Interreg CENTRAL EUROPE

Co-funded by the European Union

TRANSGEO

Report on the transnational repurpose potential in Central Europe

TRANSGEO Deliverable 2.2.1

Version 1

10 2025

Authors

Monika Hölzel Jacques Brives	GeoSphere Austria	monika.hoelzel@geosphere.at jacques.brives@geosphere.at	Austria
Ferenc Fedor János Kovács	CROST Regional Development Nonprofit Ltd. University of Pécs	fedor.ferenc@geochem-ltd.eu jones@gamma.ttk.pte.hu	Hungary
Tomislav Kurevija Marija Macenić	University of Zagreb - Faculty of Mining, Geology and Petroleum Engineering	tomislav.kurevija@rgn.unizg.hr marija.macenic@rgn.unizg.hr	Croatia
Matej Prkič	Local Energy Agency Pomurje	matej@lea-pomurje.si	Slovenia
Katrin Sieron	State Office for Mining, Geology and Raw Material of Brandenburg	Katrin.Sieron@lbgr.brandenburg.de	Germany

Declaration of generative AI and AI-assisted technologies in the writing process:

During the preparation of this work, the authors used ChatGPT and the machine translator and writing tool DeepL in order to correct the grammar of the writing. After using these tools/services, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Table of contents

1 Executive Summary **4**

2 Introduction **6**

3 Background of well selection process **7**
3.1 Data availability in database 7
3.1.1 North German Basin 9
3.1.2 Molasse Basin 9
3.1.3 Vienna Basin 9
3.1.4 Pannonian Basin 9
3.2 Criteria Catalogue 10

4 North German Basin (Germany) **12**
4.1 ATES 13
4.2 DBHE 17
4.3 BTES 21
4.4 HE 25
4.5 EGS 29
4.6 Summary of the repurposing potential of the North German Basin 33

5 Molasse Basin (Germany - Austria) **35**
5.1 ATES 36
5.2 DBHE 40
5.3 BTES 43
5.4 HE 46
5.5 EGS 50
5.6 Summary of the repurposing potential of the Molasse Basin in Germany and Austria 53

6 Vienna Basin (Austria) **55**
6.1 ATES 57
6.2 DBHE 61
6.3 BTES 65
6.4 HE 69
6.5 EGS 73
6.6 Summary of the repurposing potential of the Vienna Basin 77

7 Pannonian Basin (Slovenia - Croatia - Hungary) **79**
7.1 Croatian part of Pannonian Basin 80
7.1.1 ATES 81
7.1.2 DBHE 84

7.1.3 BTES 86
7.1.4 HE 88
7.1.5 EGS 90
7.1.6 Summary of the repurposing potential of the Pannonian Basin (Croatian part) 93

7.2 Hungarian part of Pannonian Basin 94
7.2.1 ATES 96
7.2.2 DBHE 98
7.2.3 BTES 100
7.2.4 HE 102
7.2.5 EGS 104
7.2.6 Summary of the repurposing potential of the Pannonian Basin (Hungarian part) 106

7.3 Slovenian part of Pannonian Basin 111
7.3.1 ATES 112
7.3.2 DBHE 115
7.3.3 BTES 117
7.3.4 HE 120
7.3.5 EGS 121
7.3.6 Summary of the repurposing potential of the Pannonian Basin (Slovenian part) 123

8 Summary of the repurpose potential in Central Europe 125

9 References 133

1 Executive Summary

This report was prepared by the consortium of the project TRANSGEO and represents Deliverable 2.2.1, "Report on the transnational repurpose potential in Central Europe". Its purpose is to evaluate the potential of reusing existing hydrocarbon wells for geothermal applications in Germany, Austria, Slovenia, Croatia, and Hungary. Using the online well assessment tool developed in TRANSGEO Activity 1.4, regional databases compiled in Activity 2.1 were analysed to determine the suitability of wells for five geothermal technologies: Aquifer Thermal Energy Storage (ATES), Deep Borehole Heat Exchangers (DBHE), Borehole Thermal Energy Storage (BTES), Hydrothermal Energy (HE), and Enhanced Geothermal Systems (EGS). The report reflects the views of the authors.

This deliverable quantifies the repurposing potential of these wells and provides stakeholders, such as well owners, municipalities, industry, and policymakers, with first-order information on where geothermal reuse may be feasible. It contributes to the wider project objective of supporting the transition from hydrocarbon production towards sustainable geothermal energy in Central Europe and of strengthening transnational cooperation in the energy transition.

National datasets from Germany, Austria, Slovenia, Croatia, and Hungary were compiled using a common template and integrated into a relational database. Data inconsistencies were corrected, borehole naming conflicts resolved, and all entries transformed into a uniform geographic coordinate system. Calculated values such as geothermal gradients and surface temperatures were added to ensure comparability across hydrocarbon basins.

A criteria catalogue was then applied through a decision tree, classifying wells according to a traffic-light system: potentially suitable (green), uncertain (yellow), or not suitable (red). This system is permissive, meaning that incomplete data do not exclude a well but highlight the need for further investigation. Results are visualised in a browser-based dashboard environment, which integrates supplementary geospatial information such as land use, Natura 2000 sites, and district heating networks.

The basin-level assessment provides a first step towards evaluating the repurposing potential of hydrocarbon wells across Central Europe, highlighting the most promising technologies and regional differences. The results are summarised as follows:

- In the North German Basin (2,974 wells), the analysis indicates a low potential for DBHE, with 2.4% of wells classified as suitable. BTES (1.7%) and HE (1.7%) present less potential, while ATES (0.5%) and EGS, with 0.7%, rank lowest, with very few wells meeting the necessary criteria.
- For the Molasse Basin (2,020 wells), DBHE and BTES emerge as the most promising options, with 11% and 9.6% of wells suitable for repurposing with these technologies. HE, with 7.5%, presents moderate potential, whereas ATES and EGS are found to be marginal in this region with only 1.5% and 1.1%, respectively.
- In the Vienna Basin (3,357 wells), the overall suitability is low. DBHE (7.6%) and BTES (7%) record the highest potential, followed by HE with 5.7%. EGS and ATES are lowest, with 0.6% and 0.4%, respectively.
- The Pannonian Basin shows varied results: DBHE (16.6%) and EGS (10.8%) show the strongest potential, HE (8%) and BTES (6.3%) emerge with lower potential, and ATES is lowest with 0.7%.

In total, approximately 8,900 wells were systematically assessed. DBHE consistently emerges as the most promising reuse method across all regions, while HE and BTES demonstrate moderate but site-specific potential. ATES remains limited due to geological constraints, and EGS has the lowest overall reuse potential, though localised opportunities exist.

The findings confirm that geothermal repurposing of hydrocarbon wells could play an important role in supporting the regional energy transition and reducing reliance on fossil fuels. All wells, but especially wells classified as “uncertain”, require detailed site-specific feasibility studies to verify the potential before investment or implementation. To unlock the full potential, harmonisation of data availability and regulatory frameworks across countries will be essential, ensuring that technical feasibility can be translated into practical projects.

The TRANSGEO project (https://www.interreg-central.eu/projects/transgeo/) is co-funded by the European Regional Development Fund through the Interreg Central Europe program. The overall objective of TRANSGEO is to investigate the potential to transform abandoned hydrocarbon wells into new sources of green geothermal energy. To reach this goal, the TRANSGEO team is 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.

2 Introduction

The well assessment tool developed within TRANSGEO Activity 1.4 (IT tool: https://transgeo.eu/) was applied to all regional databases established under TRANSGEO Activity 2.1 to evaluate and quantify the potential for repurposing existing hydrocarbon wells for geothermal energy production. The assessment also encompassed a transnational analysis of infrastructure and heat demand, enabling the identification of areas suitable for implementing five geothermal well-repurposing technologies elaborated in TRANSGEO Activity 1.1: Aquifer Thermal Energy Storage (ATES), Deep Borehole Heat Exchanger (DBHE), Borehole Thermal Energy Storage (BTES), Hydrothermal Energy (HE), and Enhanced Geothermal Systems (EGS).

The resulting outputs support a structured transition from conventional hydrocarbon extraction to geothermal energy utilization across Central Europe, promoting sustainable energy development in rural regions. Figure 1 shows the TRANSGEO Central Europe region, the 4 sedimentary basins targeted in TRANSGEO, and the participating countries: Germany, Austria, Slovenia, Croatia, and Hungary.

Figure 1: TRANSGEO Central Europe region (green) and basin outlines (blue).

The following sections describe the structure of the TRANSGEO database, the well assessment (IT) tool and the well selection criteria used to identify suitable candidates for geothermal repurposing. These criteria yield a filtered database and a series of spatial datasets and maps highlighting regions with potential for the five geothermal applications across Central Europe.

3 Background of well selection process

3.1 Data availability in database

The relational database was originally designed for comprehensive drilling data entry (Figure 2). Over time, it became clear that not all sections required further development; thus, the current structure reflects available data but remains expandable (e.g., reservoir levels, laboratory results).

The database contains information from four basins across five countries, characterized by high heterogeneity due to differing national regulations. Data were collected through standardized national templates developed via consultation, except for Croatia, where data were directly uploaded. Following integration, quality control was performed to correct inconsistencies and omissions. As well, identifiers served as the key linking field; duplicate names were resolved' for example, German Molasse Basin wells, lacking short names, were assigned "GMB-serial number" identifiers.

Validated data, including coordinates and key attributes (country, basin, etc.), were imported into ArcGIS via JSON files, transformed to WGS84 (EPSG:4326), and reintegrated with calculated parameters (e.g., geothermal gradients, surface temperatures) derived from spatial data. Measurement units were standardized and adjusted as necessary.

Each country's database is accessible only to designated national administrators, while a central supervisor retains full access.

A dashboard provides a filtered, interpreted projection of the database, displaying key well information and usability based on a decision tree. It operates on a Google Maps interface, supporting supplementary map layers (KML, *.kmz, *.geotiff). Due to Google's 5 MB file size limit, maps are simplified to local well environments. Examples include CORINE layers, municipal boundaries (>5,000 inhabitants), Natura 2000 sites, heat consumption (Austria), and district heating networks (Hungary). Geotiff files display geospatially referenced heat, well, or basin maps; their inclusion does not affect calculations.

Filtering is possible by country and basin, with boundaries provided by partners. Some wells (n = 189; 168 in Germany, 21 in Slovenia) fall outside defined basin limits but remain included in analyses. Basin boundary refinement may alter future assessments. The current evaluation reflects the June 2025 status.

The initial database design and implementation are detailed in TRANSGEO Deliverables D.2.1.1-D.2.1.4.

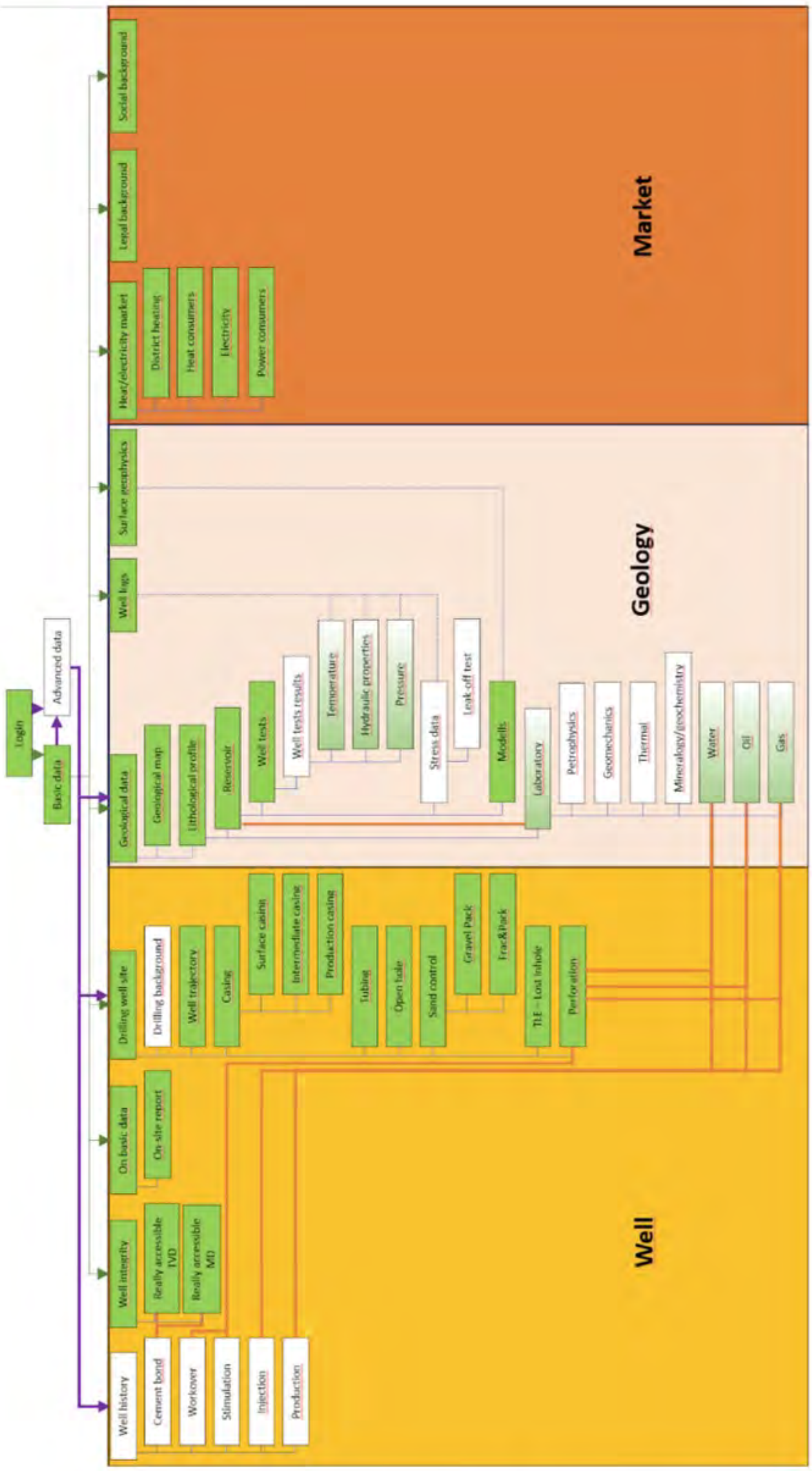


Figure 2: Database flow chart with relevant data.

