must be confirmed. If there is insufficient water, or if removal of water will cause disturbance beyond a threshold of acceptability, water must be delivered to the site for drilling operations. Care must be taken



to control spills and minimize the impact of transport vehicles. Overall, water consumption can be minimized.

- **Induced seismicity, surface subsidence or uplift due to injection or production - induced alteration of the effective stresses in the subsurface, related compaction/expansion of rock formations, and/or fault slip**
 - Induced seismicity and subsidence can be minimised or avoided by reinjecting produced fluid to maintain a mass balance in the reservoir, targeting reservoirs far away from seismogenic faults, monitoring induced seismicity and halting operation if ground movements exceed a pre - defined threshold. Traffic - light and early warning systems can be designed in advance and used to assess seismic impact in real time and guide responsive action. Uplift due to swelling rock can be mitigated by sealing off respective geological sections to avoid water influx.
- **Temperature changes of shallow groundwater and related biological and chemical alterations in the vicinity of a well, due to the production of high - temperature fluids from depth or directly due to heat storage in a groundwater aquifer**
 - To avoid heating the subsurface and impacting the surrounding ecosystems, the well should be isolated from intersecting groundwater bodies, e.g., by multiple cemented casings and insulating materials, and heat should be isolated from the local environment.
 - Heat storage in shallow aquifers is tightly regulated by maximum temperatures and storage capacities, both of which are designed into the system and depend on the local conditions. To avoid impact on public use of drinking water supplies, heat is not stored in drinking water aquifers.
- **Effects on waterways and living organisms due to surface disposal of produced geothermal fluid, if not reinjected into the subsurface**
 - By allowing the produced water to cool before pumping it into a surface water body, or, alternatively, by not allowing surface disposal of produced water with high or problematic chemical content, impacts of highly saline geothermal fluids on fish, plants, or other surface life can be minimized or eliminated.
- **Accumulation and/or release of natural radionuclides, natural gases such as methane (CH₄), carbon dioxide (CO₂), or hydrogen sulfide (H₂S), or other components of highly saline geothermal fluids**
 - Re - injection of produced water isolates the materials from the surface environment. Avoiding scaling and precipitation by adapting the pressure and temperature conditions in the system and/or using scaling inhibitors and/or suitable materials reduces the risk of forming radioactive scales.
 - If re - injection of the gas is not possible, it may be separated and burned on - site for an additional source of heat, or they can be collected for another use.

3.2. Environmental challenges of well repurposing

Well repurposing almost always presents reduced environmental impacts when compared with drilling new wells, and usually can completely avoid the impacts resulting directly from drilling operations. However, the following specific challenges of repurposing old wells, compared to drilling new ones are seen:

- **Well integrity:** Old wells may have degraded casings, cement, and other components, leading to structural weaknesses which make them susceptible to leaks under high pressure or temperature variations during geothermal operations. A well with compromised integrity can allow geothermal fluids, oil, or gas to migrate into surrounding formations, freshwater aquifers, or to the surface, potentially leading to contamination if not properly sealed.



- **Inadequate design:** Existing wellheads, surface infrastructure, and well completions may not have been designed for high temperatures, high pressures, or highly corrosive geothermal fluids and may require significant upgrades and workover to prevent potential environmental impacts.
- **Regulatory and monitoring gaps:** Old wells may have incomplete documentation, making it difficult to assess their suitability for reuse. Adapting old wells to geothermal use may fall into regulatory grey areas, complicating oversight and enforcement of environmental protections.
- **Legacy pollution:** Historical hydrocarbon production could leave behind contaminations from earlier operations. In some cases, boreholes have been used as waste disposal sites and thus cannot be repurposed.
- **Legacy emissions:** Old wells with integrity problems may emit residual hydrocarbons such as methane, contributing to greenhouse gas (GHG) emissions.
- **Induced seismicity and subsidence:** Legacy hydrocarbon extraction may have altered the geological stress field, e.g., by significant reservoir pressure reduction, increasing the susceptibility of faults to slip and the surface to subside. Such sites may be suitable for geothermal reinjection wells.

3.3. Environmental advantages of well repurposing

In almost all cases, well reuse has a smaller environmental impact than drilling a new well. Specific advantages of reusing old wells compared to drilling new wells are:

- **Reduced land use, impact on the ecosystem and surface disturbances:** Land use and impact on the ecosystem are reduced by well reuse as no new land needs to be cleared to build a new drill site, and associated workover operations are typically shorter in duration and often require smaller machinery, less noise and less traffic compared to drilling a new well.
- **Less waste generation:** New wells produce waste such as drill cuttings, muds and fluids. Reusing old wells reduces or eliminates the generation of such waste streams.
- **Reduced use of material and energy:** Reusing an existing well requires less casing and cement, and associated energy consumption, as the main casing sections are already in place.
- **Reduced number of wells:** Reuse of wells reduces the total number of wells drilled. Thus, fewer wells are penetrating multiple groundwater bodies, which reduces the risk of mixing/leakage. Reduction of the number of wells preserves subsurface integrity by avoiding “over - drilling” in a certain area. In addition, fewer wells will need to be abandoned, reducing use of financial and material resources and potential leakage pathways.
- **Reduced risk of contamination:** By using existing wells and production facilities, when they are available, there is a reduced risk of spills or leaks associated with constructing new storage tanks, pipelines, or wells. Additionally, well integrity is regularly and proactively monitored and maintained in an actively used well, also reducing contamination risk.
- **Reduced greenhouse gas (GHG) emissions:** Drilling new wells requires substantial energy, from equipment operation to material transport. Reusing old wells eliminates much of this energy demand and it also reduces land clearance, resulting in fewer associated greenhouse gas (GHG) emissions.



3.4. Strategies to reduce environmental impacts

To mitigate environmental impacts, certain strategies should be considered. These strategies ensure that old wells can be effectively and sustainably converted for geothermal use, while minimizing environmental harm. For repurposing an old well, the following are specifically relevant:

- **Well integrity assessment:** At the beginning of the project, conduct a comprehensive well integrity assessment to evaluate the condition of the well. This typically includes multi - finger caliper logs, cement bond logs and pressure tests of different sections of the casing. Additionally, casing thickness logs and borehole imager logs may be added to investigate the status of a well.
- **Retrofitting and repairs:** Implement cementing and sealing technologies to mitigate leakage, and retrofit or replace aging infrastructure to properly handle the expected geothermal fluid properties, temperatures and pressures.
- **Choose and adapt a suitable technology:** There are varied options for geothermal energy development. Thus, it is important to apply the optimal design (e.g., sealing off a certain well section if it has a well integrity problem) and technology (e.g., closed vs. open system) for the specific location and use case specifically considering well integrity.

In addition, the actions below are relevant for all geothermal development, including well reuse:

- **Environmental impact assessment:** Carry out a detailed environmental impact assessment for a planned geothermal project, to ensure that all site - specific environmental risks and impacts are identified and assessed before a decision is made to permit the proposed project (Figure 82). Projects should be designed to minimise the environmental impact from the beginning, via the use of tailored mitigation strategies.
- **Monitoring:** Establish robust environmental monitoring systems, e.g., to detect contamination, emissions, seismicity and surface movements. Monitoring is required to obtain data that informs rational resource management decisions by developers and regulatory authorities, verifies that management decisions are having the desired outcomes, gives the public confidence in the environmental management process, and increases knowledge of geothermal systems and how to develop them in an environmentally responsible way. Contingency plans should be developed for accidental spills, leaks, or other environmental incidents, to ensure regulatory compliance. Measurements should start well before geothermal operations begin, so that a good baseline dataset is available. Measurements should extend outside the geothermal field to have control points away from the engineering works and should contain a sufficient number of locations to ensure that the loss of some measurement points does not harm the monitoring programme. Use trained staff and document the data adequately to acquire high quality data and analysis. Data analysis procedures can be improved by automatic processes, which should be accompanied by manual oversight and (re-) interpretation.
- **Regulatory frameworks:** Adhere to stringent local, national, and international geothermal and environmental regulatory frameworks. Typically, an environmental impact assessment is requested and monitoring and other requirements to prevent environmental degradation are set by authorities within the granted concession, and authorities must confirm that the monitoring program is carried out when required and as specified. Granting of permits can be subject to restrictions, often defined via the environmental impact assessment. Monitoring data should be periodically reviewed, and permits should have appropriate lifetimes so that they must be periodically renewed. Typically, at least mining and water authorities are involved in these procedures.
- **Mitigation measures:** Environmental risk mitigation measures, as described above, are essential for all geothermal projects. Reuse of older wells requires a particular focus on using corrosion - resistant



materials, inhibitors, and other methods to manage chemical interactions, minimize scaling and prevent leaks.

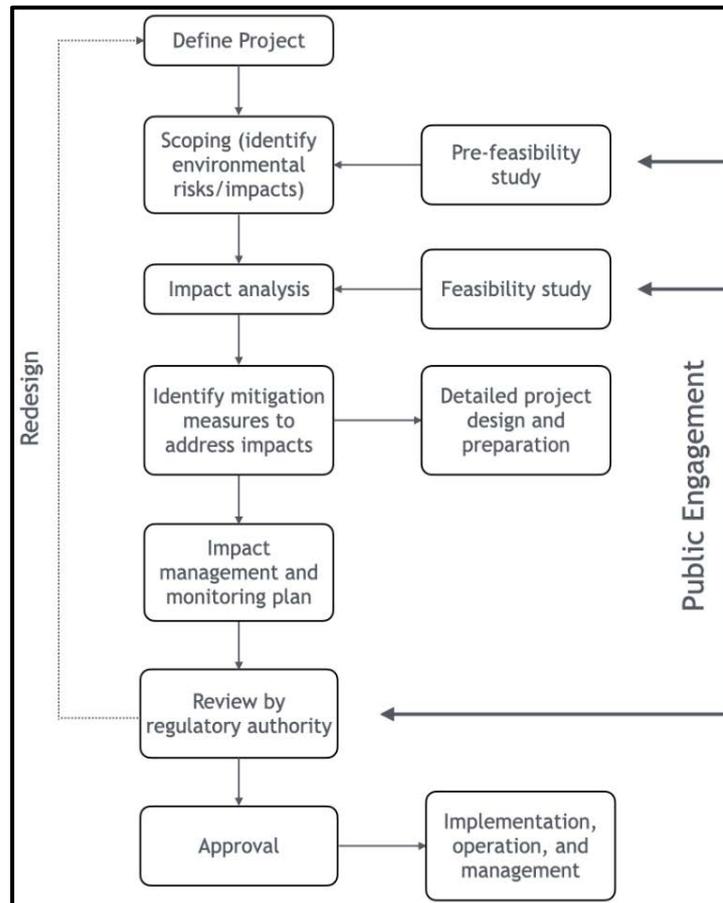


Figure 82: Environmental impact assessment of a geothermal project

Source: adaptation from Dougherty and Hall, 1995; Kusum, 2017

Public engagement may take place at any stage, but it typically occurs at the Scoping, Feasibility, and Review stages, to receive feedback and input from the community, experts and decision makers.

3.5. Environmental considerations for geothermal technologies

Specific environmental considerations are required for application of various geothermal technologies:

- **Deep Borehole Heat Exchangers (DBHEs) and Borehole Thermal Energy Storage (BTES):** These wells have the least environmental impact, since the working fluid is not in direct contact with the rock mass and reservoir fluid. However, significantly more wells are needed to extract the same amount of energy as in open systems, meaning more wells penetrate geological barriers and increase the likelihood of environmental impacts, thus high well integrity is especially important in closed systems.
- **Hydrothermal Energy production (HE):** Such projects may cause any of the environmental impacts described above. Reinjection of the produced water is the most important mitigation measure, to isolate it from the surface and avoid potential contamination of waterways, and also to avoid ground subsidence through maintenance of the material balance in the reservoir. Reinjection can be difficult in some geological settings, so care must be taken to ensure reinjection is possible and



sustainable for the long term. The large number of successful projects over many years has resulted in long - term experience and engineering, as well as regulatory procedures and boundary conditions that limit these impacts. As a result, environmental impacts are comparatively small and manageable in Hydrothermal Energy (HE) systems.

- **Aquifer Thermal Energy Storage (ATES):** These systems are typically relatively shallow and thus present a higher risk for shallow groundwater aquifers than deeper systems. System design and operation should focus on minimising the impact on shallow groundwater, especially near drinking water supplies.
- **Enhanced Geothermal Systems (EGS):** Potentially the deepest geothermal systems, usually several km in depth. Only a few exist worldwide, as the technology is still in research and development and hydraulic stimulation treatments are required to develop the subsurface heat exchanger and fluid flow paths. As a result, the environmental impact of these systems is potentially the largest, with particular emphasis on the risk of induced seismicity and the type of stimulation fluid used. However, decades of research and development have demonstrated that associated environmental impacts can be minimised.

While the environmental impacts of repurposing hydrocarbon wells for geothermal energy are relatively manageable compared to drilling new wells, they require proactive measures to mitigate risks and reduce potential impacts. Effective monitoring, adherence to best practices and innovative technologies will ensure that the transition to geothermal energy is both sustainable and environmentally friendly.



4. Financing

During the implementation of well repurposing investments, one of the most challenging activities is the search and selection of an adequate financial program, call, tender or source in general, which can provide sufficient funding for the realization of the planned activities. The 5 countries of the consortium offer different transnational (EU), national, regional and, in some cases, local financing opportunities in the forms of traditional, alternative or innovative instruments, which support the implementation of geothermal and well repurposing investments. Thereby, these financial instruments cover a variety of activities such as mapping and establishing databases, adaptations of old hydrocarbon wells, connections to district heating systems, as well as drilling of new wells and fostering further investments based on geothermal energy use through well repurposing. In order to present the currently available financing opportunities, the following Subchapters give a summary of the current situations in Austria, Croatia, Germany, Hungary and Slovenia.

4.1. Financing opportunities for geothermal and well repurposing investments

In the 5 countries of the consortium there are different possibilities to financially support geothermal investments, whereby this Subchapter filters out the most important ones which are accessible on the transnational (EU), national, regional or local level. Support for geothermal energy varies among the countries presented, where some provide domestic funding for geothermal investments, but most of them support their geothermal projects with European Union funding. Mainly, there are traditional financing options and innovative ones which can be used, but programs specifically aimed at the repurposing of abandoned hydrocarbon wells are still limited or indirectly accessible. Also, in several countries, projects aimed at repurposing abandoned hydrocarbon wells are being implemented with the involvement of the private sector capital, as one of the most significant funding sources. To give more insights into the financing opportunities in the 5 countries of the consortium, the lists below cover the most available and used ones for geothermal and well repurposing investments. Thereby, for all countries the most significant financing instruments are presented in more detail.