3.1.1 North German Basin

The North German Basin (NGB) database consists of three parts: Mecklenburg Western-Pomerania (Mecklenburg-Vorpommern), Brandenburg, and Saxony-Anhalt (Sachsen-Anhalt), which were states of East Germany. Note, that the database includes data from the eastern part of the NGB as this belongs to the Central European region.

The Mecklenburg Western-Pomerania database contains 630 wells and the database contains 9641 data points. The Brandenburg database contains 1,127 wells with 24,103 data points. The Saxony-Anhalt database contains 1,385 wells with 14,986 data points. No well-test results were integrated. During data handling for neighboring states, the Brandenburg state had some wells from Mecklenburg-Vorpommern in its database, which had to be filtered out, and vice versa. Finally, 3,107 wells with more than 45,000 data points are provided.

3.1.2 Molasse Basin

The Molasse basin database consists of two parts, the German and Austrian databases.

The German database contains 1,354 wells, with 17,595 data entries. In the database, since no short names were provided, a unique name was generated for each borehole, consisting of "GMB" (German Molasse Basin) and a serial number, e.g., GMB-132.

The Austrian database contains 666 wells, with 6,514 data points.

3.1.3 Vienna Basin

The Austrian database contains 3,359 wells, with 49,824 data points. For the Austrian database, there is an overlap between the Vienna Basin and the Molasse Basin for geological reasons. Thus, in the border areas, it was defined per well which basin a given well belongs to.

3.1.4 Pannonian Basin

The Pannonian Basin database consists of three parts: the Hungarian, Slovenian, and Croatian database.

There are 1336 geothermal wells, 8,244 oil and gas exploration and production wells, 2,362 other deep wells (raw minerals and coal) and 2,187 abandoned wells handled by Mining Property Utilization Nonprofit Public Ltd. (BVH) deeper than 500 m. 221 hydrothermal wells, 110 oil and gas wells, 381 other deep wells and 74 abandoned wells deeper than 400 m have not been integrated into the database yet. These wells are hidden in the database, not queryable, but displayable. BVH has preliminarily qualified 624 of the abandoned wells and considered 177 of them potentially suitable for geothermal projects. These wells have been integrated into the TRANSGEO database. Hence, the TRANSGEO database contains 12,807 data points from only 177 abandoned and pre-qualified wells.

The Croatian database contains 115 wells with almost 10,000 data points. The data in this case is integrated directly into the database, connecting to the IT tool.

The Slovenian database contains 265 wells deeper than 500 m, with 20,971 data points. Of the Slovenian wells, 244 are located within the Pannonian Basin, and 21 are outside it.

3.2 Criteria Catalogue

The criteria catalogue reviews and assesses, from a feasibility perspective, all the conditions that may influence the geothermal reuse of abandoned hydrocarbon wells, and defines the concepts related to the target and its feasibility. Feasibility encompasses market, technological, and geological conditions, as well as associated market, technological, and geological risks.

The key elements of the criteria catalogue are described below. By identifying the factors to be considered in the decision, the data field for selecting a given technology can be compiled—i.e., the set of data without which a feasibility decision cannot be made (TRANSGEO Deliverable 1.3.1). Based on the relational database and the criteria catalogue, a decision tree (Figure 3) can be built, which in practice serves as a query system to help select the geothermal technologies that are feasible for each well. The query system works on the basis of a traffic light system, i.e. a well classified as suitable is green, a well classified as uncertain or to be retained is yellow, a well excluded from further evaluation is red. The query is permissive, i.e. a lack of data does not mean that a well is excluded from further evaluation, but it does draw attention to the fact that the primary evaluation must be followed by a much more comprehensive evaluation. In other words, wells assessed as suitable or uncertain based on the primary assessment are only a project option, which should always be reviewed in detail.

	Technology	EGS	HS	DBHE	BTES	ATES
1	Goal	Electricity (and heat)	Heat			
	Well/Market	W/M				
	Heat storage	Production			Storage/production	
	Well status	Pr?/Shut-in/TA/A?/U?	Pr?/Shut-in/TA/A?/U?	Pr?/Shut-in/TA/A?/U?	Pr?/Shut-in/TA/U?	Pr?/Shut-in/TA/A?/U?
	Well integrity	No, possible?, proven?	No, possible?, proven?	No, possible?	No, possible?	No, possible?, proven?
	Protected areas	Yes, No?	Yes, No?	Yes, No?	Yes, No?	Yes, No?
2	Market	M/I	M/A/I			
3	Geology	Cl, Ca, M/P	Cl, Ca	Cl, Ca, M/P	Cl, Ca, M/P	Cl, Ca, M/P
	BHT	>100 oC	>35 oC	>20 oC	< 100 oC	any
	Depth	>1000	>400	>400	3000>D>400	3000>D>400
	Well distance	<2 km	<2 km	irrelevant	<2 km	<2 km
4	Mineralogy	qualification	qualification	irrelevant	irrelevant	qualification
	Water chemistry	qualification	qualification	irrelevant	irrelevant	qualification
	Gas content	qualification	qualification	irrelevant	irrelevant	qualification
	Porosity	< 10% (< 30?)	> 30% (any?)	any	any	> 30% (>10?)
	Permeability	< 10 exp(-14) (-12?)	>10 exp(-12) (-14?)	any	<10 exp(-12) (any?)	any
	Water flow rate	< 100	> 10	irrelevant	irrelevant	> 100 (>50?)
	Productivity Index	< 10	> 10	irrelevant	irrelevant	> 10
	Minimum casing	>=7 (<7?)	>=7 (<7?)	>=7 (<7?)	>=7 (<7?)	>=7 (<7?)
	Impermeable layers	No importance	No importance	No importance	No importance	need
	Reservoir thickness	irrelevant	>10 (>5?)	irrelevant	irrelevant	>10 (>5?)

Figure 3: Decision tree summary chart.

The decision tree is supported by sufficient spatial and market data to characterize the area surrounding each well. Market definition is based on agricultural, industrial, and residential zones derived from the

CORINE system, complemented by municipal boundary polygons for settlements with populations exceeding 5,000. Consequently, local market conditions can be clearly delineated.

Additionally, adequate information exists on the proximity of wells to Natura 2000 sites and, in most cases, to other nearby wells. This spatial data is particularly relevant for evaluating technologies such as hydrothermal systems that require reinjection, where well spacing is a critical parameter.

The information on the status of well technology varies from country to country, i.e. the status and integrity of the well are often not given. Measured depths (MD) of wells are almost everywhere known, and temperatures can be calculated directly or indirectly for a given depth. Based on these, a primary rating for the applicable technologies can be determined.

Due to differing regulatory frameworks across countries, the amount of publicly available data on reservoirs suitable for integration into a comprehensive database remains limited. Where sufficient data exist, a more detailed and reliable assessment can be performed. Such an assessment should account for key geological and reservoir characteristics—such as rock type, flow rate, and reservoir thickness—as well as technological factors, including casing dimensions, depth intervals, and cement plug locations.

At present, the flow rate classification criteria (<10, 10-100, >100 L/s) are overly restrictive, leading to many potential projects being categorized as uncertain ("yellow"). For Aquifer Thermal Energy Storage (ATES) and hydrothermal projects, these thresholds should be re-evaluated and adjusted to better reflect practical conditions when assessing well suitability.

Several crucial parameters—such as mineralogy, water chemistry, gas content, porosity, permeability, productivity index, heat capacities of rock and water, and the presence of interbedded layers—have not yet been incorporated into the evaluation process. This omission is largely due to limited data availability. However, as more comprehensive datasets become accessible, these parameters should be integrated into reservoir assessments to improve the accuracy and reliability of feasibility evaluations.

4 North German Basin (Germany)

The North German Basin (NGB) is an intracratonic basin with a maximum sediment thickness of more than 7 km, developed after the Variscan orogenic cycle in northern central Europe. The NGB is part of the central European basin and extends from the Caledonides in the north-west to the Baltic craton in the north and east. In the south it is limited by low mountain ranges. The main tectonic evolution took place in the Mesozoic and Cenozoic period, which was basically characterized by extension linked to the breakup of Pangaea and the opening of the central Atlantic, and later, the north Atlantic. It was also affected by inversion with partial uplifting and erosion. The central depression area was located in the southern North Sea, northern and central Germany and large parts of Poland. It hosts sediments from the Zechstein to Quaternary of different facies like continental, shallow marine, limnic or marine settings. Its sandstones are especially suitable as aquifers and located in horizons of for example the Lower Cretaceous, Lower Dogger, Rhaetian-Lias, Middle Keuper and Middle Buntsandstein (Feldrappe et al. 2008). There are also relatively small sized hydrocarbon deposits, which are mainly associated with the Staßfurt carbonate of the Zechstein.

Due to the German Democratic Republic government's ambitious aim to be largely independent of raw materials, the NGB is well explored. Several deep wells (greater than 400 m in depth) for oil and gas exploration/exploitation (about half of all deep boreholes), copper, tungsten, and iron ore, as well as for underground utilization (storage and waste disposal), geological mapping, etc., were drilled at this time. So there are a total of 2,974 deep boreholes available in the databases of the State Offices for Geology in Brandenburg, Mecklenburg-Western Pomerania and Saxony-Anhalt.

Before German reunification, all wells were state-owned. The majority of deep wells remain in state hands today. For example, Brandenburg owns all copper and iron exploration and a part of oil and gas wells. However, this does not mean these wells are accessible (mostly abandoned and the land has been revitalized). After 1990, some deep wells (especially oil and gas) were transferred to the private sector. Today, the largest private-sector operator of hydrocarbon wells is Neptune Energy. However, oil and gas production stopped completely in Brandenburg and Saxony-Anhalt a few years ago. Only two sites remain in Mecklenburg-West Pomerania (Lütow and Mesekenhagen; BVEG Jahresbericht 2024).

In Germany, the most widely used method for deep geothermal energy extraction (with a depth greater than 400 m) has been Hydrothermal (HE). Aquifer Thermal Energy Storage (ATES) and Deep Borehole Heat Exchanger (DBHE) follow in second and third place, respectively. Enhanced Geothermal Systems (EGS) is used far less, mainly in research settings. In the following, the hypothetical reusability of the existing wells for each of the geothermal applications is displayed. As technical data of the boreholes (integrity, etc.) is currently still limited, the criteria mostly influencing the classification into suitable/not suitable and acceptable is the distance to potential markets. In later stages and during the post-project use of the tool, data for potentially interesting boreholes can be inserted and further criteria can be evaluated before contemplating actual reuse.

In the future of geothermal energy use in Germany, most probably a combination of geothermal energy and other renewable energy sources is likely an ideal pathway to achieve the ambitious EU climate goals (e.g., Welsch et al., 2018).

4.1 ATES

ATES systems have been applied already in some cases in Germany. Especially in the NGB heat/cold storage systems are potentially attractive due to lower temperatures in some of the potential aquifers. Nevertheless, when considering all five technologies, ATES ranks fourth out of five in terms of potential use (Table 1).

From the input dataset of 2,974 wells (Figure 4), 721 (24.2%) are suitable (Figure 6), 1,718 (57.8%) are suitable with certain restrictions (Figure 8), and 535 (18.0%) are not suitable for reuse as Aquifer Temperature Energy Storage (ATES; Table 1).

This number reduces significantly, if only wells from 1990 (Figure 5) onward are considered for potential reuse: only 14 wells would be classified as suitable and still 87 wells would be uncertain ("suitable with restrictions") to reuse implementing ATES application (Figure 7, Figure 9, Table 1). The main concentration of these uncertain and suitable wells lie within the northern NGB (Mecklenburg-Western Pomerania), central and southeastern Brandenburg, and western part of the eastern NGB in Saxony-Anhalt (Figure 7, Figure 9, Table 1). Six of the more recent borehole locations are unsuitable for an ATES application, taking into account the parameters considered in the IT-tool.

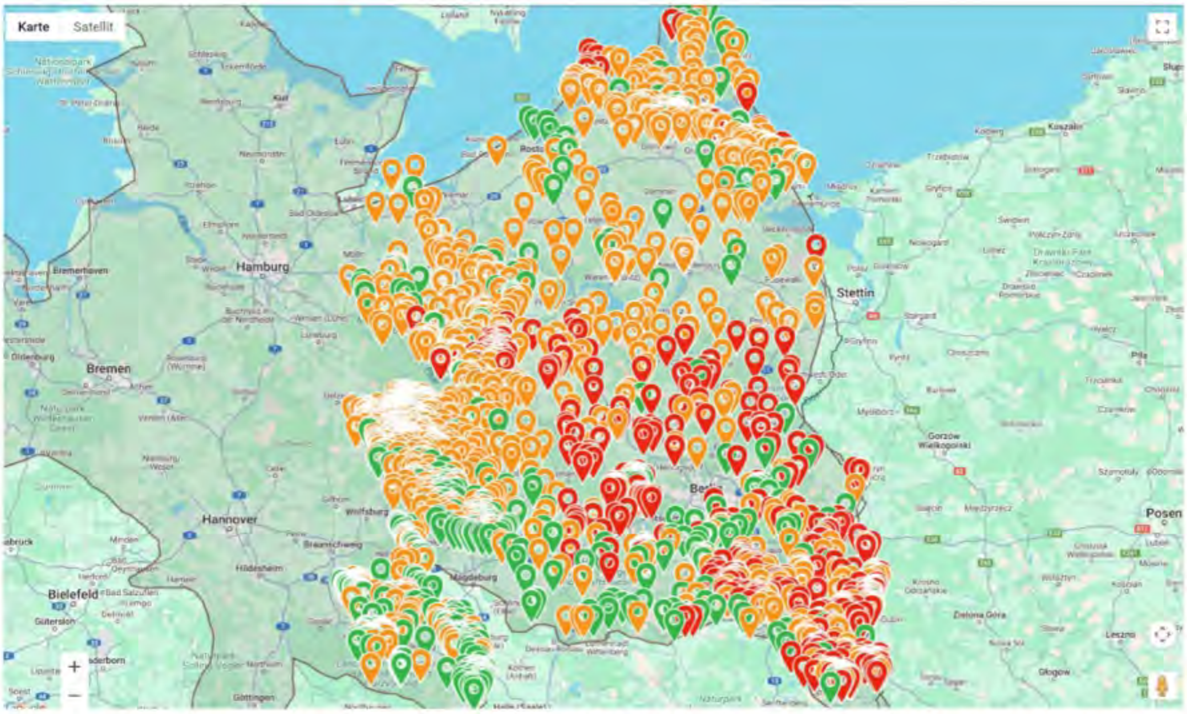


Figure 4: Map of the repurpose potential in the TRANSGEO part of the North German Basin for ATES.

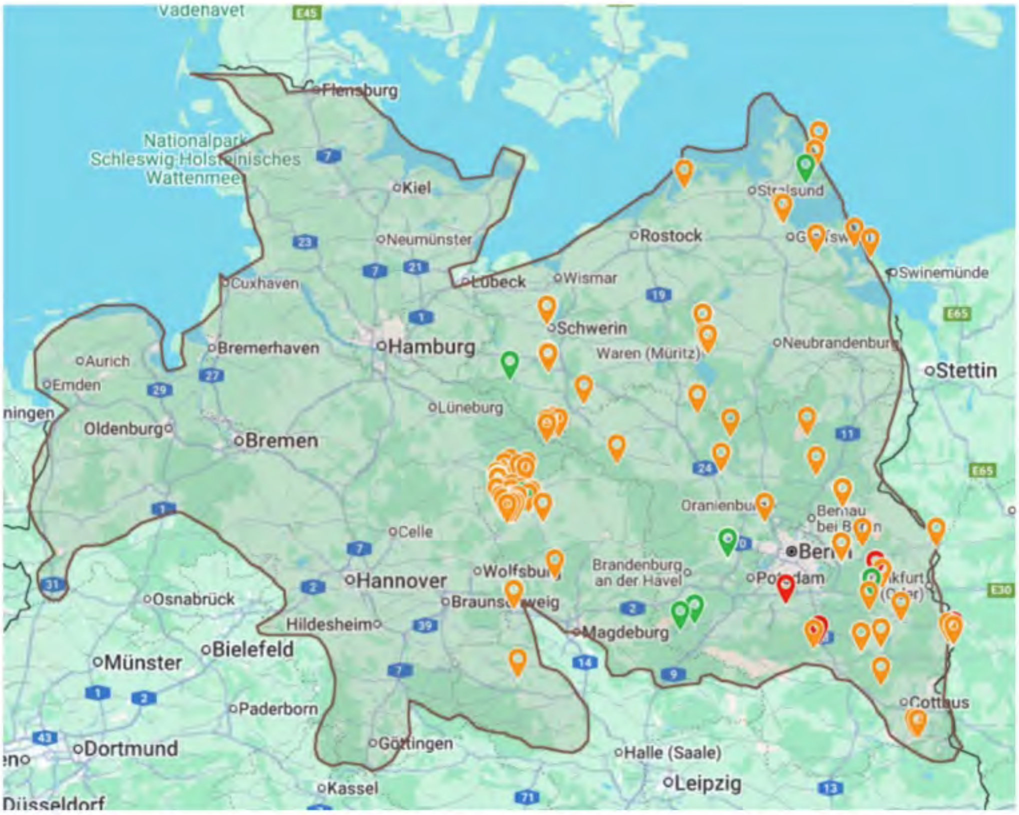


Figure 5: Map of the repurpose potential in the TRANSGEO part of the North German Basin for ATES for wells drilled later than 1990.

North German Basin	ATES (absolute)	ATES (percentage)	ATES (absolute; wells ≥1990)	ATES (percentage; wells ≥1990)
Total of wells	2974	100	2974	100
Suitable	721	24.2	14	0.4
Uncertain	1718	57.8	87	2.9
Not suitable	535	18.0	2873	96.6

Table 1: Absolute numbers and percentages of reusable wells for ATES in the North German Basin

Figure 6: Suitable wells for reuse as ATES in the North German Basin.

Figure 7: Suitable wells for reuse as ATES in the North German Basin drilled later than 1990.

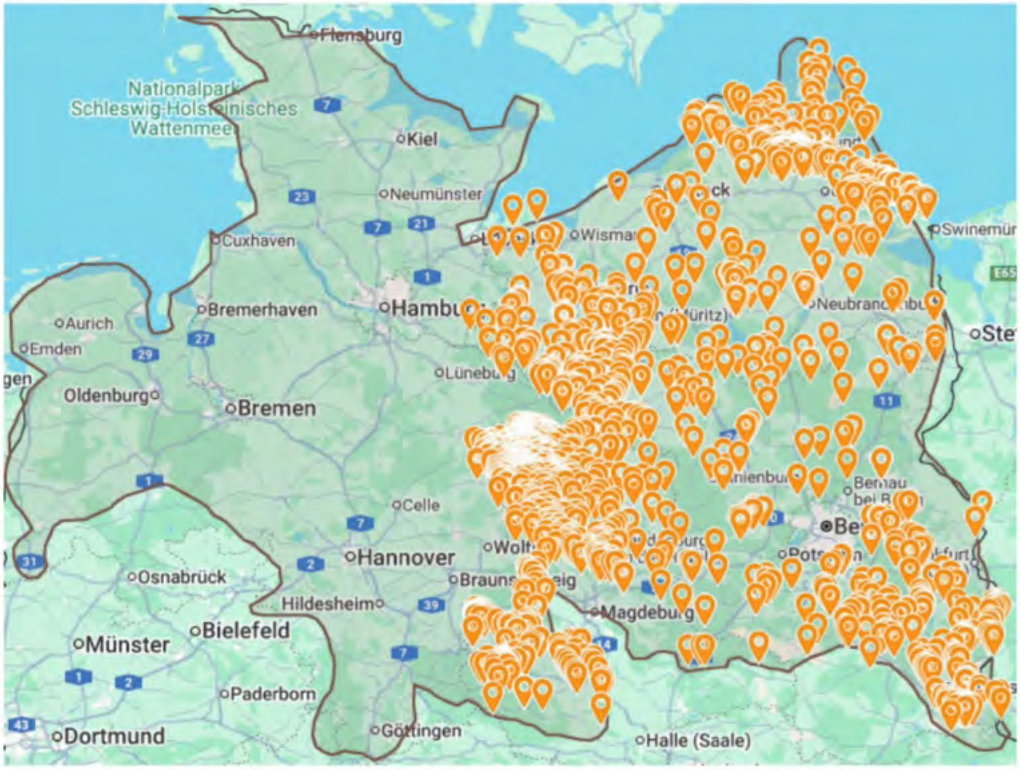


Figure 8: Suitable wells with restrictions for reuse as ATES in the NGB.

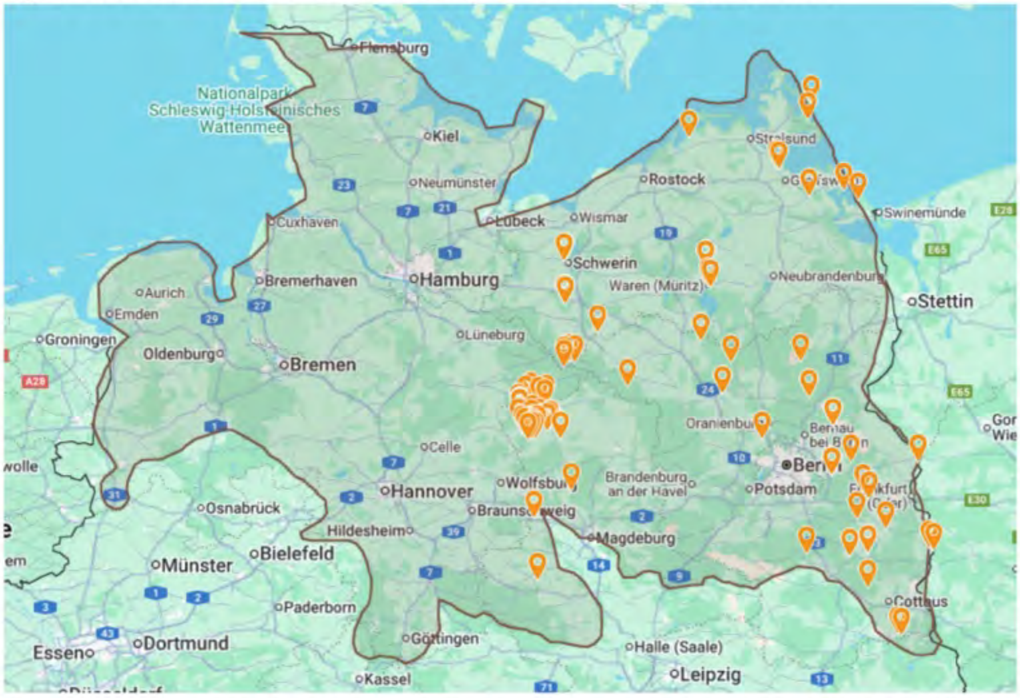


Figure 9: Suitable wells with restrictions for reuse as ATES in the NGB drilled later than 1990.

4.2 DBHE

The Deep Borehole Heat Exchanger (DBHE) application is likely the most promising reuse scenario for Germany, as it largely aligns with strict groundwater protection and general environmental protection laws (closed system). As the heat output in the suitable aquifers within the NGB is not very high, a combination with more efficient heat pumps and nearby heat consumers are important.

In the context of a potential market, 1,803 (60.6%) wells in the working area are suitable (Figure 12), 548 (18.4%) are suitable with certain restrictions (Figure 14), and 623 (20.9%) are not suitable for reuse as DBHE (Table 2) from the input dataset of 2,974 wells (Figure 10).

When filtering the wells older than 1990 (Figure 11), the potentially useful well locations (suitable and uncertain) for an DBHE application would reduce to 84. Of these 72 (2.4%) would be categorised as suitable (Figure 13) and 12 (0.4%) suitable with some restrictions (Figure 15, Table 2).