AUSTRIA

Deep geothermal energy continues to have a great potential in Austria and could play a significant role in the energy system of the future. According to the Federal Ministry for Climate Protection, as well as the Climate and Energy Fund, the currently known and technically exploitable potential of deep geothermal energy in Austria could be as high as 1.000 MW of thermal power. In light of this, it is not surprising that projects aimed at utilising geothermal energy are supported in Austria through a combination of transnational (EU) and national funding.

Traditional financing opportunities

- **National funding programs:** Austria explicitly includes well reuse in its national funding programs, making it one of the few countries with dedicated support for such projects. This funding can be crucial for projects that aim to repurpose abandoned wells for geothermal energy.
- **Green financing instruments:** Austria has a robust green financing framework, including green bonds, loans and deposits. These instruments are designed to support environmentally friendly projects, which could include well reuse initiatives if they align with green criteria.



Innovative financing opportunities

- **Transnational (EU) funding programs:** Austria can access EU funding programs like Horizon Europe and the European Structural and Investment Fund (ESIF), which can support innovative geothermal energy projects and well reuse initiatives.
- **Green bonds and loans:** Austria's green bond framework is aligned with international standards, and the country has successfully issued green bonds to finance green expenditures, including renewable energy projects. This could be an innovative way to finance well reuse projects if they meet the green criteria.
- **Private sector capital:** Encouraging private sector investments through green financing instruments can provide additional innovative financing options for well reuse projects. Austria's strong green financing market makes it attractive for private investors interested in sustainable projects.

Apart from the mentioned, some of the most used financing instruments are the following:

UFI - Umweltförderung im Inland

UFI is Austria's most important national environmental support program, operated by the Bundesministerium für Klimaschutz (BMK) and administered by Kommunalkredit Public Consulting (KPC). The program has an annual budget of approximately 80.000.000 EUR for general environmental protection purposes. For geothermal district heating systems and geothermal energy production facilities, the subsidy rate is 30% of environmental costs, up to a maximum of 2 million EUR for deep geothermal projects. This form of aid is non - repayable, available on a continuous basis, and has no application deadline.

Klima- und Energiefonds- Tiefengeothermie Program

This national climate protection fund operates within the framework of the Climate and Energy Fund with a budget of 10.000.000 EUR, specifically targeting the preparation of deep geothermal projects and the reduction of drilling risks. The program consists of five modules, ranging from basic preliminary studies to pilot drilling. The first module supports basic preliminary studies with a maximum of 20.000 EUR with a subsidy rate of 50 - 70%, 50% for competitors and 70% for non - competitors (local authorities, etc.). The second module finances feasibility studies with a maximum of 100.000 EUR with a 50% subsidy rate. The third module supports exploration and exploratory research with a maximum of 1.000.000 EUR, with a 30% subsidy rate, including exploratory drilling. The fourth module supports pilot drilling with a maximum of 3.000.000 EUR, with a 30% subsidy rate, on the important condition that the subsidy does not have to be repaid if the project is not implemented. The fifth module supports citizen participation and information events. The program is applicable to projects deeper than 300 m, with a minimum thermal capacity of 1 MW, for district heating and cooling, renewable electricity generation, and the use of deep geothermal energy in industrial processes.

Raus aus Öl und Gas Program

This national heating replacement program is financed by the NextGenerationEU recovery fund with a total budget of 550.000.000 EUR, of which 158.900.000 EUR is contributed by the EU. The program aims to support the transition from fossil fuels (coal, natural gas, oil) to sustainable heating systems, including heat pumps (ground source, air source), geothermal heating systems, connection to district heating and biomass boilers. Co - financing can be up to 75%, with a maximum of 11.000 EUR in federal support and 3.000 - 8.000 EUR in provincial support. Although this program is not directly aimed at repurposing abandoned hydrocarbon wells, but primarily at supporting residential heating replacement projects, it also finances the installation of geothermal heat pump systems.

FFG Energieforschung Ausschreibung 2025

The Federal Ministry for Innovation, Mobility and Infrastructure (BMIMI) and the Climate and Energy Fund have set themselves the goal of jointly developing a broad spectrum of solutions for green transformation,



therefore they have been launching a 17.000.000 EUR funding call for climate friendly technologies “Made in Austria”. The call for proposals is aimed at innovative companies and research institutions that are implementing projects in the following areas:

- Energy generation and storage technologies
- Hydrogen, renewable gases and carbon capture, utilisation and storage,
- System design and operation of flexible, integrated energy systems
- Digital transformation of the energy transition
- Efficient energy use, including conversion
- Social transformation
- System analyses - R&D services.

„Sauber Heizen für Alle 2025” Program

The Federal Ministry of Agriculture, Forestry, Climate Protection, Environment, Regional Affairs, and Water Management (BMLUK) will continue to support low - income households in switching from fossil fuel heating to sustainable, climate - friendly heating systems. The “Clean Heating for All” funding program is financed by the federal government and implemented in cooperation with the provinces. This support, which is available exclusively to private individuals, is primarily intended for the replacement of fossil fuel heating systems (natural gas, oil, coal/coke multi - fuel and electric - powered night storage or direct heat storage heaters) with new, climate - friendly heating systems.

Wien Energie & OMV joint venture (deep)

The joint venture between Wien Energie and OMV uses a mixed financing model dominated by private investment. Wien Energie holds a 51% stake in the project, while OMV holds 49%. The total investment amounts to approximately 90.000.000 EUR, of which approximately 15.000.000 - 20.000.000 EUR is public funding. The sources of financing include approximately 9.300.000 EUR in support from the UFI (Betriebliche Umweltförderung) for a high - performance heat pump, an additional 8.000.000 EUR in support from the BMK, support from the Climate and Energy Fund, and support from the European Investment Bank (EIB). Although the program does not involve repurposing abandoned hydrocarbon wells, but rather new drilling, it serves as an important model for cooperation between the private sector and public funding in the field of geothermal energy production.

CROATIA

The Croatian part of the Pannonian Basin is exceptionally favorable for geothermal water exploration and extraction, as the average geothermal gradient is 60% higher than the European average. According to the National Energy and Climate Plan, 68 MW of geothermal capacity is planned to be achieved by 2030 and 405 MW by 2050. This would mean that by 2050, more than 30% of the country’s electricity needs could be covered by geothermal and nuclear sources combined. Croatian geothermal and well repurposing investments are, also, funded through a combination of transnational (EU) and national funding, whereby they are divided into traditional and innovative ones.

Traditional financing opportunities

- **Public support schemes:** Croatia relies heavily on public funding sources for energy - related projects. The Croatian Bank for Reconstruction and Development (HBOR) offers preferential loans and guarantees for energy efficiency improvements, which could indirectly support well reuse projects if they align with broader energy efficiency goals.



- **Transnational (EU) funding programs:** Croatia can access EU funding programs like Horizon Europe and the European Structural and Investment Fund (ESIF), which can support geothermal energy projects and well reuse initiatives.

Innovative financing opportunities

- **Green financing instruments:** Croatia has a growing green financing market, with institutions like HBOR providing green loans. These instruments could be leveraged for innovative projects involving well reuse if they meet green criteria.
- **Private sector capital:** Encouraging private sector investments through green financing instruments can provide additional innovative financing options for well reuse projects. Also, The European Bank for Reconstruction and Development (EBRD) can provide further support to private investors in Croatia, which could be beneficial for well reuse initiatives.
- **Energy Service Companies (ESCOs) and Public - Private Partnerships (PPPs):** These models can facilitate financing for energy - related projects by sharing risks and costs between public and private entities. While not specifically targeted at well reuse, they could be adapted for such projects.
- **Citizen - led initiatives:** Energy cooperatives and communities in Croatia can also play a role in financing local energy projects, potentially including well reuse initiatives if they align with community goals.

Further details about the frequently used financing mechanisms are provided as stated:

CBRD (HBOR) - Energy Efficiency Loans for Entrepreneurs

The national bank loan program, jointly operated by the Croatian Bank for Reconstruction and Development (HBOR) and the Ministry of Regional Development and EU Funds, has a total budget of 250.000.000 EUR. Of this, 150.000.000 EUR comes from the European Regional Development Fund (ERDF), while 125.000.000 EUR is provided by commercial banks. The program offers low - interest loans with partial capital repayment options to entrepreneurs planning energy efficiency investments and renewable energy installations. Although the program is not specifically aimed at repurposing abandoned hydrocarbon wells, it can also be applied to geothermal renewable energy investments.

EPEEF (FZOEU) - Environmental Protection and Energy Efficiency Fund

The national environmental fund operates with a variable budget, which includes, for example, 120.000.000 EUR for energy renovation of family homes. The FZOEU provides non - repayable grants and interest - free loans for environmental and energy efficiency purposes. The program is available on an ongoing basis and, while not directly focused on repurposing abandoned hydrocarbon wells, supports a wide range of renewable energy and energy efficiency projects. In September 2023, FZOEU signed a cooperation agreement with the Croatian Hydrocarbon Agency (CHA) to promote the use of geothermal energy.

NRRP - Exploring geothermal potential in 6 cities

Under the National Recovery and Resilience Plan (NRRP), the EU Recovery Plan project has a budget of 50.000.000 EUR, which is provided entirely as non - repayable aid (100% aid intensity). The project aims to explore the geothermal potential of 6 Croatian urban areas: Velika Gorica, Osijek, Vinkovci, Vukovar, Sisak and Zaprešić. The project is being implemented by CHA and will finance the drilling of 4 new wells. The idea is to reduce a significant investment needed in the early stage of the project and geological risk by drilling new geothermal wells, conducting environmental impact assessments, collecting new geophysical data, preparing geological and geophysical studies and ensuring spatial planning status.



EEA and Norway Grants - Increased Geothermal Energy Production Capacity

New cooperation agreements between Croatia and 3 donor nations (Iceland, Liechtenstein and Norway) were signed in September 2025. The donor countries have committed more than 133.100.000 EUR to Croatia via the EEA and Norway Grants. This cooperation spans from fostering green transition, investments in local development, green and blue business innovation, as well as strengthening justice and rule of law. Croatia is set to participate in 4 collaborative programs through EEA and Norway Grants:

- The environmental transition program aims to speed up the shift towards a more sustainable society. This initiative will focus on enhancing energy security and developing institutional capabilities, with special emphasis on underdeveloped areas including island territories, countryside regions, and mountainous zones.
- The community development program seeks to build stronger, more inclusive and sustainable local communities. The program will improve accessibility to high - quality STEM learning opportunities and civic education in underdeveloped regions, while also promoting inclusive educational practices.
- The sustainable business innovation program focuses on environmental and marine sectors, working to enhance green economic value and competitive advantage through support for a sustainable economy rooted in low - carbon and circular economic principles.
- The judicial system program will expand access to a high - quality justice system that operates independently, transparently, and efficiently, adhering to international and European human rights frameworks while enhancing correctional facilities. This program will include support for improving mediation services.

GERMANY

The German government has set a target of 10 GWh/year of geothermal energy production by 2030. The cabinet recently classified geothermal projects as “of outstanding public interest” in order to accelerate their implementation. Here, traditional and innovative financing instruments are crucial for implementing renewable energy investments.

Traditional financing opportunities

- **Debt financing:** Long - term loans from local banks are a primary financing instrument for geothermal projects, including well reuse. These loans often require a strong project plan and technical documentation.
- **Municipal financing:** Municipalities can provide guarantees for projects, making external capital available after initial phases are completed. This model is particularly useful for projects with long - term development goals.
- **Transnational (EU) funding programs:** Germany can access EU funding programs like Horizon Europe and the European Structural and Investment Fund (ESIF), which can support geothermal energy projects and well reuse initiatives.

Innovative financing opportunities

- **Green financing instruments:** Germany's green financing market is robust, with institutions like the European Investment Bank (EIB) supporting green investments. While not specifically targeting well reuse, these instruments could be leveraged for innovative projects if they meet green criteria.
- **Public - Private Partnerships (PPPs):** Encouraging private sector investments through PPPs can provide additional innovative financing options for well reuse projects. This model allows for shared risks and costs between public and private entities.



- **Crowdfunding and community - led initiatives:** Community - These instruments can also support local energy projects, potentially including well reuse initiatives if they align with community goals.

Furthermore, the most used financing instruments are the following:

Federal Funding for Efficient Heating Networks (BEW)

A comprehensive German national funding program designed to accelerate the decarbonization of heat supply systems. The program is funded by the Federal Ministry for Economic Affairs and Climate Action. The BEW supports both the transformation of existing heating networks and construction of a new efficient heating network system across Germany. The program specifically targets projects powered by at least 75% renewable energies and waste heat, taking a systemic approach that covers planning costs, investment expenses and operating cost subsidies. The program targets companies, municipalities and non - profit organisations. It funds various measures for heating network transformation and new construction, including:

- Preliminary studies and feasibility assessments
- Comprehensive investments in system infrastructure
- Individual improvement measures
- Projects spanning from planning through experimental development stages.

KfW Development Bank Programs (Heat Pump Subsidy Program)

The KfW Renewable Energies Premium Program offers comprehensive financial support for heat pump installations, providing up to a 70% total funding through multiple subsidy components. The funding structure includes basic funding at 30%, a climate speed bonus of 20%, an income bonus of 30%, and an efficiency bonus of 5% specifically designed for geothermal heat pump systems.

The Deep Geothermal Support Program

This program offers comprehensive funding for geothermal energy projects through multiple financial mechanisms. The program provides up to a 2.000.000 EUR in repayment bonuses, combined with 2.500.000 EUR specifically allocated for drilling operations. Additionally, participants can receive installation support calculated at 80 EUR/kW of heat power capacity, capped at 100.000 EUR. The program targets projects with drilling depths exceeding 400 m that access thermal fluid with temperatures of at least 20 °C. It operates through 3 cumulative funding modules: plant funding, drilling cost subsidies and additional cost subsidies to ensure comprehensive project support. Companies can access funding via bank transfer arrangements, while municipalities have the option of direct loan facilities. The maximum loan amount reaches 25.000.000 EUR, covering up to 80% of eligible project costs.

Individual Building Efficiency Measures program

The Federal Office for Economic Affairs and Export Control (BAFA) offers financial support for geothermal heat pumps through their Individual Building Efficiency Measures program. The funding covers 35% of investment costs with a minimum investment threshold of 2.000 EUR. Property owners can receive an additional 10% bonus if they are replacing an existing heating - oil based heating system, making the total potential funding up to 45%.

North Rhine - Westphalia Energy Program

North Rhine - Westphalia has launched an ambitious geothermal energy initiative through the progres program. The program allocates nearly 20.000.000 EUR to support 1.250 geothermal systems, offering enhanced drilling subsidies ranging from EUR 35 - 50 EUR/m. The total funding in the recent years reaches 40.000.000 EUR through North Rhine - Westphalia Bank. This comprehensive funding structure aims to accelerate geothermal energy adoption by reducing financial barriers and mitigating drilling risk for developers.



Bavaria Geothermal Alliance

Bavaria has extended its Geothermal Alliance funding program, allocating significant resources to major geothermal development projects. The program includes substantial investments of 62.300.000 EUR designated for the Grünwald expansion project and 50.000.000 EUR for Gräfelting initiatives, demonstrating Bavaria's commitment to advancing its geothermal development strategy. The program focuses specifically on large - scale municipal and district heating geothermal projects, with coordination managed through the Bavarian State Ministry of Economic Affairs. Project applications are processed through established Bavarian state energy programs in partnership with municipal authorities, creating a streamlined approach for community - based geothermal development across the region.

Berlin - Brandenburg Deep Geothermal Exploration Project

The Berlin - Brandenburg region has launched a major deep geothermal exploration initiative covering 550 km² under a large - scale mining permit. The project receives substantial federal funding totaling over 18.000.000 EUR, with 8.000.000 EUR allocated specifically for the Prenzlau project and 10.000.000 EUR for the NEUruppin project. This regional development program aims to explore and develop geothermal resources across multiple municipalities in the designated area. The initiative represents a significant investment in renewable energy infrastructure, focusing on identifying and harnessing underground thermal resources for sustainable energy production.

HUNGARY

Programs supporting the use of geothermal energy in Hungary are mobilizing significant transnational (EU) and national funds to achieve the targets set for 2030. The Hungarian government aims to reduce natural gas consumption in public institutions and businesses by 25% through geothermal energy. In Hungary preliminary complex vulnerability and impact assessment have been carried out for more than 20 potential geothermal areas under the concession system. According to experts, there are 28 areas with good geothermal potential and existing district heating infrastructure. Further 17 areas have good geothermal potential and heat demand, but no district heating network has yet been built. In Hungary, traditional and innovative financing instruments for the reuse of existing wells, particularly for geothermal energy, are supported through a combination of transnational (EU) and national funding mechanisms.

Traditional financing opportunities

- **Public support schemes:** Hungary offers various public funding schemes for energy - related projects. The Hungarian Development Bank (MFB) provides preferential loans for energy efficiency improvements, which could indirectly support well reuse projects if they align with broader energy efficiency goals.
- **Transnational (EU) funding programs:** Hungary can access EU funding programs like Horizon Europe and the European Structural and Investment Fund (ESIF), which can support geothermal energy projects and well reuse initiatives.
- **National Recovery and Resilience Plan (NRRP):** Hungary's NRRP includes investments and reforms aimed at increasing the resilience and sustainability of the economy, with a significant focus on the green transition. This could provide opportunities for projects related to well reuse if they contribute to the green transition goals.

Innovative financing opportunities

- **Green financing instruments:** Hungary has a green bond framework in place, which allows financing of projects related to energy efficiency, among other green categories. While not specifically targeting well reuse, these instruments could be leveraged for innovative projects if they meet the green criteria.



- **Private sector capital:** Encouraging private sector investments through green financing instruments can provide additional innovative financing options for well reuse projects. The European Investment Bank (EIB) supports green investments in Hungary, which could be beneficial for well reuse initiatives.
- **Energy efficiency loans:** The Hungarian National Bank (MNB) promotes green retail lending, including energy - efficient home renovations. While not directly applicable to well reuse, this framework demonstrates Hungary's commitment to green financing, which could be adapted for other environmental projects.

Apart from the mentioned, further financing instruments available in Hungary are:

Swiss - Hungarian Cooperation Program II

The aim of the program is to increase the use of geothermal energy sources by modernizing existing (active or closed, producing and/or injection) thermal wells and, in addition, by converting unused, state - owned hydrocarbon wells with significant untapped geothermal potential into thermal wells. Furthermore, it promotes geothermal energy production and through other surface engineering activities that support the efficiency and growth of utilisation, the connection of geothermal wells to heating systems and/or the connection of new consumers to geothermal - based district heating systems. This gives the public access to reliable and environmentally friendly heating solutions.

Horticultural geothermal developments (KFMOP)

A total of 50.000.000.000 HUF is available to support developments related to horticultural greenhouses and cold stores, of which 20.000.000.000 HUF can be used specifically for supplying existing facilities with green energy, including geothermal energy. Applicants may request a maximum of 5.000.000.000 HUF in support, with up to 70% of eligible costs.

Jedlik Ányos Energy Program

Hungary's largest energy modernization program to date is being launched with the Jedlik Ányos Energy Program, which will provide more than 450.000.000.000 HUF in support for energy efficiency, renewable energy and network development investments. The aim is to strengthen domestic energy independence, increase the proportion of locally produced energy and reduce the burden on the population. The program aims to renew the entire energy system, from the greening of district heating to biogas production and corporate energy storage. A significant part of the program is financed by EU funds, primarily from the Modernization Fund, supplemented by national resources. Under this program a total of more than 42.000.000.000 HUF in state subsidies is available for geothermal projects in 3 main areas:

- Reducing geothermal drilling risks
- Geothermal - based electricity and heat production
- Geothermal energy utilisation preferential loan scheme

The program also includes 2 other district heating projects that incorporate geothermal elements:

- Modernization and development of district heating systems based on renewable energy
- Modernization and development of district heating system infrastructure.

SLOVENIA

Under the current Integrated National Energy and Climate Plan (NECP), Slovenia is committed to achieve a target of at least 30% - 35% share of renewable energy consumption by 2030, with a share of 52% in the electricity sector, 41% in the heating and cooling sector and 26% in the transport sector. In order to achieve higher targets for climate neutrality and the share of renewable energy in the gross final consumption, the



Introduction of Installations for the Production of Electricity from Renewable Energy Sources Act (ZUNPEOVE) was adopted, which facilitates the development of deep geothermal projects.

Traditional financing opportunities

- **Transnational (EU) funding programs:** Slovenia can access EU funding programs like Horizon Europe and the European Structural and Investment Fund (ESIF), which can support geothermal energy projects and well reuse initiatives.

Innovative financing opportunities

- **Green financing instruments:** Slovenia has a growing green financing market, with institutions like the European Bank for Reconstruction and Development (EBRD) supporting green bonds and energy efficiency measures. This could be leveraged for innovative projects involving well reuse if they align with green criteria.
- **Private sector capital:** Encouraging private sector investments through green financing instruments can provide additional innovative financing options for well reuse projects. Slovenia's participation in EU green initiatives makes it attractive for private investors interested in sustainable projects.
- **Collaborative projects:** Participating in international or regional collaborative projects focused on geothermal energy or environmental sustainability could also provide innovative financing pathways. These projects often involve multiple stakeholders and can attract funding from various sources.

Apart from the listed, crucial funding is provided through the following instruments:

Slovenian Environmental Public Fund (Eko Sklad)

The primary goal of this organization is to foster environmental protection development through financial support mechanisms, including soft loans and grants for diverse environmental investment initiatives. The Fund develops and executes yearly strategies that form the basis for issuing public tender announcements. While not specifically targeting well reuse, it supports various environmental initiatives that could indirectly benefit projects involving repurposing of abandoned hydrocarbon wells for geothermal energy.

European Commission Aid Scheme

Slovenia has established a 150.000.000 EUR renewable energy support scheme, approved by the European Commission that provides substantial financial assistance for clean energy projects, which explicitly includes geothermal installations. This scheme provides direct grants of up to 25.000.000 EUR per beneficiary, targeting legal entities, cooperatives, individuals engaged in business activities and local authorities. Eligible projects include the installation of photovoltaic, solar, geothermal and hydropower plants, as well as wind energy installations and cogeneration facilities using biomass, biogas, landfill gas and sewage gas. The Aid can cover up to 45% of the total project costs, with additional increases (up to 20% for small enterprises and 10% for medium - sized enterprises).

Public tender for co - financing the construction and restructuring of district heating and cooling systems based on renewable energy sources

Slovenia's Ministry of Environment, Climate and Energy has introduced a comprehensive 51.200.000 EUR co - financing initiative to support the construction and restructuring of district heating and cooling systems powered by renewable energy sources. This program is funded primarily through the European Cohesion and Policy Funding mechanism. The subject of the public tender is the allocation of subsidies for the co - financing of installation of heat generators using renewable energy sources, waste heat or a combination of these, and for increasing the share of renewable energy sources in district heating systems, namely:

- Heat pumps
- Solar collectors for heat production and wood biomass boilers



- The construction of heat and electricity generation plants from renewable energy sources in existing district heating systems
- The construction of new district heating systems or the expansion of existing district heating systems using renewable energy sources, waste heat or a combination of these.

OTHER FINANCING OPPORTUNITIES

Horizon Europe Program

Cluster 5 for Climate Energy and Mobility includes the Horizon Europe Work Program, which features specific calls for geothermal energy innovation with a total budget of 234.000.000 EUR available for energy projects. The program focuses on both shallow and deep geothermal applications, including drilling technologies, reservoir characterization, and subsurface engineering, requiring collaborative consortiums and targeting TRL 7 - 9 demonstration activities. Expected outcomes include de-risking and cost reduction of geothermal resource development for developers and energy providers, sustainable energy generation for citizens from geothermal resources across various geological settings, increased technology leadership and competitiveness for European industry in the geothermal energy supply chain and environmentally sound technological innovation aligned with societal values. Key focus areas include subsurface engineering, well design, drilling and completion, as well as reservoir characterisation and development planning.

Clean Energy Transition

The Clean Energy Transition funding allocates 9.140.000 EUR specifically for Coordination and Support Action Grants, while project grants typically range from 1.000.000 - 20.000.000 EUR and span of 3 - 5 years. The program actively supports geothermal energy projects through its calls and focuses on renewable energy deployment and energy efficiency improvements.

Clean Energy Transition Partnership

The Clean Energy Transition Partnership (CETP) supports geothermal energy projects through specific modules. Thereby, calls focus on advanced renewable energy technologies and include geothermal energy for power applications as a novel topic. The program supports different approaches for geothermal energy research and innovation. The partnership coordinates approximately 100.000.000 EUR in total funding across all participating countries.

Innovation Fund

The Innovation Fund provides grants for commercial deployment of innovative low-carbon technologies and environmental benefits. It focuses on innovative renewable energy generation and energy storage, including geothermal applications. The Fund specifically supports deep geothermal projects, which are eligible under renewable energy technology categories.

4.2. Well repurposing practices in the Central European region

Different financing sources enable a more professional, efficient and quality implementation of the planned activities, ensuring, thereby, an easier and faster transition from fossil-based energy carriers to geothermal energy and providing the region with the opportunity to use the naturally available renewable energy sources, as well as become energy neutral. Regarding the repurposing of abandoned hydrocarbon wells, the socio-economic analyses of the heat demand structures in the fields of industry, agriculture and municipality, as well as the feasibility studies have shown that the process of repurposing abandoned hydrocarbon wells is more cost effective and less expensive than drilling new geothermal wells. As for the practices in the 5 countries of the consortium, well repurposing projects are more or less widespread,



whereby the reasons for the popularity of such activities lies, among others, in the availability of the various suitable financing opportunities.

To support the previous theoretical descriptions of the financing instruments and present the practical application of the same, examples of several geothermal and well repurposing projects applied and implemented in the 5 countries of the consortium are presented below. Furthermore, examples of projects carried out through an international partnership between the Central European and other European countries are, also, provided. Since not all projects are strictly related to well repurposing, but cover a wider range of various geothermal topics, the presented examples are divided into the following 2 categories:

- Geothermal projects - drilling new and using existing geothermal wells for heating, cooling and electricity purposes, geothermal mapping, researching, modelling, testing and networking
- Well repurposing projects - reusing abandoned hydrocarbon wells for heating, cooling and electricity purposes.

Once summarized with the main information in the Table below, examples of projects strictly related to repurposing of abandoned hydrocarbon into geothermal wells are presented in more detail through the following information:

- Project acronym and title
- Financing source/instrument (transnational (EU), national, regional, local ; traditional, alternative, innovative)
- Budget and co - financing rate
- Duration (month and year of implementation)
- Project description and reasons for (not) obtaining funds from the selected financing source/instrument (if applicable)
- Official link to the project (if applicable).

Table 17: Examples of geothermal and well repurposing projects

Project acronym and title	Financing instrument	Country
Geothermal projects		
CLUSTHERM (Creating a Central European Thermal water Research Cluster)	7th Framework Program	Austria, Croatia, Hungary, Romania
DARLINGe (Danube Region Leading Geothermal Energy)	Interreg Danube Transnational Program	Croatia, Hungary, Slovenia, Romania, Bosnia and Herzegovina, Serbia
HyTheC (Multidisciplinary approach to creating conceptual models of hydrothermal systems)	Croatian Science Foundation (HRZZ)	Croatia, Germany, Ireland
USES4HEAT	Horizon Europe	Belgium, Bulgaria, Croatia, Italy, Greece,



(Underground Large Scale Seasonal Energy Storage for Decarbonised and Reliable Heat)		Norway, Spain, Sweden
Deep Geothermal Energy Database (Real Green Transition)	European Economic Area (EEA) Energy and Climate Change Program	Croatia
ATESREF (Aquifer thermal energy storage and reinjection using the example of Fürstenfeld)	FFG Austrian Research Promotion Agency (Federal Ministry of the Republic of Austria for Climate Action, Environment, Energy, Mobility, Innovation and Technology, Federal Ministry of the Republic of Austria for Labour and Economy) Programs: e!MISSION, Energy research, Energy Research Program 2023	Austria
Karlshagen	Federal Office of Economics and Export Control, Federal Funding for Efficient Heat Networks Programs: BAFA	Germany
Well repurpose projects		
InnoGeoPot (Innovative research methods for assessing geothermal energy potential and thermal energy storage)	Croatian Science Foundation (HRZZ)	Croatia, Slovenia, Switzerland
MEET (Multidisciplinary and multi - context demonstration of Enhanced Geothermal Systems exploration and Exploitation Techniques and potentials)	Horizon 2020	Belgium, Croatia, Germany, France, Iceland
Geothermal energy from old oil wells (A way to a little more independence!)	Austrian Climate and Energy Fund (KLIEN) (Federal Ministry of the Republic of Austria for Climate Action, Environment, Energy, Mobility, Innovation and Technology) Programs: New Energies 2020, 2nd Call for Proposals	Austria
Groß Schönebeck	Federal Ministry for Economic Affairs and Climate Protection, Federal Ministry of Education and Research	Germany
Horstberg	Federal Ministry for Environment, Nature Conservation and Nuclear Safety	Germany
Landau	N/A	Germany



As evident, Table 17 presents a breakdown of the various geothermal and well repurposing projects starting with the ones financed from the transnational (EU) sources (programs, calls, tenders) up to the projects which were implemented with the assistance of national institutions and financing sources/instruments. Thereby, the projects cover a variety of activities (from soft measures such as the creation of maps, databases and tools up to specific works in the forms of drilling new geothermal or repurposing existing hydrocarbon wells), as well as different time periods (with starting years of the projects from 2001 to 2024).