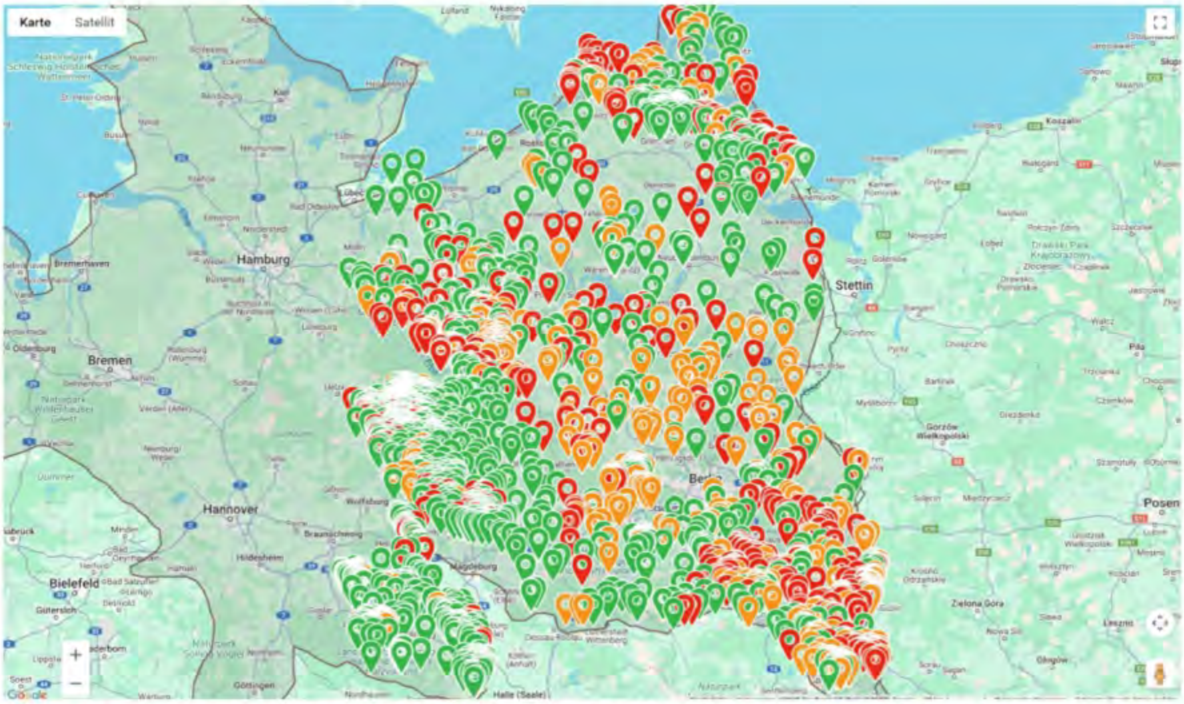


Figure 10: Map of the repurpose potential in the TRANSGEO part of the NGB for DBHE.

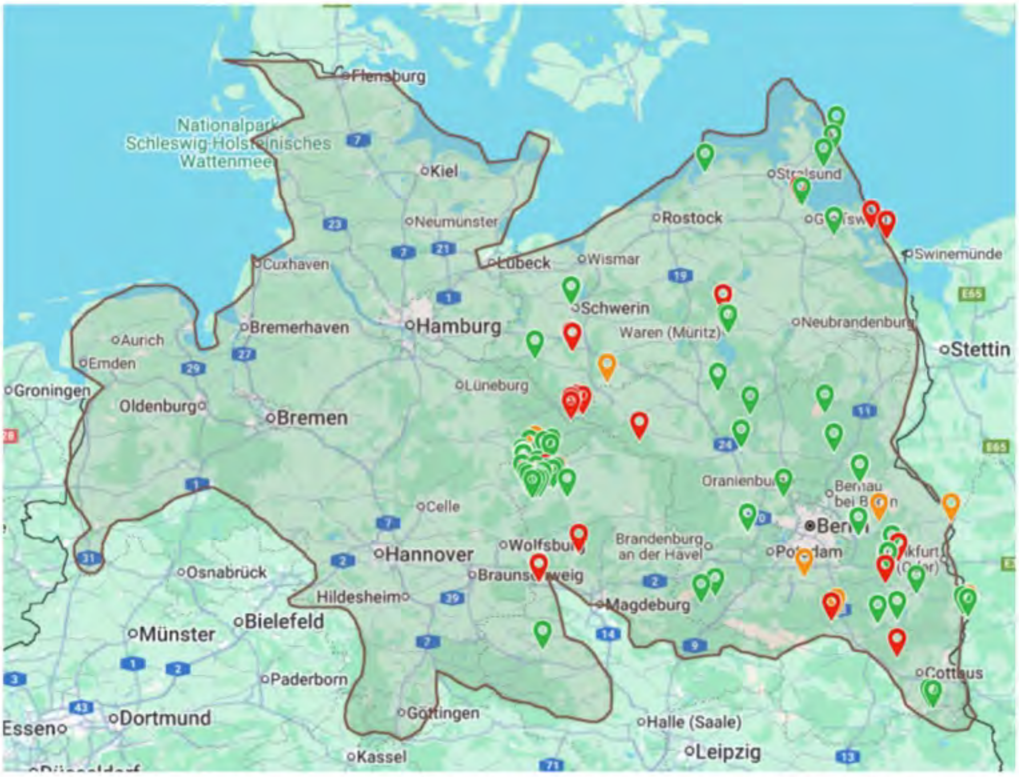


Figure 11: Map of the repurpose potential in the TRANSGEO part of the North German Basin for DBHE, taking into account wells equal or younger than 1990.

North German Basin	DBHE (absolute)	DBHE (percentage)	DBHE (absolute; wells ≥1990)	DBHE (percentage; wells ≥1990)
Total of wells	2974	100	2974	100
Suitable	1803	60.6	72	2.4
Uncertain	548	18.4	12	0.4
Not suitable	623	20.9	2890	97.2

Table 2: Absolute numbers and percentages of reusable wells for DBHE in the North German Basin

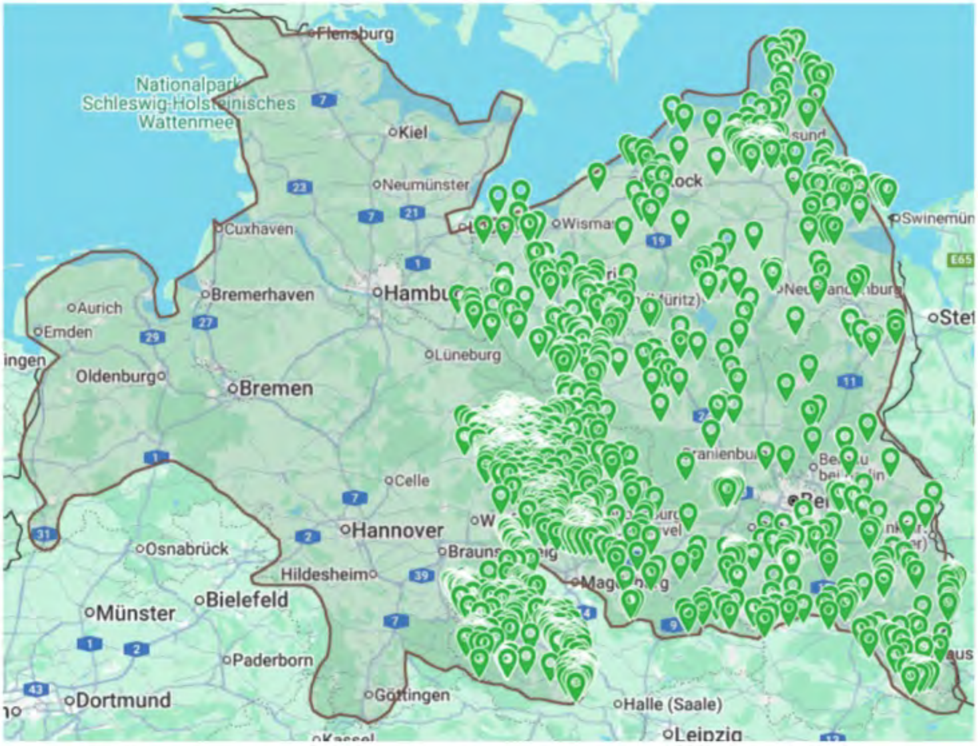


Figure 12: Suitable wells for reuse for DBHE in the North German Basin.

Figure 13: Suitable wells for reuse for DBHE in the North German Basin drilled after 1990.

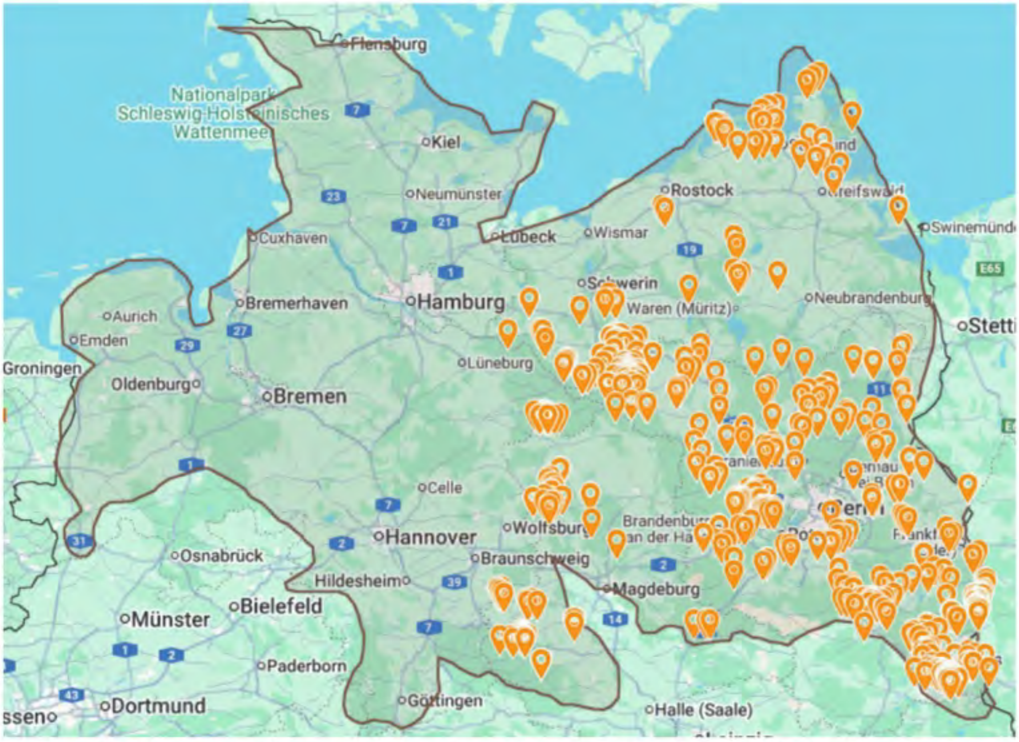


Figure 14: Suitable wells with restrictions for reuse for DBHE in the NGB.

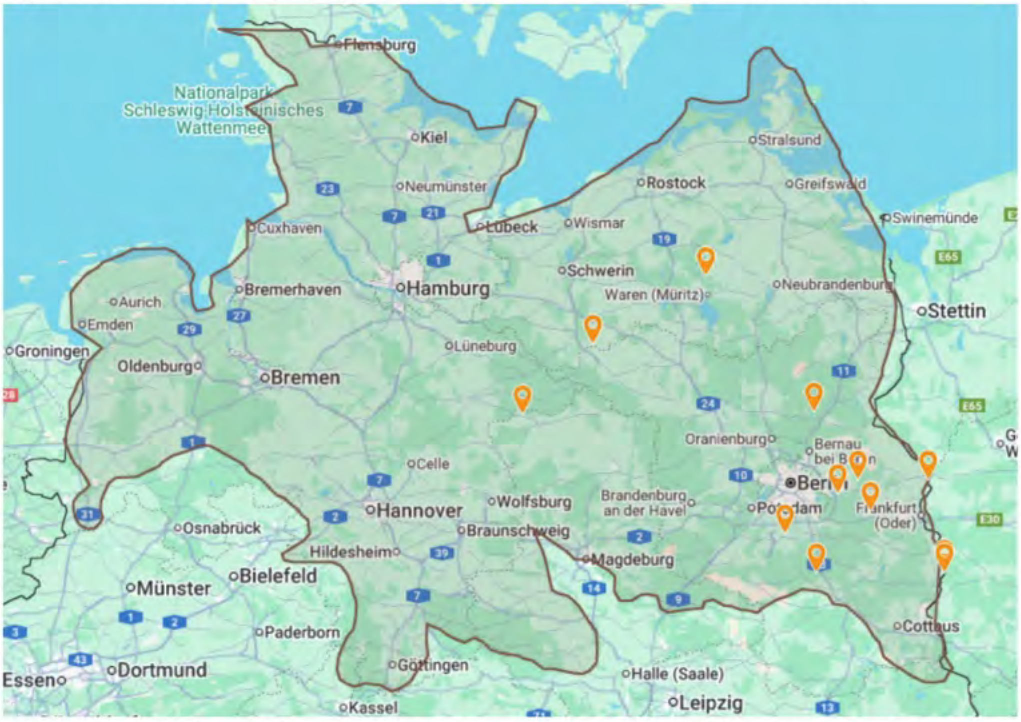


Figure 15: Suitable wells with restrictions for reuse for DBHE in the North German Basin drilled after 1990.