To give a more detailed insight into the implementation of, mainly, well repurposing projects, some of the most significant are elaborated below.

TRANSNATIONAL (EU) FINANCING INSTRUMENTS

1) **InnoGeoPot (Innovative research methods for assessing geothermal energy potential and thermal energy storage)**

Financing source/instrument: Croatian Science Foundation (HRZZ)

Budget and co - financing rate: Approximately 182.700 EUR (UNIZG - RGNF), N/A

Duration: February 2024 - February 2028

Project description: Establishing a geological - hydrogeological - thermodynamic model using data collected during the drilling of deep wells in the selected areas, as well as monitoring real data from a shallow geothermal borehole field in operation to determine heat rejection/extraction rates. Furthermore, the project aims to extend the exploitation of shallow and medium - deep geothermal potential to the application of thermal energy storage in the rock using Borehole Thermal Energy Storage (BTES) systems, as well as the possibility of exploiting geothermal potential by revitalizing abandoned wells via deep closed - loop BHE. The developed geological - hydrogeological - geothermal model will provide a better insight into the shallow and medium - deep geothermal potential of the area and define the areas where it is possible to use Borehole Thermal Energy Storage (BTES) systems. Here, the assessment of geothermal potential through the revitalization of abandoned wells will also be considered. The research area in Croatia includes the wider area of the city of Zagreb, the city of Ljubljana and the border area between Slovenia and Croatia.

Official link: University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering: InnoGeoPot (<https://www.rgn.unizg.hr/en/innogeopot>)

2) **MEET (Multidisciplinary and multi - context demonstration of Enhanced Geothermal Systems exploration and Exploitation Techniques and potentials)**

Financing source/instrument: Horizon 2020

Budget and co - financing rate: Approximately 11.720.000 EUR, around 85%

Duration: May 2018 - October 2022

Project description: Boosting the development of Enhanced Geothermal Systems (EGS) across Europe in various geological settings (sedimentary, volcanic, metamorphic and crystalline) by demonstrating the viability of such systems with electric and thermal power generation. Activities implemented within the project focus on gathering knowledge of Enhanced Geothermal Systems (EGS) power and heat production, increasing heat production from existing plants and converting oil wells into geothermal ones, enhancing heat - to - power conversion at low temperatures (60 - 90 °C) by using smart mobile Organic Rankine Cycle (ORC) units and replicating the technology by



promoting the penetration of EGS power and/or heat plants. The project covers 11 demonstration sites, as well as provides a roadmap of the next promising sites where the Enhanced Geothermal Systems (EGS) could be replicated in the near future.

Official link: MEET - Multi - sites EGS Demonstration (<https://www.meet-h2020.com/>)

NATIONAL FINANCING INSTRUMENTS

1) Geothermal energy from old oil wells (A way to a little more independence!)

Financing source/instrument: Austrian Climate and Energy Fund (KLIEN) (Federal Ministry of the Republic of Austria for Climate Action, Environment, Energy, Mobility, Innovation and Technology); Program: New Energies 2020, 2nd Call for Proposals

Budget and co - financing rate: Approximately 1.750.000 EUR, N/A

Duration: January 2009 - June 2011

Project description: Reusing a depleted hydrocarbon (oil) well in the central part of Vienna, whereby the well owner and operator was OMW. The project focused on the conversion and adaptation of an old hydrocarbon (oil) well into a Borehole Heat Exchanger (BHE), integration of the newly installed system into the existing heating system via a district heating network, testing of the system under realistic conditions, developing a software to identify further geothermal potential and identifying the potential for improvement. As part of the project a hydrocarbon (oil) well (Prottes T 11) with the approximate depth of 2.200 m was reactivated and reused by inserting the necessary technical infrastructure and putting it into operation through the existing district heating system. The well itself was developed as a test site for heat production and the 350 m district heating pipeline enabled the heating of a nearby public sports hall.

Official link: Climate and Energy Fund: Energy from the Earth, Air and Water - Heat pumps and Geothermal energy (https://www.klimafonds.gv.at/wp-content/uploads/2024/11/KLIEN_2011_ScienceBrunch_Energie-Erde-Luft-Wasser.pdf); sites 20, 21

2) Groß Schönebeck

Financing source/instrument: Federal Ministry for Economic Affairs and Climate Protection, Federal Ministry of Education and Research

Budget and co - financing rate: Approximately 59.500.000 EUR, 100% public funding

Duration: 2001 - ongoing

Project description: The geothermal research platform is located 50 km north - east of Berlin on the southern edge of the North German Basin. Here, 2 research wells with approximate depths between 3,9 and 4,4 km and temperatures of around 150 °C opened the opportunities for the exploration and exploitation of geothermal energy with corresponding analyses of the potential reservoirs, technical drilling development and engineering treatment, development of a sustainable thermal water cycle and the efficient conversion of energy into heat and electricity. In terms of the geothermal energy exploitation, the expansion of the site began in 2001 when a non - detectable hydrocarbon (natural gas) well (E GrSk 3/90) was reopened as an injection well and expanded into a geothermal laboratory for research purposes. Further expansions have been carried out in 2006, when a new geothermal production well (Gt GrSk 4/05) was drilled and a geothermal doublet from both wells was installed. With a series of experiments the inflow conditions of both wells were improved and the thermal water production increased. In 2011 a corrosion test section for materials



was set up for investigating the corrosion and scaling and images of the geological subsurface were created on the basis of the implemented measurements and 3D modelling.

Official link: N/A

3) Horstberg

Financing source/instrument: Federal Ministry for Environment, Nature Conservation and Nuclear Safety

Duration: October 2002 - ongoing

Budget and co - financing rate: N/A

Project description: The geothermal well (Horstberg Z1) was an abandoned hydrocarbon (natural gas) exploration well located in the North German Basin, approximately 80 km northeast of Hannover. Since 2003 the well has been used for development and implementing of a new utilisation concept for deep geothermal energy production. Here, the approach of a single - hole concept for the extraction and direct use of thermal water from low - permeability rock formations from great depths was tested and in fall 2003 2 sandstone formations were individually connected to the well. Both formations were then connected by a hydraulically created fracture over a height of 120 m and a depth of 3.800 m by fracking around 20.000 m³ of fresh water. For testing purposes, 2 methods were implemented. First, the cyclic process was tested with the cyclic injection and production phases, whereby the fracture acted as an underground heat exchanger. Second, a single - hole circulation was implemented and, by producing water from one sandstone and reinjecting it into the other one, a continuous circulation was achieved. Both methods provided proof that the created fracture remained highly hydraulically conductive throughout the entire period and can function as a heat exchanger surface. The testing in Horstberg continued after the renovation of the drilling site in 2016 and the main aim was the comprehensive characterization of the hydraulic fracture.

Official link: Federal Institute for Geosciences and Natural Resources - Geocenter Hannover: Geothermal borehole Horstberg Z1 (https://www.bgr.bund.de/DE/Themen/Nutzung_tieferer_Untergrund_CO2Speicherung/Projekte/Geothermie/Abgeschlossen/geothermie-projekt_Horstberg_Z1.html; https://www.bgr.bund.de/EN/Themen/Nutzung_tieferer_Untergrund_CO2Speicherung/Projekte/Geothermie/Abgeschlossen/Horstberg_Projekt.html)

4) Landau

Financing source/instrument: N/A

Budget and co - financing rate: N/A

Duration: N/A

Project description: In the southern part of the Landau field, 2 hydrocarbon (oil) wells, originally operated by Wintershall Holding AG, were repurposed into geothermal wells. These wells utilise underground energy for heat production. Since 2010, they have been supplying a public swimming pool and, since 2014, a car dealership with the produced geothermal energy. Thereby, the public swimming pool is supplied with geothermal heat, with a surface temperature of 37°C from a depth of 900 m and a heat pump further utilising this heat. The mining responsibility for the well supplying the public swimming pool remains with ONEO. On the other hand, the car dealership is supplied with geothermal heat, with a surface temperature of 42°C from a depth of 800 m, which is further utilised via a plate heat exchanger. Today, both wells are operated by Energie Südwest AG.

Official link: N/A



5. Challenges and Strategic Objectives

The overview of the current features from the previous Chapters shows that the geothermal and, especially, well repurposing potential in the Central European region is on a high level. Large underground basins and water aquifers ensure the existence of an energy source that, according to its quantities and temperatures, can be utilised in sectors such as industry, agriculture, municipality, balneology and housing, whereby the heating, cooling, electricity and storage demands can be fully covered. Additional potential is provided through a significant number of hydrocarbon wells, which have been closed due to abandonment of the natural gas and oil industry in certain areas, with the existing infrastructure left to decommissioning after use.

In general, the exploitation of geothermal energy is being performed through newly drilled wells, whereby the processes of exploration and exploitation themselves are followed by long - lasting procedures, intensive works and high costs. In order to mitigate some of the risks, in recent years the idea of utilising geothermal energy from abandoned hydrocarbon wells became an imperative. Reuse of the existing infrastructure requires lower investment costs, shorter works, fewer negative environmental impacts, reuse of decaying resources, as well as use of a renewable, locally available and ecologically acceptable energy source.

Apart from the benefits listed above, the process of repurposing abandoned hydrocarbon wells for further energy exploitation is considered to be a substantial investment. The age, unspecified location, unknown condition and limited accessibility of the old wells are the most significant barriers, which hinder the process of repurposing well sites for further use. Such investments often still require extensive financial resources, as the application of technologies with little to no environmental impact are stipulated in special concessions and permits.

The analysis of the geothermal and well repurposing potentials, environmental impacts and financing opportunities in the 5 countries of the consortium reveals various challenges and bottlenecks when it comes to exploration, exploitation and use of geothermal energy from abandoned hydrocarbon wells. Whether unclear regulations and complicated permitting procedures, absence of modern technological solutions, restrictive environmental conditions or lack of human and financial resources are considered, it is clear that such barriers prolong and, in many cases, discourage the implementation of high - quality energy investments.

In order to mitigate and tackle these barriers, this document offers potential solutions in forms of Strategic Objectives and corresponding Priorities, which can be applicable not only in the 5 countries of the consortium, but also in other countries located in the Central European region. To fully understand the Strategic Objectives and Priorities within this document, it is important to, firstly, present the challenges and bottlenecks occurring in the process of repurposing abandoned hydrocarbon wells into geothermal ones, classified into the following 4 Categories:

- Category 1: Legal, knowledge and social frameworks
- Category 2: Technological opportunities
- Category 3: Environmental impacts
- Category 4: Financing instruments.

The challenges and bottlenecks are also classified according to their significance into the following:

- National - specific for the 5 countries included in the project TRANSCEO (Austria, Croatia, Germany, Hungary, Slovenia) and applicable on country level
- Transnational - common for the 5 countries included in the project TRANSCEO (Austria, Croatia, Germany, Hungary, Slovenia) and applicable in the Central European region.



NATIONAL (COUNTRY SPECIFIC) CHALLENGES AND BOTTLENECKS



AUSTRIA

- The legal framework for geothermal energy is fragmented, as the regulations are split across several laws including Mining, Water Rights, and the Industrial Code, which leads to unclear procedures and prolonged approval times.
- There is no single authority responsible for geothermal regulation, and the involvement of multiple authorities makes the approval process unpredictable.
- A concession system does not exist, meaning explorers do not receive exclusive rights, which discourages potential investments.
- Access to well data is restricted because it is not publicly available and typically remains in the possession of oil companies or operators.
- Deep geothermal projects face serious regulatory challenges due to complex legal requirements, high financial risks and difficulties with obtaining insurance.
- Land ownership creates challenges, as landowners have the right to object to deep drilling beneath their property.
- The available infrastructure is inadequate, since many wells are old or unsuitable and the overall network is limited.
- Financial barriers are significant, as costs remain high and there are only limited risk - mitigation instruments available for private investors.
- Human resources in the sector are limited, with a notable shortage of trained geothermal specialists and technical staff.



CROATIA

- There is a single procedure for awarding exploration and exploitation licences, which makes the legal framework transparent and clear. Investors in geothermal energy must initiate 2 administrative procedures, which partially overlap:
 - The first procedure is regulated by the Act on Exploration and Production of Hydrocarbons (NN 52/18, 52/19, 30/21), which specifies all the necessary steps for exploring and exploiting geothermal water for energy purposes
 - The second procedure relates to the standard process for implementing renewable energy projects.

Both procedures have specific requirements and steps that must be completed to establish the legal foundation for developing a geothermal power plant. However, regulatory fragmentation across the energy, water, and environmental sectors is a bottleneck in the legal framework for implementing geothermal projects.