4.3 BTES

For Borehole Thermal Energy Systems (BTES) applications an array is needed, rather than single wells (e.g. Mielke et al., 2014). In theory, before exploiting coal fields, companies drilled tens of hundreds of wells (mostly shallow), which are unfortunately not accessible anymore - hence a great potential for extensive BTES arrays is lost.

Nevertheless, from the input dataset of 2,974 wells (Figure 16), 1,320 (44.4%) are suitable (Figure 18), 179 (6.0%) are suitable with certain restrictions (Figure 20), and 1,475 wells (49.6%) are not suitable for reuse as BTES (Table 3). If taking into account only the more recently drilled wells since 1990 (Figure 17), the numbers reduce to 50 (1.7%) suitable (Figure 19) and 12 (0.4%) suitable with restrictions (Figure 21).

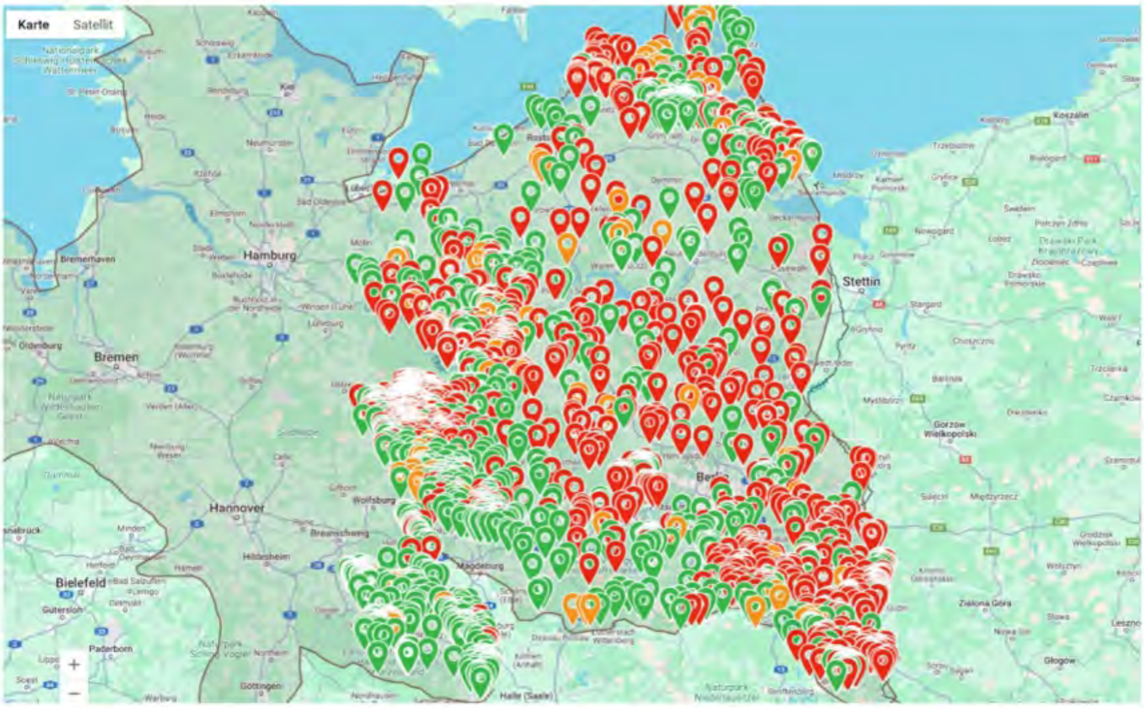


Figure 16: Map of the repurpose potential in the TRANSGEO part of the North German Basin for BTES.

Figure 17: Map of the repurpose potential in the TRANSGEO part of the North German Basin for BTES drilled after 1990.

North German Basin	BTES (absolute)	BTES (percentage)	BTES (absolute) wells ≥1990	BTES (percentage; wells ≥1990)
Total of wells	2974	100	2974	100
Suitable	1320	44.4	50	1.7
Uncertain	179	6.0	4	0.1
Not suitable	1475	49.6	2920	98.2

Table 3: Absolute numbers and percentages of reusable wells for BTES in the North German Basin.

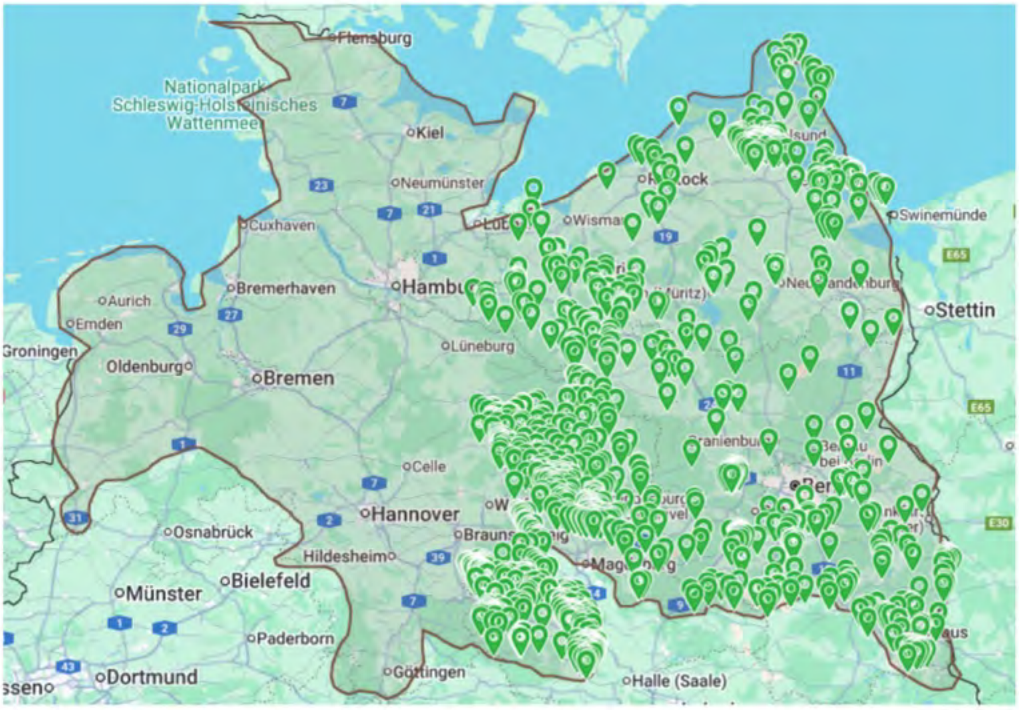


Figure 18: Wells suitable for BTES in the North German Basin.

Figure 19: Wells suitable for BTES in the North German Basin drilled after 1990.

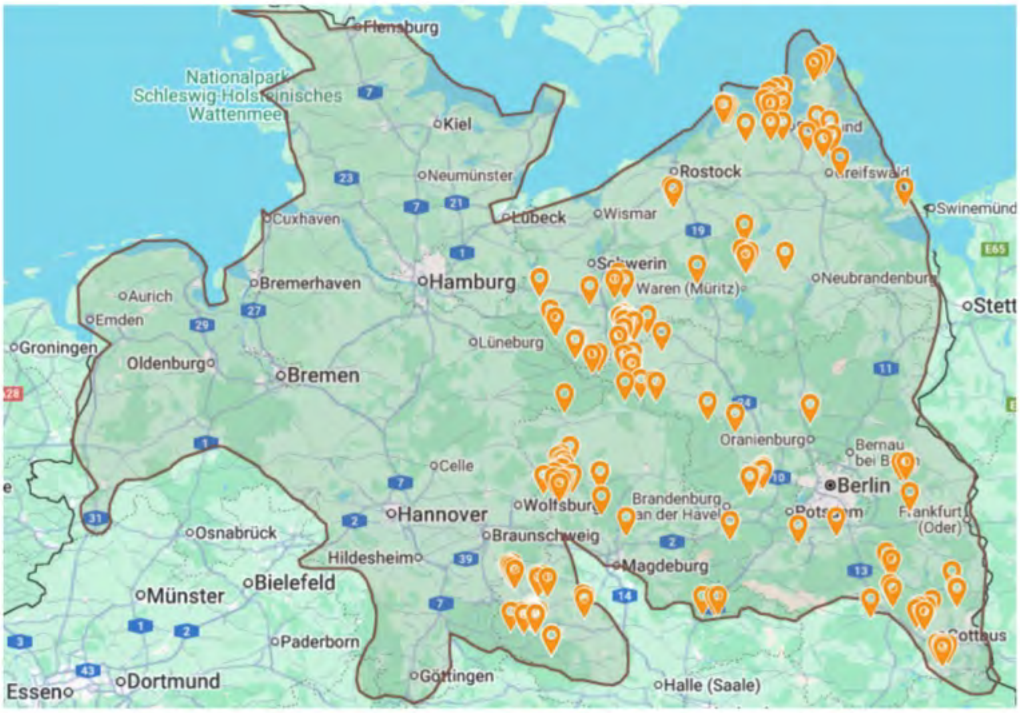


Figure 20: Wells suitable with certain restrictions for BTES in the North German Basin.

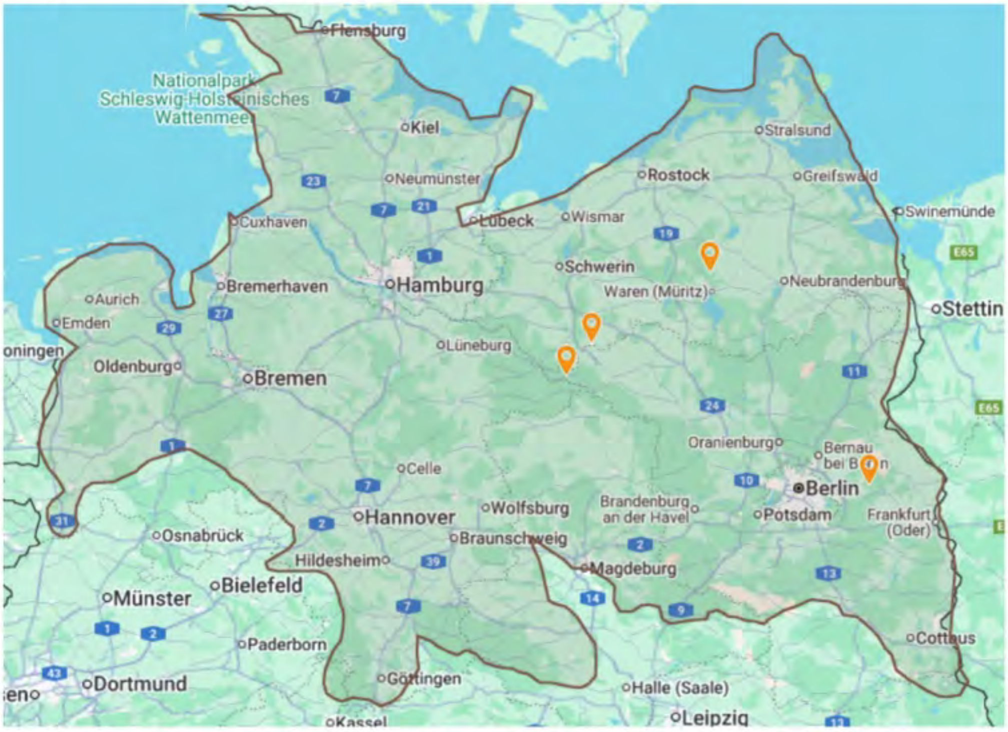


Figure 21: Wells suitable with certain restrictions for BTES in the North German Basin drilled after 1990.

4.4 HE

Hydrothermal applications have been the overwhelming part of used applications of medium-deep and deep geothermal projects in Germany so far. The reason for this lies most certainly in the lower prospecting risk, and the well known technology and costs.

From the input dataset of 2,974 wells (Figure 22), 999 (33.6%) are suitable (Figure 24), 1,090 (36.7%) are suitable with certain restrictions displayed in Figure 26, and 885 (29.7%) are not suitable for reuse as hydrothermal energy producers (HE; Table 4). If the pre-1990 wells are excluded (Figure 23), the values reduce to 52 (1.7%) suitable (Figure 25) and 32 (1%) suitable with restrictions (Figure 27).