- There is limited experience with fully completed projects in the operational phase. Most projects are in the exploration phase aimed at identifying geothermal potential and reserves. During exploration activities to date, revitalisation and testing of existing wells have been successfully conducted on few geothermal projects. The challenge for repurposing lies in the lack of visibility in planning and allocating funds at the level of the EU and Croatia, which would be directed towards such projects.
- Technical challenges are significant, as the condition of many wells is unknown. Issues include the age of the wells, their incompleteness and incompatibility with current requirements. Additionally, district heating networks are limited, covering only 10% of the country's total heat supply, which, mainly, comes from natural gas - based heating plants.
- Financial support is insufficient, as the costs for testing, refurbishment and integration of geothermal projects are high. Partial financial assistance is provided by transnational (EU and non - EU) funds, but it does not fully cover the expenses.
- Human resources in the sector are limited, with lack of expertise and training opportunities. There is also a notable disinterest in educational programs related to mining and energy, which affects workforce development.
- The infrastructure is currently underdeveloped as geothermal projects are ongoing. Further development of the infrastructure and network is expected after their completion. District heating network capacities are limited to a few urban areas in the country.
- Data for the assessment of geothermal potential are available to the public for review and use, making them transparent and open to project development in the field of geothermal energy. Inherited data may be sparsely documented due to the period when the well of interest was drilled.



GERMANY

- Complex permitting involves multiple laws and authorities and the approval processes are often lengthy due to environmental impact assessments and local opposition.
- State laws are inconsistent because each state interprets regulations differently, which causes significant discrepancies.
- Documentation is often deficient, as records for older wells are frequently incomplete.
- Land ownership and rights are problematic, since there are no exclusive exploration rights and third parties can exploit areas even after costly surveys.
- Data accessibility is limited because technical data remains restricted for 5 to 10 years, which reduces transparency.
- Many wells are old and unsuitable and district heating networks are concentrated in certain regions
- Surface infrastructure in particular must be adapted to the specific requirements of geothermal energy, which may require significant investments.
- Financial support is limited, as high investment costs and exploration risks are coupled with a few effective risk - sharing mechanisms.
- There is a shortage of skilled labor for geothermal projects, because there is no dedicated, unified university or technical education program focused solely on geothermal energy.



HUNGARY

- The legal framework has changed and developed significantly and traditional geothermal projects are now subject to the same administrative procedure (SARA), but agricultural and balneological use still requires the involvement of several authorities. In some cases, the regulations do not provide clear rights, and the powers of the various actors involved in the licensing process are not yet fully clarified. There are no specific rules for the reuse of wells, which can cause problems in certain cases.
- Policies and regulations do not provide adequate support, as the new geothermal law does not contain clear guidelines for certain areas (it may contain concession overlaps between projects) and exempts certain players.
- There are limited incentives for development, because there are no dedicated national funding and economic incentives, while state subsidies are inconsistent.
- Data gaps persist, since access to subsurface data is often restricted. However, basic data on the drillings are available.
- Exploration risks are high due to short exploration periods of only 20 months and the considerable costs of drilling, both of which deter investments. Drilling capacity cannot meet increased demand and is partly state - influenced, which can distort the market.
- The state of infrastructure poses problems, as the technical condition of most abandoned wells is unknown, costly testing is required and widespread district heating systems are lacking with particular regard to small towns.
- Financial support is not sufficiently diversified and, although efforts are being made in this regard for new projects, there is no specific financing or risk reduction program for the reuse of wells, meaning that investors face high upfront and testing costs when repurposing abandoned hydrocarbon wells.
- Human resources are limited, with severe shortage of geothermal specialists and technical staff, as well as only a few specialized educational programs available.
- Political and, mainly, economic uncertainties also significantly influence the design and construction process.
- Re - injection problems occur partly because of regulatory issues and partly due to technological and geological factors.



SLOVENIA

- The domestic market size is small, as there is only a limited number of projects and the overall local market remains restricted.
- The Integrated National Energy and Climate Plan (NECP) does not fully recognize geothermal energy through the reuse of existing natural gas and oil wells as a potential resource.
- The regulatory framework is highly complex, since permits require the involvement of multiple agencies and the approval process is very time - consuming.
- Access to data is difficult due to incomplete documentation and the overall lack of available information.
- Geothermal projects face significant financial challenges, including a high financial burden, limited government support and very few investors with specialized knowledge.
- Technical challenges also exist, such as limited reinjection systems, unknown geological structures and the need for targeted surveys.
- There are significant education gaps, as no dedicated university provides geothermal education. Instead, the knowledge base is confined mainly to programs in machinery, geology, and mining.

TRANSNATIONAL (COMMON) CHALLENGES AND BOTTLENECKS

Legal, knowledge and social frameworks
There is no uniformed regulatory environment for the authorization and licensing of geothermal projects.
There is lack of a qualified human resource base with secondary and higher education qualifications specifically related to geothermal projects.
In the absence of appropriate regulation, risk mitigation measures and financial support, opposition from stakeholders can hinder the development of geothermal projects.
Technological
Gaps in technical, geological and analytical data related to wells, as well as limited access to data and questionable data quality, make it risky to initiate projects.
In most cases, the current technological status and structural integrity of wells remain unknown.
The market for geothermal projects is often insufficiently assessed, sometimes due to lack of data and there is also a shortage of adequate infrastructure.
Environmental
Problems related to the current conditions and structural integrity of wells may cause contamination of the surface and subsurface environment, which must be remedied to enable further use.



During the commissioning and operating of wells, environmental impacts may occur, including light and noise pollution, ecosystem disruption, induced seismicity, surface movements, gas co - production, radionuclide emissions and physical or chemical changes in the produced or reinjected layers.

Financial

Without risk mitigation mechanisms and adequate financial support, exploring, testing, repurposing abandoned hydrocarbon wells and integrating them into existing energy systems is extremely risky and costly.

After the identification of the challenges and bottlenecks, solutions in the forms of Strategic Objectives and corresponding Priorities are defined, which can help in the mitigation of the barriers. Thereby, the Strategic Objectives can be defined as long - lasting goals that are to be achieved to fulfil the visions of the entities they were set by (in most cases governments or companies). On the other hand, Strategic Objectives include Priorities which stipulate immediate Measures that should be carried out to achieve the set goals.

To follow the structure and address the barriers appropriately, the Strategic Objectives and corresponding Priorities are set for the same 4 Categories as the challenges and bottlenecks listed above, taking into account the specifics of the topic they cover and principles of sustainable development. Finally, brief explanations of the Categories with their structured Strategic Objectives and corresponding Priorities are presented before and after the Figures below. Here it is important to highlight that more detailed descriptions of the Strategic Objectives and corresponding Priorities will be presented in the Transnational Action Plan (created, also, within the project TRANSCEO).

CATEGORY 1: LEGAL, KNOWLEDGE AND SOCIAL FRAMEWORKS

This Category gives an overview of the existing European and national laws and regulations, as well as strategic and planning documents regarding renewable and, especially, geothermal energy applicable in the Central European region, with the 5 countries of the consortium as starting points for the analysis. It covers the legal and administrative frameworks for well repurposing projects in the context of national, regional and local plans, concessions, permits and licences, data about the exploration and concession fields, wells and ownership, as well as environmental and regulations for abandoned wells. Also, within this Category, the educational opportunities regarding geothermal energy and well repurposing are taken into account (meaning educational and research institutions such as schools, faculties, universities, institutes and training programs for technical staff).

According to the mentioned, the relevant Strategic Objectives and corresponding Priorities are presented in Figure 83.

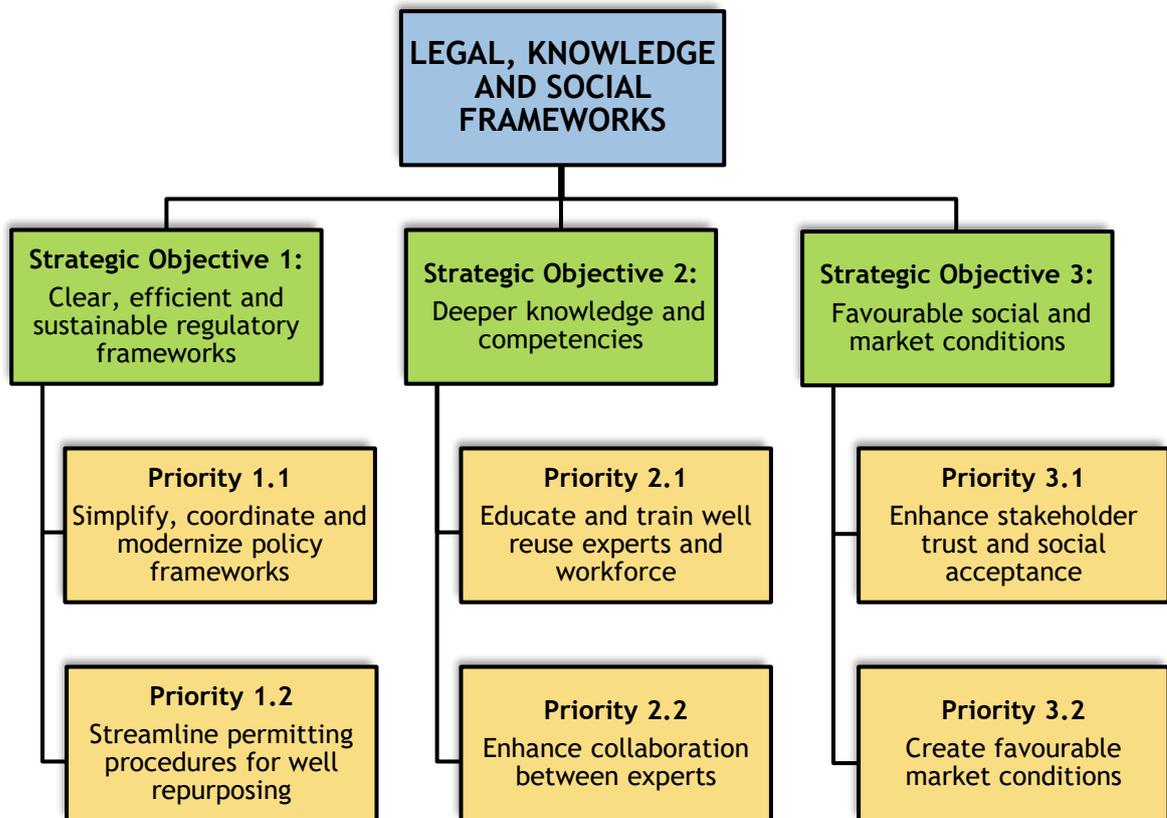


Figure 83: Strategic Objectives and Priorities supporting legal, knowledge and social frameworks

Strategic Objective 1: Clear, efficient and sustainable regulatory frameworks

Creating a clear, efficient and sustainable regulatory framework is essential for the successful development of geothermal projects and the repurposing of abandoned hydrocarbon wells. Frequent regulatory changes, fragmented legal structures, unclear institutional responsibilities and inconsistent national interpretations currently undermine investor confidence and slow project implementation.

To address these challenges, legal and administrative frameworks must be harmonized, procedures clarified and codified and long - term regulatory stability ensured. Streamlining permitting processes is particularly important, as multi - stage, multi - agency procedures often lead to unpredictable delays, higher costs, and reduced project feasibility. Simplifying the regulatory environment, increasing transparency and minimizing administrative burdens through actions such as simplified licensing models, standardized requirements, harmonized documentation and the establishment of national or regional One - Stop - Shop system would enable a more reliable project planning, reduce risks and significantly improve the overall attractiveness and sustainability of geothermal energy and well repurposing.

Strategic Objective 2: Deeper knowledge and competencies

Developing a skilled workforce and strengthening expert collaboration are essential for advancing geothermal projects and the repurposing of abandoned hydrocarbon wells in Central Europe, where shortages of qualified professionals and limited, fragmented training opportunities currently hinder innovation, delay projects and increase technical risks.

Addressing these gaps requires the creation and expansion of structured geothermal education programs at secondary, higher and postgraduate levels, implemented through universities, colleges, technical schools and research institutes and covering key fields such as geology, engineering, project management, environmental analysis and regulatory processes. These programs should include practical laboratory work,



field experience, internships and cross - border exchanges, supported by harmonized curricula, certification standards and training requirements to ensure consistent qualifications and promote student mobility and mutual recognition of skills.

At the same time, building a coordinated network linking experts across academia, industry and government is crucial for knowledge sharing, joint training, collaborative research and continuous professional development. Stronger partnerships between theoretical and practical sectors through internships, joint projects and applied research will help align academic learning with real - world challenges such as drilling, well integrity assessment, permitting and environmental monitoring. By integrating expertise, standardizing competencies and fostering structured cooperation, the region can develop a robust, internationally competitive workforce capable of supporting faster, high - quality and more sustainable geothermal deployment based on repurposed hydrocarbon wells.

Strategic Objective 3: Favourable social and market conditions

Enhancing stakeholder trust and creating favourable market conditions are crucial for accelerating the adoption of geothermal energy from repurposed hydrocarbon wells in Central Europe. Increasing awareness among policymakers, local authorities, investors, industry professionals and the public through targeted information campaigns, educational seminars, workshops and the dissemination of reliable technical and economic data helps build understanding, dispel misconceptions and strengthen support for geothermal projects.

At the same time, establishing stable, transparent and supportive market frameworks is essential to unlock the economic potential of geothermal energy, given that underdeveloped infrastructure, fragmented incentives, unpredictable regulations and limited market integration currently hinder investment. Key measures include expanding and modernizing district heating networks, enabling the integration of geothermal heat into municipal and industrial systems, introducing financial incentives, price guarantees or long - term supply contracts and improving market connections between producers, distributors and consumers. Together, strengthened stakeholder confidence and well - designed market conditions reduce investment risks, encourage cost - effective project implementation and support the broader, sustainable deployment of geothermal solutions across the region.

CATEGORY 2: TECHNOLOGICAL OPPORTUNITIES

The second Category deals with the overall geothermal potential of the Central European region, meaning characteristics of exploration and exploitation fields and wells, exploration entities and demand assessment in the forms of use (heating/cooling, district heating, electricity) and users (industrial, agricultural, municipal, balneological, housing) of geothermal energy. Furthermore, the content is narrowed down to the specific well repurposing potentials described by mapping the well assessment in the 4 Basins (North German, Molasse, Vienna and Pannonian), analysing the existing and assessment of potential infrastructure, listing entities that perform drilling and reuse investments, identifying regions and well sites suitable for 5 repurposing technologies (ATES, DBHE, BTES, HE and EGS), performing social and economic analysis of well repurposing and corresponding 5 repurposing technologies, as well as describing the potential demand market (public and private entities, purposes of using the geothermal energy from repurposed wells).

Similar to the previous, the identified Strategic Objectives and corresponding Priorities for Category 2 are presented in the Figure below.

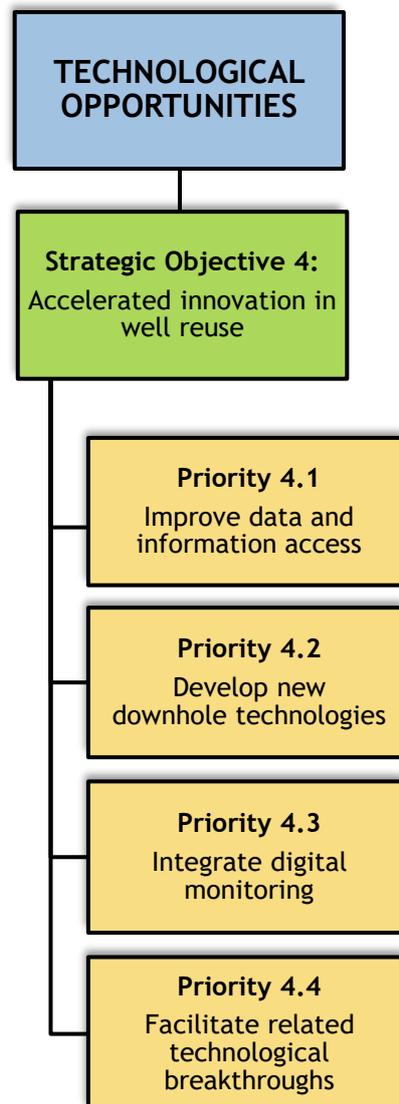


Figure 84: Strategic Objectives and Priorities supporting technological opportunities

Strategic Objective 4: Accelerated innovation in well reuse

Improving data access, advancing downhole technologies, integrating digital monitoring, and facilitating technological breakthroughs are essential for accelerating the safe and efficient repurposing of abandoned hydrocarbon wells for geothermal use in Central Europe. Strengthening data availability is a fundamental step, as gaps in geological and technical records, restricted access and inconsistent data quality currently increase uncertainty and hinder effective planning. Systematic digitization of historical well information, the creation of centralized and transparent transnational and national databases and the establishment of clear, non-discriminatory data-sharing protocols would allow developers, authorities and researchers to make informed, timely and reliable decisions.

Alongside better data, the development of innovative downhole technologies such as advanced logging tools, high-temperature and corrosion-resistant materials and real-time downhole monitoring systems is crucial for addressing aging infrastructure, unknown well conditions and long-term operational reliability, ultimately enabling safe and cost-effective geothermal conversions. Integrating digital monitoring systems further enhances operational transparency, safety and performance by allowing continuous tracking of key parameters, supporting predictive maintenance, improving regulatory oversight and boosting investor



confidence. Finally, facilitating broader technological breakthroughs through targeted research, development and demonstration projects, cross - border knowledge transfer and strong partnerships between academia, industry and government will help overcome remaining technical, economic and environmental barriers. Together, these actions strengthen risk management, improve project feasibility and support the widespread adoption of geothermal energy from repurposed hydrocarbon wells.

CATEGORY 3: ENVIRONMENTAL IMPACTS

Category 3 is the shortest part of the Transnational Strategy, but it covers a significant topic that needs to be taken into account when implementing energy investments. Here the environmental aspects of utilising geothermal energy from repurposed hydrocarbon wells are considered, whereby the analysis focuses on greenhouse gas (GHS) emissions, energy production waste, effects on the biodiversity (flora and fauna) and potential polluting impacts on soil and underground water. For this Category no division or analysis on country level has been conducted, given the assumption that the environmental aspects are equal or, at least, similar in the countries of the Central European region.

Also, the Strategic Objectives and corresponding Priorities relevant for this Category are shown in Figure 85 below.

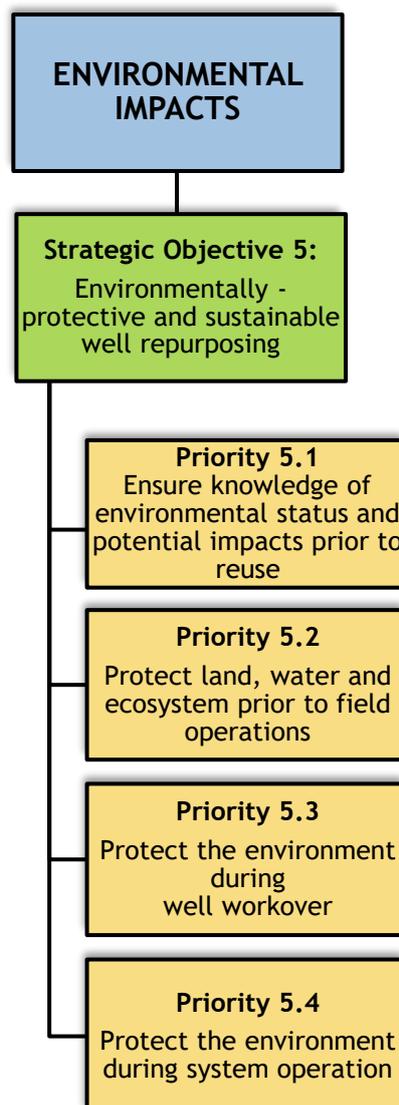


Figure 85: Strategic Objectives and Priorities supporting environmental impacts



Strategic Objective 5: Environmentally - protective and sustainable well repurposing

Ensuring environmental protection throughout the reuse of abandoned hydrocarbon wells for geothermal purposes requires comprehensive assessments, robust monitoring and stringent safeguards from pre - development through long - term operation. Many wells in Central Europe suffer from unknown or compromised integrity, increasing risks of corrosion, leakage, material degradation and contamination of soil, groundwater and surrounding strata and, therefore, systematic integrity evaluations combining physical inspections, pressure and leak tests and analyses of operational history must be conducted before reuse, followed by tailored repair, reinforcement or safe closure when necessary.

Baseline environmental surveys and continuous monitoring of gas and liquid emissions, groundwater quality and soil conditions are essential to detect pollutants such as hydrocarbons, saline water, heavy metals or harmful gases, while targeted interventions, including seal replacements, plug adjustments and installation of observation wells, ensure rapid mitigation of emerging risks. During field operations, noise, vibrations and artificial lighting can disturb surrounding communities and ecosystems, making the use of acoustic barriers, low - noise equipment, controlled lighting, careful scheduling and continuous noise and light monitoring essential. Gas emissions during drilling, pumping and maintenance must be assessed, monitored and managed through safe separation, treatment systems and emergency response protocols. During well workover activities, changes in pressure and fluid flow necessitate advanced hydrogeological modeling, reinjection scenario simulations, intermittent production tests and real - time monitoring for microseismicity and surface movement to maintain safe operational limits.

Finally, during long - term system operation, comprehensive environmental safeguards, including continuous well - integrity monitoring, spill prevention, waste and emission management, technologies to limit induced seismicity and subsidence and regular environmental audits are critical to minimizing land, water and ecosystem impacts. Together, these actions ensure that geothermal well repurposing enhances regional sustainability and environmental safety rather than introducing new ecological risks.

CATEGORY 4: FINANCING INSTRUMENTS

The last Category includes the existing financial opportunities which facilitate the implementation of geothermal and well repurposing investments. Thereby, the financial opportunities are analysed through an overview of the existing transnational (EU), national, regional and, in some cases, local funding schemes, as well as traditional, alternative and innovative financing instruments, applicable, mainly, in the 5 countries of the consortium, but, also, in the rest of the Central European region.

Finally, Figure 86 presents the set Strategic Objectives and corresponding Priorities for Category 4.

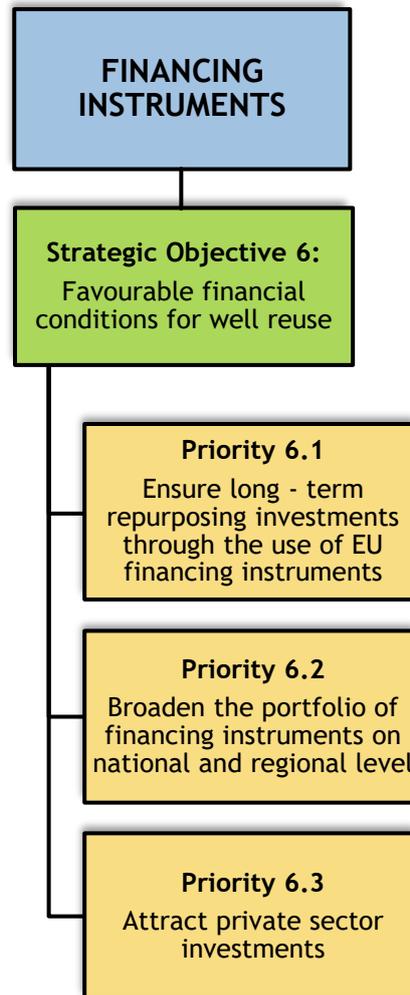


Figure 86: Strategic Objectives and Priorities supporting financing instruments

Strategic Objective 6: Favourable financial conditions for well reuse

Ensuring long - term investments in geothermal well repurposing requires a comprehensive approach combining transnational (EU) financing instruments, national and regional funding mechanisms and actions to attract private sector capital. Given the high upfront costs, technical, regulatory and operational uncertainties of geothermal projects, particularly those involving abandoned hydrocarbon wells, dedicated financial tools such as guarantees, insurance schemes, risk - sharing facilities, targeted grants, public co - financing, soft loans and results - based incentives or tax reliefs are essential to mitigate risks and make project financing more accessible and predictable. Investments in well refurbishment, modernization of surface facilities and integration with district heating, cooling, or electricity systems are capital - intensive and technically complex, necessitating innovative solutions to ensure economic viability.

Attracting private capital further requires reducing early - stage and subsurface risks through exploration insurance, feasibility studies and guarantees, creating predictable long - term revenues through purchase agreements, improving returns through tax and carbon credits and grants, as well as lowering financing costs via concessional loans, loan guarantees and blended public - private co - financing. Establishing clear, standardized investment pathways such as geothermal development companies, project aggregation platforms and green bonds combined with a stable regulatory environment, transparent permitting procedures, strong national geothermal strategies, and high - quality demonstration projects, fosters investor confidence and enables the successful scale - up of geothermal well repurposing across the region.



6. Implementation of the Transnational Strategy

As mentioned before, renewable energy sources are becoming more relevant in the decarbonization of the energy and other sectors in the European countries, whereby, apart from solar, water, wind and biomass, one of the, recently, widely used sources is geothermal energy. The regulation of geothermal energy is carried out through various legislative, legal, strategic and planning documents, which describe the current situations and potentials, as well as challenges and objectives for an optimal use of the mentioned energy source on European level.

Furthermore, various exploration studies and works carried out in the Central European region have proven the existence of significant geothermal potential, which cannot be exploited due to various legislative and legal, technological, environmental and financial barriers that occur on country level. As elaborated in the previous Chapter, each mentioned Category has several challenges and bottlenecks, which generated the main Strategic Objectives and Priorities for a rational use of geothermal energy in the Central European region, whereby, primary, in the 5 countries included in the project TRANSGEO.

Nevertheless, to successfully achieve the set Strategic Objectives and corresponding Priorities, this Chapter covers Measures that can be implemented in the future years, recommendations for achievement of the set Strategic Objectives, as well as the monitoring and reporting process of the document and all in order to make geothermal energy more regulated, available and used in the Central European region.

6.1. Recommendations and Measures for improvement

Each set Strategic Objective can be achieved by defining relevant Priorities and corresponding detailed Measures with realistic timeframes for their implementation. In the previous Chapter the most significant challenges and bottlenecks in the need for improvement, as well as the generated Strategic Objectives and Priorities have been classified into the following 4 Categories:

- Category 1: Legal, knowledge and social frameworks
- Category 2: Technological opportunities
- Category 3: Environmental impacts
- Category 4: Financing instruments.

In order to tackle the identified barriers and achieve the set Strategic Objectives and Priorities, the following Tables show the relevant Measures for their implementation. Hereby, the Measures are only listed, while a further and more detailed elaboration of the same will be covered in the Transnational Action Plan.

CATEGORY 1: LEGAL, KNOWLEDGE AND SOCIAL FRAMEWORKS

Strategic Objective 1: Clear, efficient and sustainable regulatory frameworks
Priority 1.1 Simplify, coordinate and modernize policy frameworks
Measure 1.1.1 Clarify well and land ownership, usage rights, liability and responsibilities
Measure 1.1.2 Coordinate and unify policies across jurisdictions
Measure 1.1.3 Ensure the alignment of new legislation and regulations with EU and national energy transition goals



Measure 1.1.4 Adjust national and regional strategic and planning documents for fostering geothermal energy use from repurposed wells
Priority 1.2 Streamline permitting procedures for well repurposing
Measure 1.2.1 Create One - Stop - Shop (OSS) permitting systems for well repurposing
Measure 1.2.2 Introduce fast - track approval for projects meeting well integrity verification and safety criteria standards

Strategic Objective 2: Deeper knowledge and competencies
Priority 2.1 Educate and train well reuse experts and workforce
Measure 2.1.1 Develop educational programs at secondary, university and postgraduate levels to create quality geothermal workforce in well reuse
Measure 2.1.2 Facilitate and encourage research and development programs, including joint industry - academic research on well reuse
Priority 2.2 Enhance collaboration between experts
Measure 2.2.1 Build a network of experts to accelerate and enable geothermal well reuse
Measure 2.2.2 Promote cross - border best - practice exchange through regional forums

Strategic Objective 3: Favourable social and market conditions
Priority 3.1 Enhance stakeholder trust and social acceptance
Measure 3.1.1 Raise awareness and knowledge among relevant stakeholders on the geothermal potential of repurposed hydrocarbon infrastructure
Measure 3.1.2 Mandate early and ongoing transparent stakeholder consultation with affected communities
Measure 3.1.3 Introduce community benefit agreements
Priority 3.2 Create favourable market conditions
Measure 3.2.1 Develop an integrated online platform for matching supply and demand of repurposed wells and proposing cost - effective geothermal reuse methodologies
Measure 3.2.2 Foster reuse of hydrocarbon wells by local heat market needs assessment and integration in urban planning
Measure 3.2.3 Support scaling - up of the geothermal reuse market through development of district heating systems and related infrastructure