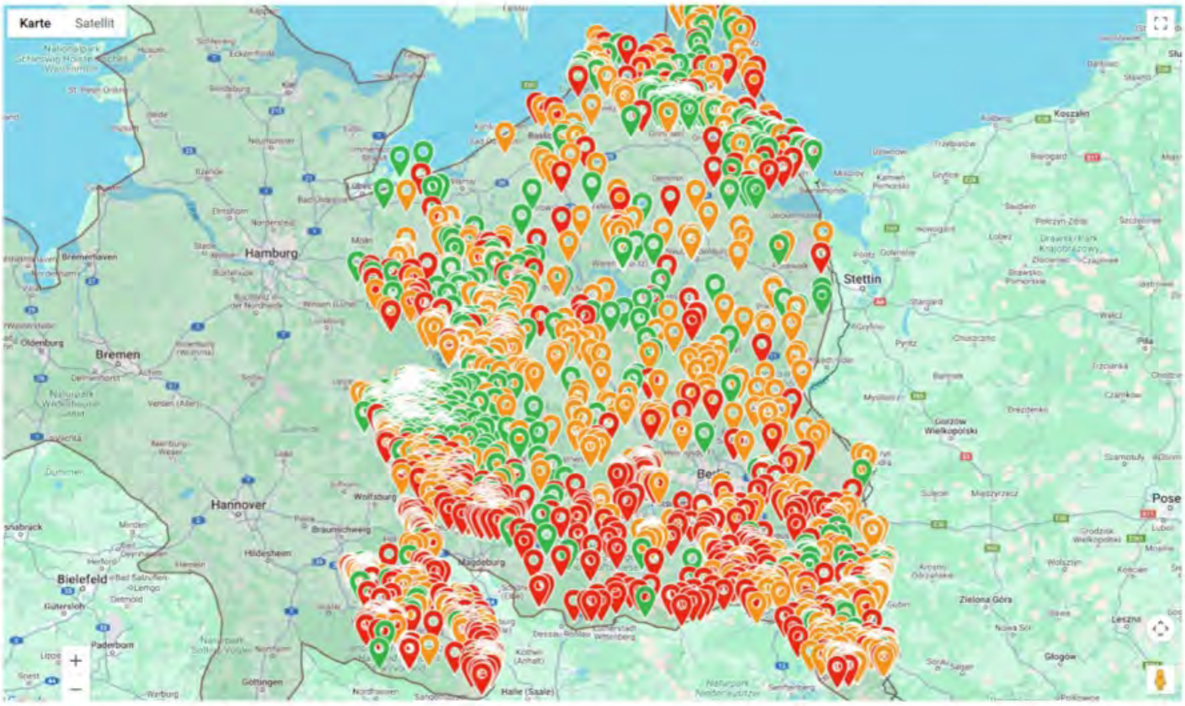


Figure 22: Map of the repurpose potential in the TRANSGEO part of the North German Basin for HE.

Figure 23: Map of the repurpose potential of wells in the TRANSGEO part of the North German Basin for HE drilled after 1990.

North German Basin	HE (absolute)	HE (percentage)	HE (absolute; wells ≥1990)	HE (percentage; wells ≥1990)
Total of wells	2974	100	2974	100
Suitable	999	33.6	52	1.7
Uncertain	1090	36.7	32	1.1
Not suitable	885	29.7	2890	97.2

Table 4: Absolute numbers and percentages of reusable wells for HE in the North German Basin.

Figure 24: Wells suitable for HE in the North German Basin.

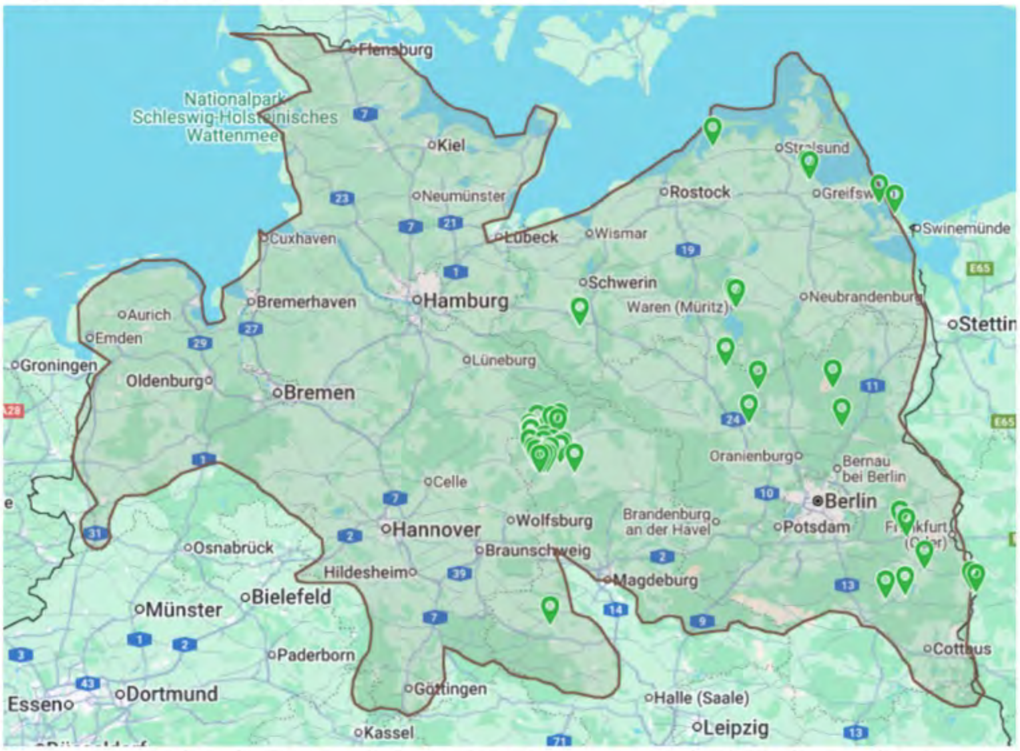


Figure 25: Wells suitable for HE in the North German Basin drilled after 1990.

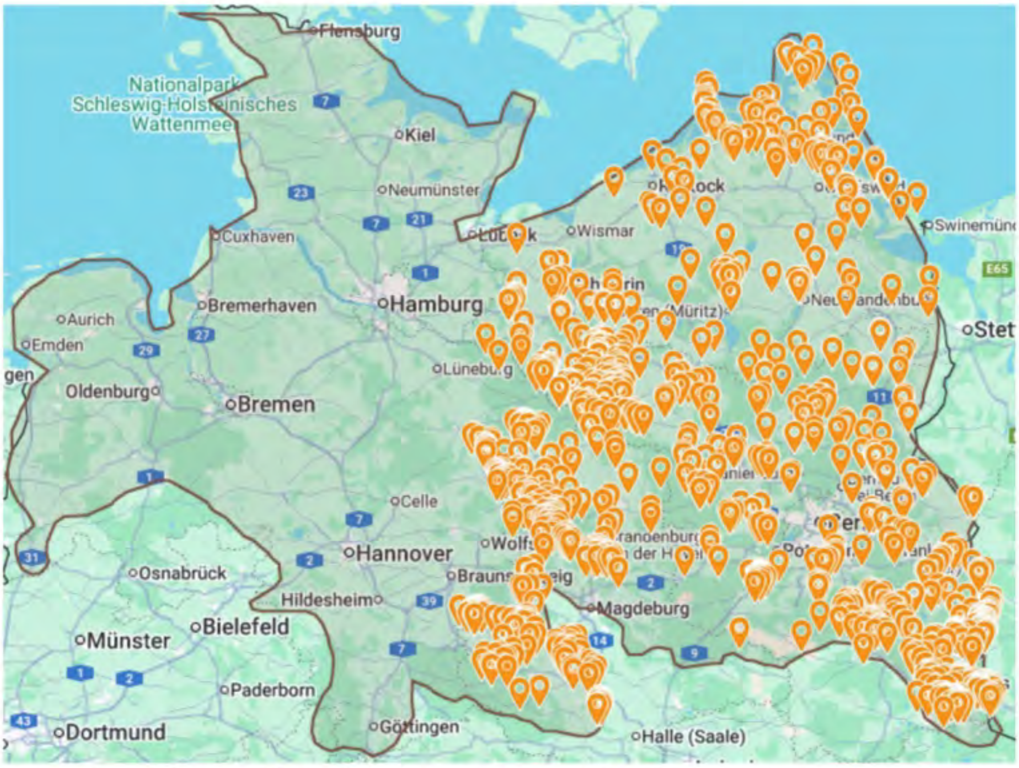


Figure 26: Wells suitable with certain restrictions for HE in the North German Basin.

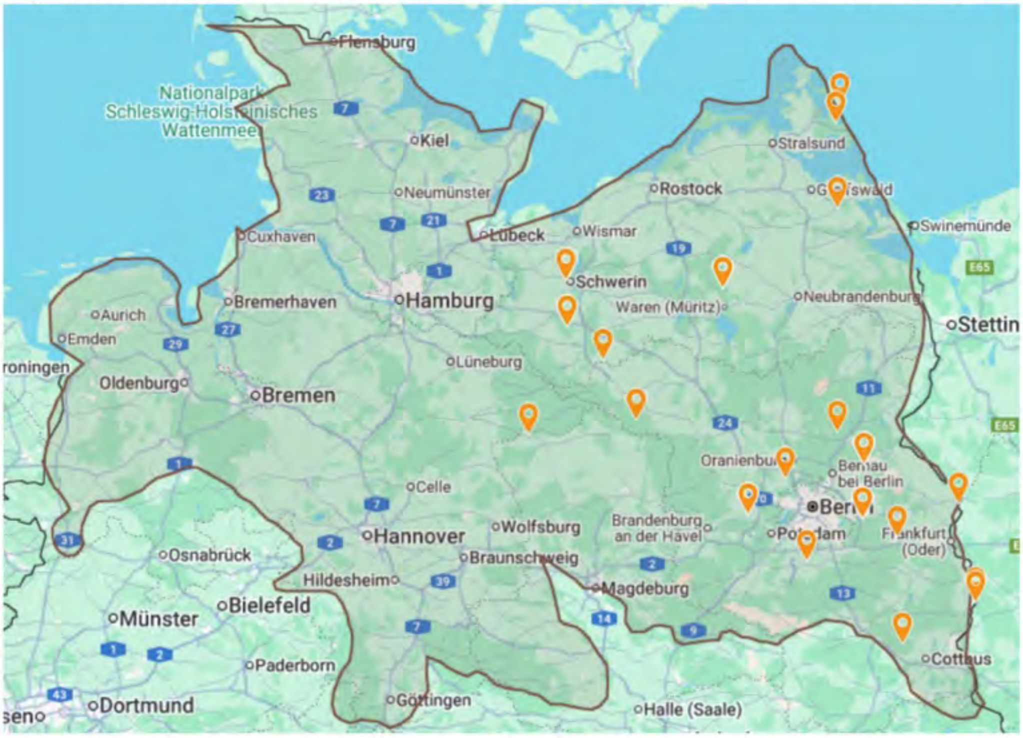


Figure 27: Wells suitable with certain restrictions for HE in the NGB drilled after 1990.

4.5 EGS

The Enhanced Geothermal Systems (EGS) for geothermal energy extraction has only been explored so far in several research projects in Germany with varying results. In general, EGS can be applied virtually anywhere, if drilling deep enough, but the method is subjected to high financial, technical and environmental risks. Further, the Technology Readiness Level is currently not as high as for other applications. Nevertheless, in northern Germany, counting on relatively low temperatures in the available aquifers, EGS might be an alternative.

From the input dataset of 2,974 wells (Figure 28), 462 (15.5%) are suitable (Figure 30), 222 (7.5%) are suitable with certain restrictions (Figure 32), and 2,290 (77.0%) are not suitable for reuse as EGS (Table 5). Taking into account only the wells drilled in 1990 or later (Figure 29), only 22 wells (0.7%) might be suitable (Figure 31) for reuse with that technology and another 9 wells (0.3%) could be used with restrictions (Figure 33, Table 5).