CATEGORY 2: TECHNOLOGICAL OPPORTUNITIES

Strategic Objective 4: Accelerated innovation in well reuse
Priority 4.1 Improve data and information access
Measure 4.1.1 Develop open - access database of candidate and reused hydrocarbon wells by upgrading TRANSCEO IT tool for well assessment
Measure 4.1.2 Require public disclosure of well integrity testing, seismic monitoring and water quality data
Measure 4.1.3 Develop screening tools to identify and assess suitable wells, using digital technologies
Priority 4.2 Develop new downhole technologies
Measure 4.2.1 Design new and innovative casing repair technologies
Measure 4.2.2 Pilot new closed - loop geothermal retrofit technologies, including plug - and - play downhole heat exchanger systems
Measure 4.2.3 Test geothermal reservoir stimulation techniques in suitable wells
Priority 4.3 Integrate digital monitoring
Measure 4.3.1 Deploy fiber - optic sensing for real - time well performance, well integrity and induced seismicity monitoring
Measure 4.3.2 Use predictive digital twins to optimize energy extraction and system design
Priority 4.4 Facilitate related technological breakthroughs
Measure 4.4.1 Develop solutions for reinjection problems in difficult geology
Measure 4.4.2 Develop highly efficient heat pump technologies to enable heat utilisation of low and medium enthalpy geothermal energy potential

CATEGORY 3: ENVIRONMENTAL IMPACTS

Strategic Objective 5: Environmentally - protective and sustainable well repurposing
Priority 5.1 Ensure knowledge of environmental status and potential impacts prior to reuse
Measure 5.1.1 Conduct environmental impact assessment
Measure 5.1.2 Conduct baseline well integrity assessment
Priority 5.2 Protect land, water and ecosystem prior to field operations
Measure 5.2.1 Restore habitat and remediate pollution
Measure 5.2.2 Mitigate noise and light pollution
Measure 5.2.3 Avoid gas emissions and apply safe management protocols
Priority 5.3 Protect the environment during well workover
Measure 5.3.1 Ensure workover operational plan to manage hydrogeological and geo - mechanical risks



Measure 5.3.2 Conduct well repair or retrofit to avoid leakage and isolate well from swelling formations
Measure 5.3.3 Limit sound and light disturbance by insulating the site and operating during daytime
Priority 5.4 Protect the environment during system operation
Measure 5.4.1 Reinject produced fluids to avoid subsidence, scaling, gas/radionuclide release and waste processing
Measure 5.4.2 Conduct appropriate monitoring/inspection and maintenance to detect and prevent leaks and other potential environmental impacts

CATEGORY 4: FINANCING INSTRUMENTS

Strategic Objective 6: Favourable financial conditions for well reuse
Priority 6.1 Ensure long - term repurposing investments through the use of EU financing instruments
Measure 6.1.1 Create targeted grant programmes for well repurposing at EU level
Measure 6.1.2 Establish a well repurposing community in Central Europe
Measure 6.1.3 Foster transnational project collaborations for EU funding (including community - led initiatives)
Priority 6.2 Broaden the portfolio of financing instruments on national and regional level
Measure 6.2.1 Introduce innovative public funding programs for environmental remediation and well testing
Measure 6.2.2 Initiate national and regional funding mechanisms for well repurposing
Priority 6.3 Attract private sector investments
Measure 6.3.1 Educate potential investors on well repurposing for geothermal energy production
Measure 6.3.2 Facilitate private sector investment and Public - Private Partnerships (PPPs)

6.2. Achievement of the Strategic Objectives

Apart from the defined Measures, the achievement of the Strategic Objectives requires, also, an organizational approach by including the most relevant institutions, personnel and methods into their realization. Since the Transnational Strategy is developed within the project TRANS GEO, the implementation of the same will be carried out, mostly, by the partner organisations from the 5 countries of the consortium, which cover a wide range of expertise and professionals in the fields of geology, engineering (geothermal, oil mining, electrical, mechanical), economy, industry, policy advocacy and project management.

The joint knowledge, expertise and experience of the partner organizations will ensure a thorough implementation of the Transnational Strategy on, firstly and primary, national levels in the 5 countries of the consortium, whereby special focus will be set on changes in the national legislatives and legal frameworks for geothermal energy use through the transformation of abandoned hydrocarbon wells into geothermal ones. Also, further improvement can be made through encouraging the alignment of the national legislatives and legal frameworks with the overall European strategic and planning documents covering the



topics of renewable energy sources and geothermal energy, out of which the most significant are the Renewable Energy Directive (with its revisions RED II and RED III), Energy Efficiency Directive, European Green Deal, Affordable Energy Action Plan and the European Geothermal Action Plan (which will be published in 2026) (European Commission, 2025).

Furthermore, the realization of the document's vision can be ensured through support activities, including various public and private entities, out of which the most significant are the following:

- **Public entities**

- Relevant ministries (e.g., energy, environmental protection, sustainable development, regional development, construction, economy, finance, etc.)
- National, regional and local governmental units (e.g., regions, provinces, counties, cities, towns, municipalities, etc.)
- Research and educational institutions (e.g., universities, faculties, institutes, centres, etc.)
- Companies in public ownership (e.g., research companies, companies for exploitation of hydrocarbons, utility companies, etc.)
- Agencies and institutions in public ownership (e.g., development, energy, sectoral agencies, etc.)
- Non - governmental organizations (NGOs) (e.g., local action groups, relevant associations, citizen communities, etc.)

- **Private entities**

- Companies in private ownership (e.g., research companies, companies for exploitation of hydrocarbons, drilling companies, utility companies, etc.)
- Research and educational institutions (e.g., universities, faculties, institutes, centres, etc.)
- Service companies (e.g., project designers, architects, constructors, equipment providers, etc.).

Related to the mentioned, timely coordination, as well as vertical and horizontal cooperation with the relevant public and private entities can ensure a deeper infiltration of the Transnational Strategy into different governmental levels, as well as fields of operation. Apart from the mentioned institutional entities, a stronger realization of the document's objectives can be achieved through the involvement of the general public. Different dissemination activities such as promotional campaigns, awareness raising workshops, working groups with public consultations and study visits can provide the general public a better insight into the geothermal energy and its characteristics, as well as take their thoughts, needs and preferences into account when shaping the policies and activities related to the transformation of abandoned hydrocarbon wells into geothermal ones. To foster the interest of such a wider stakeholder group, highlighting the potential use of geothermal energy in sectors such as industry, agriculture and municipality may be crucial to raise awareness of the benefits the renewable energy source brings. The involvement of the general public can, also, ensure a wider perspective in considering geothermal energy as a potential energy source and help in the consideration of starting such investments in the Central European region.

In order to gather deeper knowledge and experience, quality and efficient cooperation on transnational level is, also, required. Applying and implementing new projects within different transnational financing instruments with the topics of renewable energy sources, and especially geothermal energy, can provide wider best practice examples and knowledge sharing, replication of technological and technical solutions, spread of research results and strengthen the cooperation with relevant institutions abroad. Also, transnational programs and projects are considered as financing sources covering a wide range of activities



(from soft measures to infrastructural works) which can lead to a better accessibility to various technologies and technical solutions, easier research activities and overcoming some of the barriers hindering the geothermal energy exploration, exploitation and use.

Finally, as the Transnational Strategy is considered to be an overall framework document covering the current potentials, environmental impacts, financing instruments, as well as challenges, Strategic Objectives and Priorities with corresponding Measures when using geothermal energy from abandoned hydrocarbon wells, it is important to highlight that its implementation will be ensured, mostly through the accompanying Transnational Action Plan. Apart from the theoretical background presented in the Transnational Strategy, the Transnational Action Plan will contain detailed Measures with the identified activities, resources, timeframes and indicators of success serving, thereby, as a practical guidance document for public and private entities involved into the process of geothermal energy utilisation.

6.3. Monitoring and reporting

As mentioned before, the Transnational Strategy is an overall theoretical framework document, whose implementation is carried out through different activities and cooperation with relevant public and private entities. In this process it is important to establish a well - organized monitoring and reporting system, in order to ensure a successful implementation and remove actual barriers, as well as mitigate potential risks that may occur during the realization of the documents' vision.

In these terms, the activities of monitoring and reporting will be defined by the partner organisations from 5 countries of the consortium, whereby the implementers will agree upon the personnel, ways, frequency and extensiveness in which these activities will be carried out. Related to the mentioned, monitoring implies the collection, analysis and comparison of the achieved vision and goals presented in the Transnational Strategy, as well as revisions of the set Strategic Objectives, Priorities and Measures when needed. On the other hand, reporting will contribute to the determination of the achievement level of the set Objectives, tackling potential hindering factors and planning future steps in the implementation of the document.

Furthermore, as this document was not foreseen as one of the national strategic and planning documents that are, mostly, developed by national authorities, the process of monitoring and reporting will, at first, be carried out within the consortium of the project TRANSCEO. Since the overall aim is to promote the Transnational Strategy and accept its guidance on national levels, in the later phases the monitoring can be carried out and reporting submitted to the public entities (mainly, national and regional authorities) selected as the control bodies for the implementation of the document.

Since the Transnational Strategy is paired with the Transnational Action Plan, its influence will be monitored and reported through detailed Measures and their indicators of success, as well as the set timeframes for their realization. Finally, continuous monitoring and reporting will contribute to further revisions of the content, set vision and goals of the Transnational Strategy and ensure the alignment of the document with the new legislative and legal frameworks, as well as market situations.



7. Concluding remarks

Geothermal energy is slowly becoming one of the most significant renewable energy sources in the world. Characteristics such as wide distribution, possibility of continuous supply, lower negative impact on the environment and decreased costs increase the popularity of utilising this energy source for industrial, agricultural and municipal purposes. In this process one of the largest potential future beneficiaries of geothermal energy is Europe, whereby its Central part has a potential to become a key player in geothermal energy, tapping into its rich natural resources to advance sustainable development. Here, geothermal energy is, mainly, exploited by drilling new wells, using different technological solutions and methods for a smoother utilisation of the energy source. Considering the high investment costs, complicated procedures and negative impacts on the environment, recent thinking and research indicates that geothermal energy can be utilised from abandoned hydrocarbon wells.

The project TRANSGEO considers the possibilities of repurposing the leftover decaying hydrocarbon infrastructure into functional geothermal facilities for generation of electrical, heating and cooling energy across the 5 countries of the consortium. The socio - economic analyses, IT tool for well assessment and its corresponding report, as well as the feasibility studies have formed this **Transnational Strategy for the structural change of fossil fuel producing regions to geothermal**, which presents a theoretical guideline document for public and private stakeholders, with the aim of tackling the current challenges and barriers related to geothermal energy utilisation from repurposed abandoned hydrocarbon infrastructure in the Central European region.

Covering a wide range of information about the current features related to repurposing of abandoned hydrocarbon wells in the 5 countries of the consortium, the Transnational Strategy has generated conclusions related to the fact that the Central European region builds on existing infrastructure, with some areas demonstrating mature utilisation systems, while others are gaining traction through targeted initiatives. Legislative landscapes differ, offering both potential and obstacles, with efforts needed to align regulations and improve investment conditions, while educational changes are needed to cultivate a capable workforce, providing a solid base for long - term progress. The geological potential across the region is significant, though challenges such as limited data access highlight the value of cooperative resource assessment. Also, environmental impacts could be mitigated through careful technical, logistical and strategic project design and monitoring, which must be conducted at all times in compliance with international, national and local environmental regulations. Finally, the lack of adequate financial opportunities with diverse applicable activities is solvable with better transnational cooperation, networking and attraction of innovative instruments, with private capital being the basis for starting investments.

Relying on the mentioned findings, the Transnational Strategy generated 4 main categories (legal, knowledge and social frameworks; technological opportunities; environmental impacts; and financing instruments), in which significant improvements are necessary for a more sustainable energy utilisation and alignment with the global climate goals. Here, Strategic Objectives and Priorities with accompanying Measures provide potential solutions for the identified challenges and obstacles, as well as present a step forward in the use of renewable energy sources.

Finally, the theoretical insights provided in this document are the basis for the development of the **Transnational Action Plan with intervention set for geothermal reuse of abandoned hydrocarbon wells**, where a more practical approach will ensure that meeting the set Strategic Objectives, Priorities and Measures becomes one of the paths towards a more sustainable and energy neutral Central Europe.



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Annexes

Annex A - Zusammenfassung

Das Projekt TRANSCEO - Nachnutzung stillgelegter Bohrlöcher für die geothermische Energieerzeugung - wird von einem Konsortium aus elf Partnerorganisationen in fünf mitteleuropäischen Ländern (Österreich, Kroatien, Deutschland, Ungarn und Slowenien) durchgeführt, wobei fachübergreifende Kompetenzen in Forschung und Wirtschaft im Bereich der Geothermie genutzt werden, um hochstrukturierte, praxisorientierte und wissenschaftliche Lösungen in Form von digitalen Werkzeugen, Dokumenten und anderen nachhaltigen Lösungen herauszuarbeiten.

Ein Ergebnis der gemeinsamen Zusammenarbeit ist eine **Transnationale Strategie für den strukturellen Wandel von fossilen Brennstoff produzierenden Regionen hin zur Geothermie**. Ausgangspunkt dafür sind zahlreiche Projektaktivitäten und -ergebnisse sowie das gesamte Fachwissen des Konsortiums. Die wichtigsten Datenquellen sind hierbei drei sozioökonomische Analysen zur Nachnutzung stillgelegter Bohrlöcher für industrielle, landwirtschaftliche und kommunale Zwecke. Des Weiteren dienen das im Projekt erstellte IT - Tool, welches zur Bohrlochbewertung herangezogen werden kann, sowie der dazugehörige Bericht und eine vergleichende Analyse der politischen Rahmenbedingungen in verschiedenen Regionen als Grundlage. Diese Daten wurden aus wissenschaftlichen Forschungsarbeiten, verfügbaren Datenbanken, Vergleichen bestehender strategischer Dokumente, gemeinsamen Konsultationen und dem Wissensaustausch zwischen den Partnerorganisationen zusammengetragen. Dieses strategische Dokument ist ein methodischer Leitfaden für verschiedene öffentliche und private Interessengruppen und soll eine regulierte und organisierte Nutzung der geothermischen Energie aus stillgelegten Kohlenwasserstoffinfrastrukturen steuern.

Um die festgelegte Projektziele zu erreichen, deckt die transnationale Strategie die aktuelle Situation in den fünf am Projekt beteiligten Ländern, hinsichtlich der legislativen, rechtlichen und bildungspolitischen Merkmale, der Umweltauswirkungen und der finanziellen Möglichkeiten ab. Die Bedeutung des Dokuments liegt in der Identifizierung von Herausforderungen und Hindernissen, die bei der Umsetzung von Geothermieprojekten und Investitionen auftreten. Durch gründliche Analysen wurde gezeigt, dass langwierige Verwaltungsverfahren, Mangel an qualifiziertem Personal, technologische Lücken und unzureichende, umfassende Finanzierungsmöglichkeiten die größten Problemfaktoren sind.

Um die identifizierten Probleme anzugehen, enthält die transnationale Strategie auch Vorschläge und Lösungen in Form von Zielen, Prioritäten und Maßnahmen, die in vier Hauptkategorien unterteilt sind: rechtliche, bildungspolitische und soziale Rahmenbedingungen; technologische Möglichkeiten; Umweltauswirkungen und Finanzierungsinstrumente. Der Schwerpunkt liegt dabei auf der Vereinfachung und Verbesserung der Verfügbarkeit der verschiedenen Ressourcen, die zur Steigerung der Nutzung von Geothermie aus bereits vorhandener Infrastruktur erforderlich sind. Da diese Schwerpunktkategorien und Empfehlungen nur in gekürzter Form dargestellt werden, dient dieses Dokument als Grundlage für die künftige Entwicklung des **Transnationalen Aktionsplans mit Maßnahmenpaket zur geothermischen Nutzung stillgelegter Kohlenwasserstoffbohrungen**.

Das Projekt TRANSCEO (<https://www.interreg-central.eu/projects/transgeo/>) wird vom Europäischen Fond für regionale Entwicklung im Rahmen des Programms Interreg Mitteleuropa 2021 - 2027 kofinanziert. Das übergeordnete Ziel des Projekts TRANSCEO ist es, das Potenzial zur Umwandlung stillgelegter Kohlenwasserstoffbohrungen (Erdgas und Erdöl) in neue Quellen für grüne Geothermie zu untersuchen. Um dieses Ziel zu erreichen, stellen die TRANSCEO - Partnerorganisationen neue Instrumente und Kenntnisse zur Verfügung, um Gemeinden und Industriezweige bei der Energiewende zu unterstützen und wirtschaftliche und technische Hindernisse für die Wiederverwendung von Bohrlöchern abzubauen.



Annex B - Sažetak

Projekt TRANSGEO - Revitalizacija napuštenih bušotina za eksploataciju geotermalne energije provodi konzorcij od 11 partnerskih organizacija iz 5 srednjoeuropskih zemalja (Austrija, Hrvatska, Njemačka, Mađarska i Slovenija). Kombinacijom znanja, stručnosti i istraživanja u području korištenja geotermalne energije nastaju visoko strukturirani, praktično utemeljeni i znanstveni rezultati u obliku digitalnih alata, dokumenata i drugih održivih rješenja.

Jedan od dokumenata proizašlih iz zajedničke suradnje je **Transnacionalna strategija za strukturnu promjenu regija koje proizvode fosilna goriva prema geotermalnoj energiji**. Početni ulazni podaci za ovaj dokument bili su brojni projektni zadaci i rezultati, kao i ukupna stručnost konzorcija. Glavni izvori podataka bile su tri socioekonomske analize prenamjene napuštenih bušotina za industrijsku, poljoprivrednu i komunalnu uporabu, IT alat za procjenu bušotina i pripadajuće izvješće te komparativna analiza političkih okvira u različitim regijama. Podaci su prikupljeni iz znanstvenih i istraživačkih radova, dostupnih baza podataka, usporedbe postojećih strateških dokumenata, kao i zajedničkih konzultacija i razmjene znanja među partnerskim organizacijama. Ovaj strateški dokument izrađen je s namjerom da posluži kao teorijski vodič za različite javne i privatne dionike te ih usmjeri prema reguliranijem i organiziranijem korištenju geotermalne energije iz napuštene infrastrukture ugljikovodika. Nadalje, dokument i njegovi nalazi odražavaju isključivo stajališta autora.

Kako bi se postigli zadana vizija, svrha i ciljevi, Transnacionalna strategija obuhvaća trenutačno stanje u 5 zemalja uključenih u projekt TRANSGEO s aspekta zakonodavnih, pravnih i obrazovnih značajki, okolišnih utjecaja te financijskih mogućnosti za korištenje geotermalne energije iz napuštenih bušotina ugljikovodika. Značaj dokumenta očituje se u prepoznavanju izazova i prepreka koje se javljaju pri provedbi geotermalnih projekata i ulaganja, pri čemu su opsežne analize pokazale da su dugotrajni administrativni postupci, nedostatak kvalitetnog i stručnog kadra, tehnološki jaz te nedovoljno sveobuhvatne mogućnosti financiranja najveći ometajući čimbenici.

Kako bi se odgovorilo na identificirane prepreke, Transnacionalna strategija predstavlja prijedloge i rješenja u obliku strateških ciljeva, prioriteta i mjera, grupiranih u četiri glavne kategorije: pravni okvir, znanje i društveni aspekti; tehnološke mogućnosti; okolišni utjecaji i financijski instrumenti. Njihov je opći fokus usmjeren na pojednostavljenje i poboljšanje dostupnosti različitih resursa potrebnih za unapređenje korištenja geotermalne energije iz već postojeće infrastrukture. Kako su ove tematske kategorije i preporuke prikazane samo u sažetom obliku, dokument služi kao osnova za buduću izradu **Transnacionalnog akcijskog plana s nizom mjera za prenamjenu napuštenih bušotina ugljikovodika za geotermalnu upotrebu**.

Projekt TRANSGEO (<https://www.interreg-central.eu/projects/transgeo/>) sufinanciran je iz Europskog fonda za regionalni razvoj kroz program Interreg Središnja Europa 2021. - 2027. Opći cilj projekta je istražiti potencijal prenamjene napuštenih bušotina ugljikovodika (plinskih i naftnih) u nove izvore zelene geotermalne energije. Kako bi se taj cilj ostvario, partnerske organizacije projekta TRANSGEO razvijaju nove alate i znanja za podršku zajednicama i industrijama u energetskej tranziciji te uklanjanje ekonomskih i tehničkih prepreka za ponovnu uporabu bušotina.



Annex C - Vezetői Összefoglaló

A TRANSGEO projekt - Felhagyott kutak átalakítása geotermikus energia termelésre - egy 5 közép - európai országból (Ausztria, Horvátország, Németország, Magyarország és Szlovénia) származó, 11 partner szervezetből álló konzorcium által valósul meg, amelynek keretében a geotermikus energia hasznosításának területén meglévő tudás, szakértelem és kutatások kombinációja jól strukturált, gyakorlati és tudományos eredményeket hoz létre digitális eszközök, dokumentumok és egyéb fenntartható megoldások formájában.

A közös együttműködés eredményeként született dokumentum, a **Transznacionális stratégia, mely a fosszilis tüzelőanyagot termelő régiók geotermikus energia felhasználásával történő szerkezeti átalakulást mutatja be**, és amelynek kiindulási alapját számos projekttevékenység és -eredmény, valamint a konzorcium általános szakértelme képezte. A fő adatforrások a következők voltak: 3 társadalmi - gazdasági elemzés a felhagyott kutak ipari, mezőgazdasági és kommunális célokra való átalakításáról, a kutak értékelésére szolgáló informatikai eszköz és a hozzá tartozó jelentés, valamint a különböző régiók politikai kereteinek összehasonlító elemzése. Ezeket az adatokat tudományos és kutatási cikkekből, elérhető adatbázisokból, a meglévő stratégiai dokumentumok összehasonlításából, valamint a partner szervezetek közötti közös konzultációkból és tudásmegosztásból gyűjtötték össze. Ez a stratégiai dokumentum tehát azzal a szándékkal készült, hogy elméleti iránymutatásként szolgáljon a különböző állami és magánszereplők számára, azzal a céllal, hogy ösztönözze őket a felhagyott szénhidrogén-infrastruktúrából származó geotermikus energia szabályozottabb és szervezettebb hasznosítására. A dokumentum és annak megállapításai kizárólag a szerzők véleményét tükrözik.

A kitűzött jövőkép, célok és célkitűzések elérése érdekében a Transznacionális Stratégia a TRANSGEO projektben résztvevő 5 ország jelenlegi helyzetét fedi le a jogalkotási, jogi és oktatási jellemzők, a környezeti hatások és a geotermikus energia hasznosításának pénzügyi lehetőségei tekintetében a felhagyott szénhidrogén-kutakból. A dokumentum jelentősége abban rejlik, hogy azonosítja a geotermikus projektek és beruházások megvalósításában felmerülő kihívásokat és akadályokat, amelyek alapos elemzése alapján a legjelentősebb gátló tényezők a hosszadalmas adminisztratív eljárások, a minőségi és szakértő személyzet hiánya, a technológiai hiányosságok és a nem kielégítő átfogó finanszírozási lehetőségek.

Az azonosított akadályok leküzdése érdekében a transznacionális stratégia stratégiai célok, prioritások és intézkedések formájában javaslatokat és megoldásokat is tartalmaz, amelyeket négy fő kategóriába soroltak: jogi, elméleti és társadalmi keretek; technológiai lehetőségek; környezeti hatások; valamint finanszírozási eszközök. Átfogó céljuk a már meglévő infrastruktúrából származó geotermikus energia hasznosításának javításához szükséges különböző erőforrások egyszerűsítése és elérhetőségének javítása. Végül, mivel ezek a fókusz kategóriák és ajánlások csak tömör formában kerülnek bemutatásra, ez a dokumentum a **Transznacionális Akcióterv** alapját is képezi, mely **az elhagyott szénhidrogénkutak geotermikus újrahhasznosítására irányuló beavatkozásokat mutatja be**.

A TRANSGEO (<https://www.interreg-central.eu/projects/transgeo/>) projektet az Európai Regionális Fejlesztési Alap társfinanszírozza az Interreg Közép - Európa 2021 - 2027 program keretében. A TRANSGEO projekt átfogó célja annak vizsgálata, hogy a felhagyott szénhidrogén (földgáz és olaj) kutakat hogyan lehetne új, zöld geotermikus energiaforrásokká alakítani. E cél elérése érdekében a TRANSGEO partner szervezetek új eszközöket és ismereteket biztosítanak a közösségek és az iparágak támogatására az energetikai átállás során, valamint a kutak újrahhasznosításának gazdasági és műszaki akadályainak leküzdésére.



Annex D - Povzetek

Projekt TRANSGEO - Revitalizacija opuščenih vrtin za proizvodnjo geotermalne energije je izvedel konzorcij 11 partnerskih organizacij iz petih srednjeevropskih držav (Avstrija, Hrvaška, Nemčija, Madžarska in Slovenija). Z združevanjem znanja, strokovnosti in raziskav na področju rabe geotermalne energije se odraža v visoko strukturiranih, na praksi temelječih in znanstvenih rezultatih, kot so digitalna orodja, dokumenti in druge trajnostne rešitve.

Eden izmed dokumentov, nastalih v okviru skupnega sodelovanja, je **Transnacionalna strategija za strukturne spremembe regij, ki proizvajajo fosilna goriva, v geotermijo**. Izhodišča zanjo predstavljajo številne projektne aktivnosti in rezultati ter celovito strokovno znanje konzorcija. Glavni viri podatkov so bile tri socio-ekonomske analize ponovne uporabe opuščenih vrtin za industrijske, kmetijske in komunalne namene. Hkrati je bilo razvito IT - orodje za oceno vrtin z ustreznim poročilom ter primerjalna analiza politik in zakonodajnih okvirov v različnih regijah. Podatki so bili zbrani iz znanstvenih in raziskovalnih publikacij, razpoložljivih podatkovnih zbirk, primerjav obstoječih strateških dokumentov ter skupnih posvetovanj in izmenjave znanja med partnerskimi organizacijami. Ta strateški dokument je bil pripravljen z namenom uporabe kot teoretična usmeritev za različne javne in zasebne deležnike ter jih usmerjati k bolj regulirani in organizirani rabi geotermalne energije iz opuščene infrastrukture za pridobivanje ogljikovodikov. Dokument in njegove ugotovitve odražajo izključno stališča avtorjev.

Za dosego zastavljene vizije, namena in ciljev Transnacionalna strategija obravnava trenutno stanje v petih državah, vključenih v projekt TRANSGEO, z vidika zakonodajnih, pravnih in izobraževalnih značilnosti, okoljskih vplivov ter finančnih priložnosti za izrabo geotermalne energije iz opuščenih vrtin. Pomen dokumenta je v identifikaciji izzivov in ovir pri izvajanju geotermalnih projektov in naložb. Temeljite analize so pokazale, da so dolgotrajni administrativni postopki, pomanjkanje usposobljenega strokovnega kadra, tehnološke vrzeli in nezadostne celovite možnosti financiranja glavni zaviralni dejavniki.

Za odpravo ugotovljenih ozkih grl Transnacionalna strategija predstavlja tudi predloge in rešitve v obliki strateških ciljev, prioritet in ukrepov, razvrščenih v štiri glavne kategorije: pravni, poznavalski in družbeni okviri; tehnološke priložnosti; okoljski vplivi; ter finančni instrumenti. Njihov skupni poudarek je na poenostavitvi in izboljšanju dostopnosti virov, potrebnih za povečanje izrabe geotermalne energije iz že obstoječe infrastrukture. Ker so te vsebinske usmeritve in priporočila predstavljene zgolj v strnjeni obliki, dokument služi kot osnova za nadaljnji razvoj **Transnacionalnega akcijskega načrta z naborom ukrepov za geotermalno ponovno uporabo opuščenih hidrokarbonskih vrtin**.

Projekt TRANSGEO (<https://www.interreg-central.eu/projects/transgeo/>) sofinancira Evropski sklad za regionalni razvoj v okviru programa Interreg Srednja Evropa 2021 - 2027. Glavni cilj projekta TRANSGEO je raziskati potencial preoblikovanja opuščenih vrtin za pridobivanje ogljikovodikov (zemeljskega plina in nafte) v nove vire zelene geotermalne energije. Za dosego tega cilja partnerske organizacije TRANSGEO zagotavljajo nova orodja in znanja za podporo skupnostim in industriji pri energetskem prehodu ter za odpravo ekonomskih in tehničnih ovir pri ponovni uporabi vrtin.