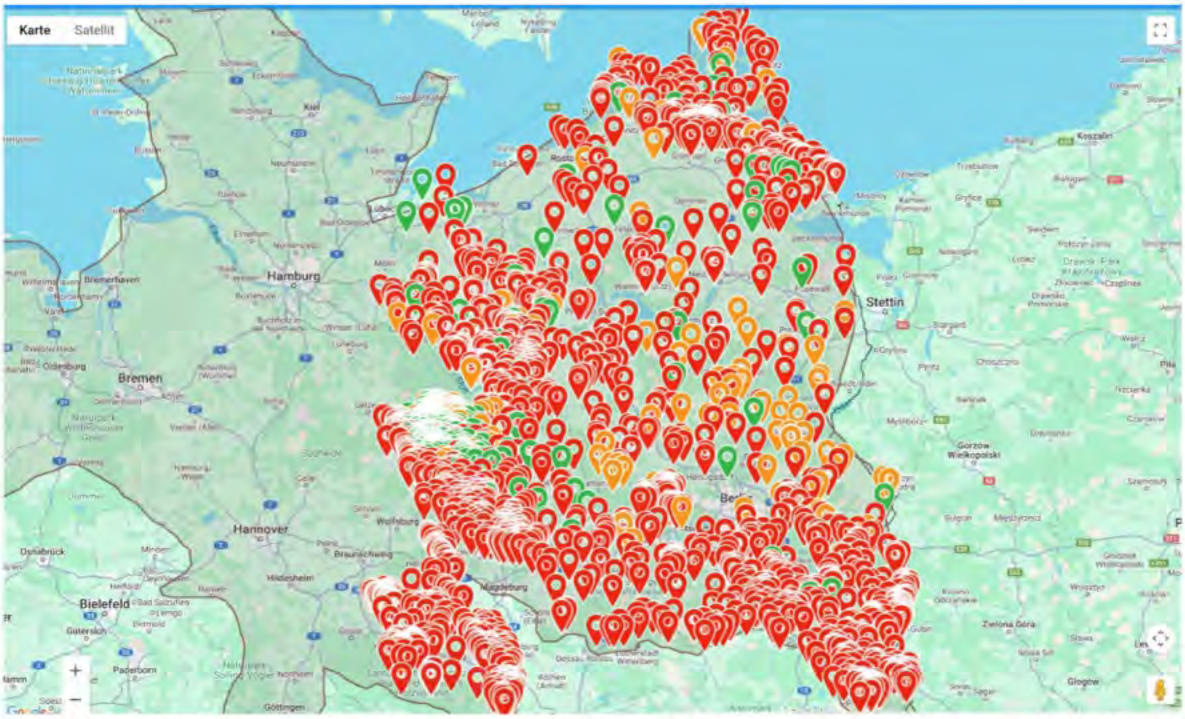


Figure 28: Map of the repurpose potential in the TRANSGEO part of the North German Basin for EGS.

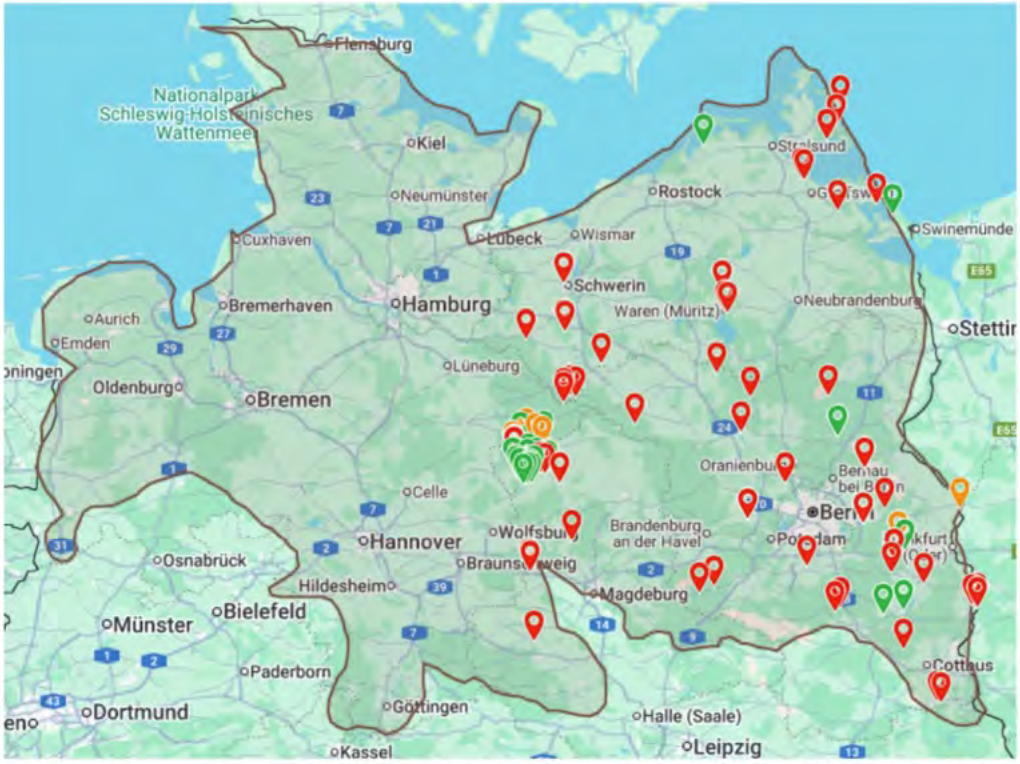


Figure 29: Map of the repurpose potential of wells in the TRANSGEO part of the North German Basin for EGS drilled after 1990.

North German Basin	EGS (absolute)	EGS (percentage)	EGS (absolute; wells ≥1990)	EGS (percentage; wells ≥1990)
Total of wells	2974	100	2974	100
Suitable	462	15.5	22	0.7
Uncertain	222	7.5	9	0.3
Not suitable	2290	77.0	2943	99.0

Table 5: Absolute numbers and percentages of reusable wells for EGS in the North German Basin.

Figure 30: Wells suitable for EGS in the North German Basin.

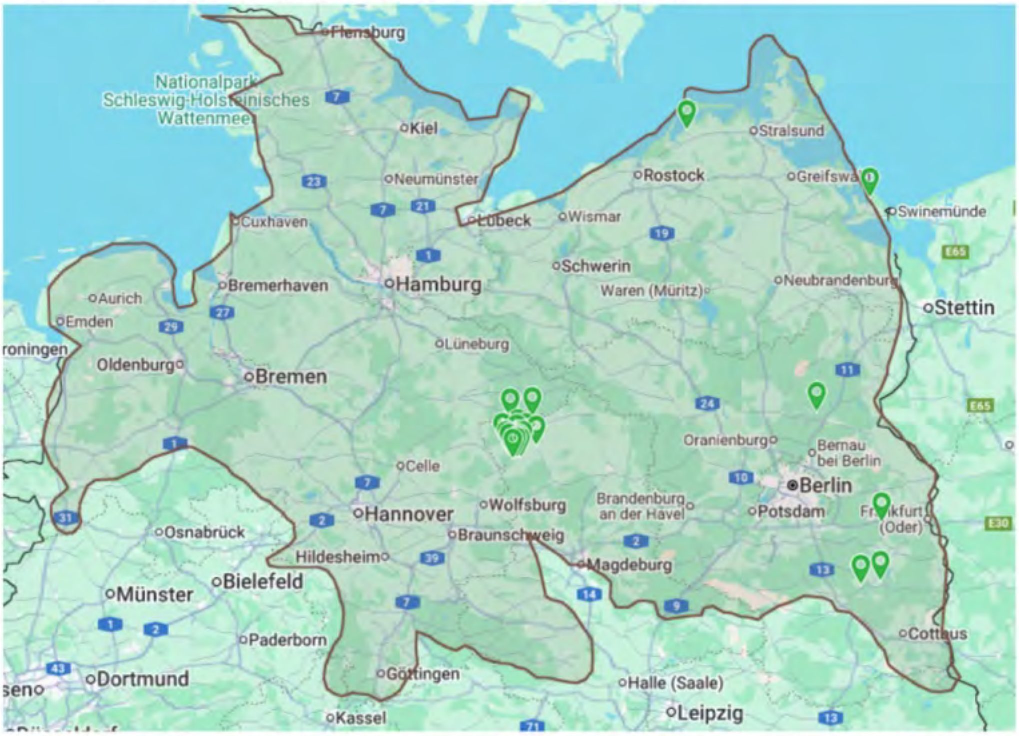


Figure 31: Wells suitable for EGS in the North German Basin drilled after 1990.

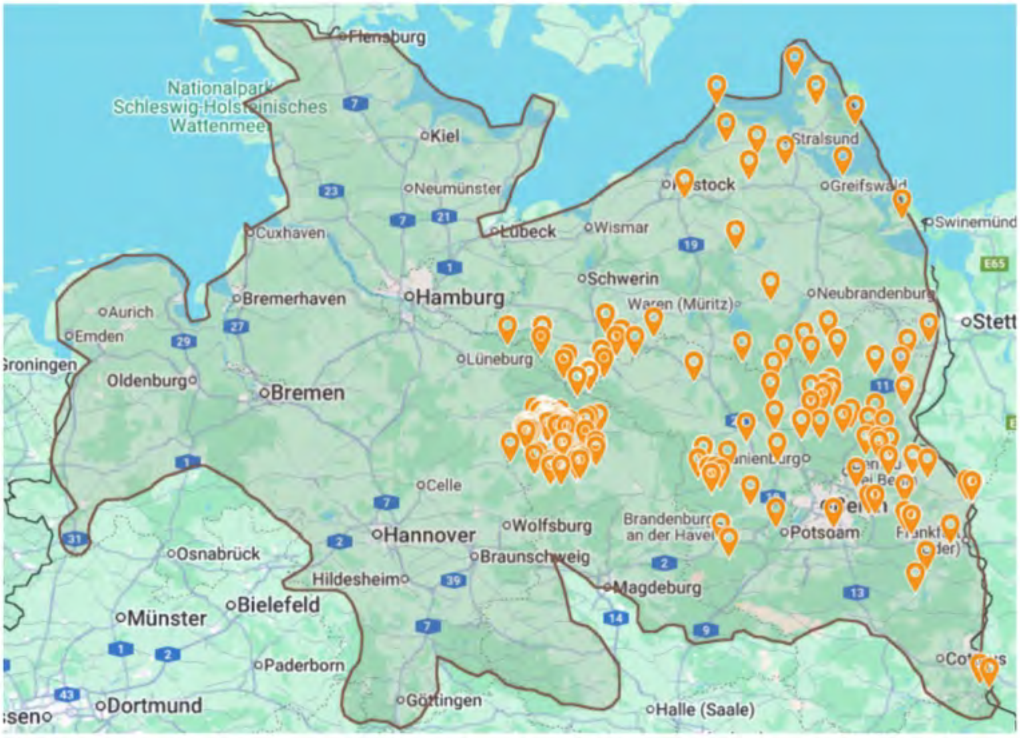


Figure 32: Wells suitable with certain restrictions for EGS in the North German Basin.

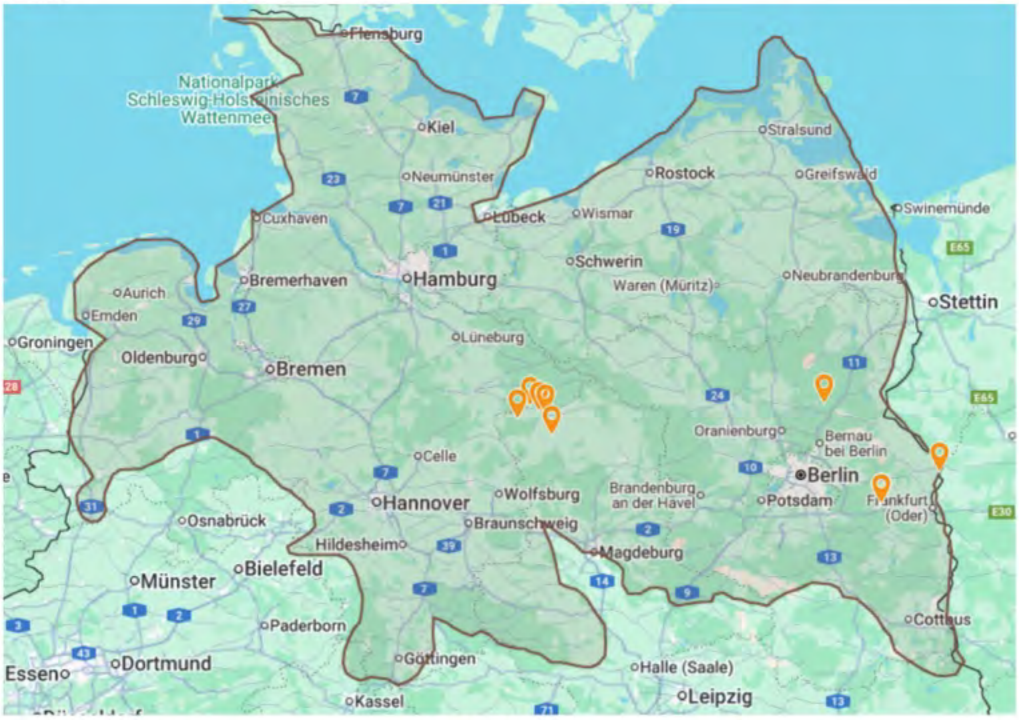


Figure 33: Wells suitable with certain restrictions for EGS in the North German Basin drilled after 1990.

4.6 Summary of the repurposing potential of the North German Basin

It seems that the potential of reuse in the North German Basin is higher compared to other basins (Table 6 and Table 7). The majority of wells in the North German Basin were drilled during the 1950s to the 1980s. Their condition is largely uncertain and almost all of them have been sealed according to the Federal Mining Act. Only 107 boreholes were drilled after 1990, which is a low amount compared to other TRANSGEO partner countries. The lower numbers of well selections of boreholes younger than 35 years are highlighted in Table 8 and Table 9.

North German Basin	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute)	2974	2974	2974	2974	2974
Suitable	721	1803	1320	999	462
Uncertain	1718	548	179	1090	222
Not suitable	535	623	1475	885	2290

Table 6: Absolute numbers of reusable wells for the 5 geothermal methods in the Central Europe part of the North German Basin based on all available wells in the TRANSGEO database (2,974 wells).

North German Basin	ATES	DBHE	BTES	HE	EGS
Suitable	24.2	60.6	44.4	33.6	15.5
Uncertain	57.8	18.4	6.0	36.7	7.5
Not suitable	18.0	20.9	49.6	29.8	77.0

Table 7: Percentages of reusable wells for the 5 geothermal methods in the Central Europe part of the North German Basin based on all available wells in the TRANSGEO database (2,974 wells).

North German Basin	ATES	DBHE	BTES	HE	EGS
Suitable	14	72	50	52	22
Uncertain	87	12	4	32	9
Not suitable	2873	2890	2920	2890	2943

Table 8: Absolute numbers of reusable wells for the 5 geothermal methods in the Central Europe part of the North German Basin after 1990, which are 107 wells. The wells drilled prior 1990 fall into the not suitable category.

North German Basin	ATES	DBHE	BTES	HE	EGS
Suitable	0.5	2.4	1.7	1.7	0.7
Uncertain	2.9	0.4	0.1	1.1	0.3
Not suitable	96.6	97.2	98.2	97.2	99.0

Table 9: Percentages of wells drilled after 1990 for well reuse in relation to all available wells of the TRANSGEO database (2,974) for the 5 geothermal methods in the Central Europe part of the North German Basin. The wells drilled prior 1990 fall into the not suitable category.

5 Molasse Basin (Germany - Austria)

The Molasse Basin is the foreland basin in the North of the Alps and ranges from France, Switzerland, Germany, Austria, to the Czech Republic. This report refers to the Austrian and German sections of the basin only. The basin is filled with sediments that host hydrocarbons (oil and gas) at different levels. Hydrocarbon exploration is the reason for the intense exploration and drilling of wells.

In Austria, in the Molasse Basin, approximately 1,200 wells with a greater depth than 300 m (GeoSphere Austria Database) have been drilled in the last 80 years, and approximately 300 are still in production, including gas storage wells (pers. comm. RAG Austria). The main hydrocarbon operators in Germany and Austria are and were, amongst others, MOBIL OIL Deutschland, Wintershall, Ruhrgas, RAG Austria, ADX VIE GmbH, OMV, RWE-DEA, ONEO (RDG), and Juniper.

The Molasse dataset has been compiled from Austrian and German databases. Since the legal regulation for subsurface data publication between the 2 states differs, certain information is not available for both countries in the same manner. In the Austrian dataset, the well owner is indicated in the dataset for every well and can be identified for further requests. In Germany 285 wells are without ownership notice. The recent well status is totally missing in the Austrian dataset due to publication rights and partly in Germany (Table 10). Therefore the number of wells suitable for geothermal does not equal the sum of active wells in Austria. A final determination of the availability of a well has to be requested from the well owner.

Well Status	Germany	Austria	Molasse total
no status info	532	666	1198
abandoned	677	---	677
open	127	---	127
partly abandoned	18	---	18

Table 10: Numbers of wells in the German and Austrian part of the Molasse, which have the information of the recent well status.

For the Austrian well dataset the drilling year is available for every well. Therefore, the authors chose to filter out wells drilled before 1990 for the Austrian dataset, based on the consideration that the average lifespan of an oil and gas well is approximately 30 to 40 years (Planète Énergies, 2015; IOGP, 2018; OGA, 2018). There are 86 wells drilled since 1990 in the database of the Austrian part of the Molasse Basin. While older wells can be valuable candidates for repurposing, those drilled too long ago may no longer exist in usable condition, they may have been fully decommissioned or permanently sealed, making them inaccessible for geothermal conversion. Therefore, this filtering step helps to exclude wells that are likely beyond their operational lifespan and no longer suitable for reuse. The Well Assessment Tool queries the well database for open and closed geothermal applications. For open systems, such as ATES and HE, an aquifer with specific properties is required. For the Molasse Basin, the merged Malmian aquifer for Austria and Germany is included into the database, along with well top and base values for both countries, derived from geological models. Shallower aquifers, which exist, are not included so far.

5.1 ATES

From the input dataset of 2,020 wells (Figure 34), 84 (4.2%) are suitable (Figure 35), 611 (30.2%) are suitable with certain restrictions (Figure 36), and 1,325 (65.6%) are not suitable for reuse as Aquifer Temperature Energy Storage (ATES; Table 11).

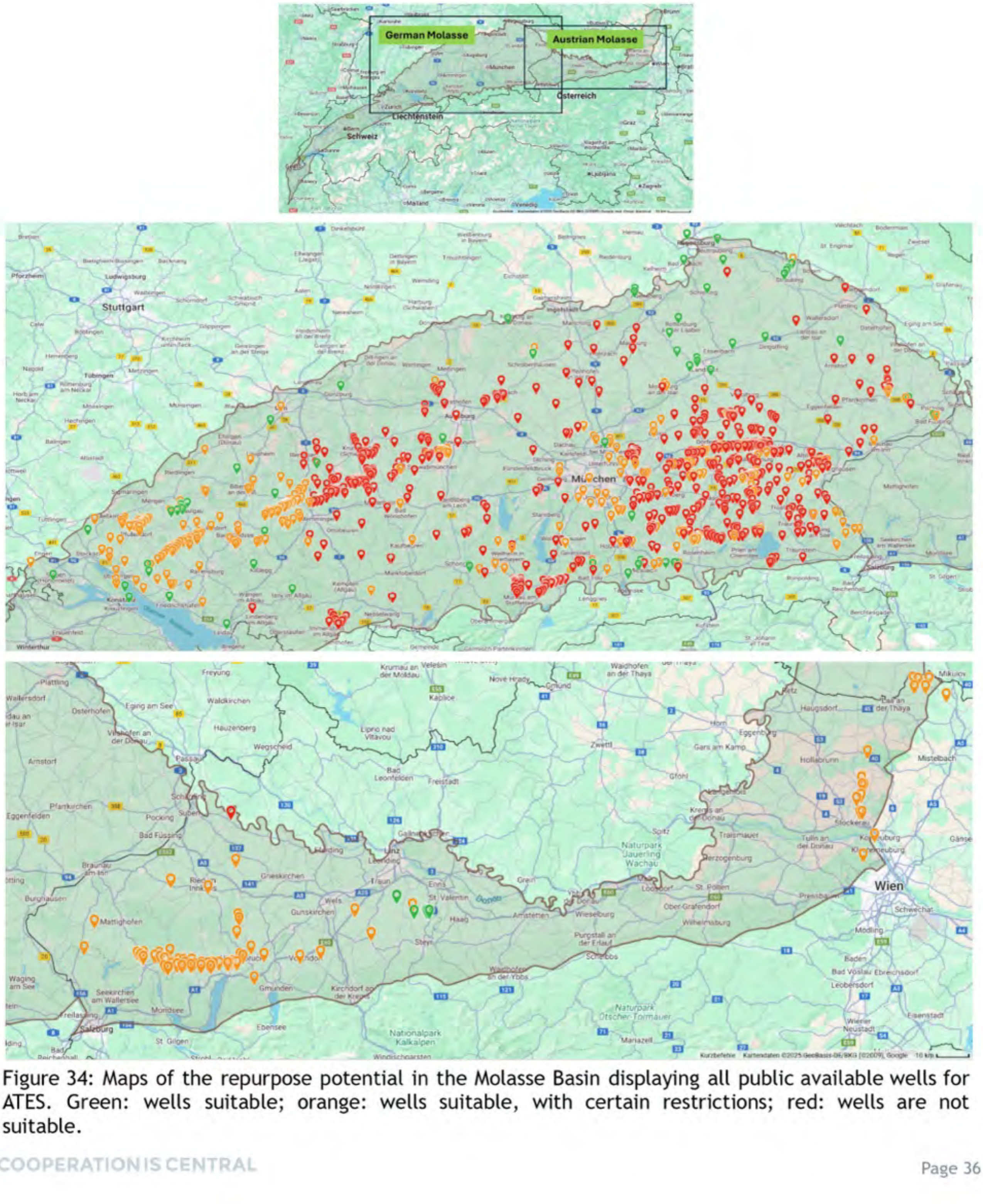


Figure 34: Maps of the repurpose potential in the Molasse Basin displaying all public available wells for ATES. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

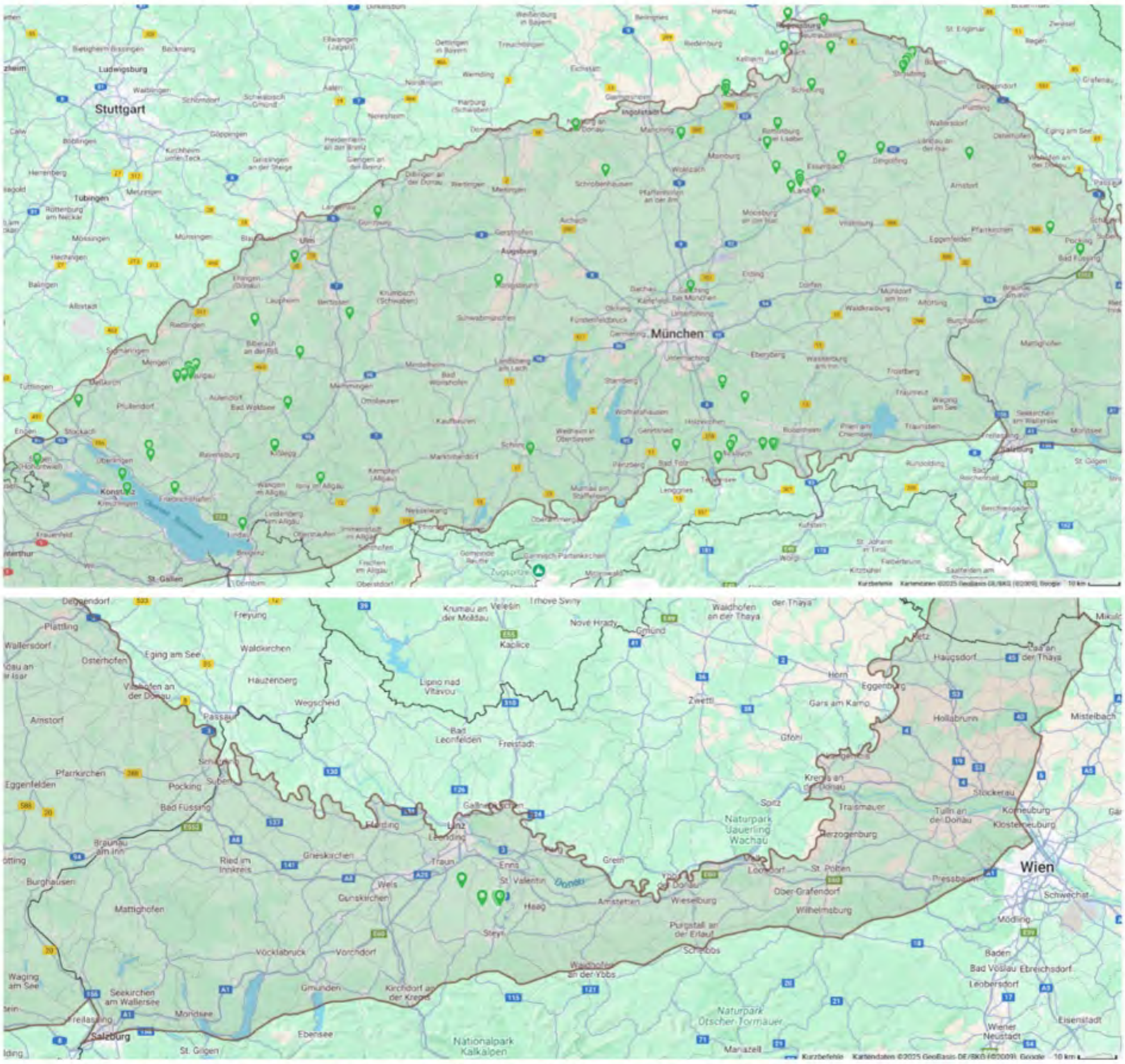


Figure 35: Map of the repurpose potential in the Molasse Basin displaying all public available wells for ATES. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

In Austria the suitability for ATES is mainly restricted to the area of Stadlkirchen (municipality of Dietach, district Steyr-Land, state Upper Austria). The query results in 10 wells (Figure 35), which mainly belong to the former gas fields and later gas storages of Thann, Teufelsgraben (both operated by OMV) and Stadlkirchen (RAG Austria; Kreutzer, 1993). In the German Molasse Basin, the density of potentially useful well locations for ATES applications is much greater, especially north and south of the Munich area and in the western part. This is probably based on two aspects: greater population density in the German part of the basin, and the occurrence of aquifers with sufficient storage capacity and permeability (adequate for seasonal storage). Currently ambitious new geothermal projects in Munich include newly drilled ATES wells (Stadtwerke München, 2025).

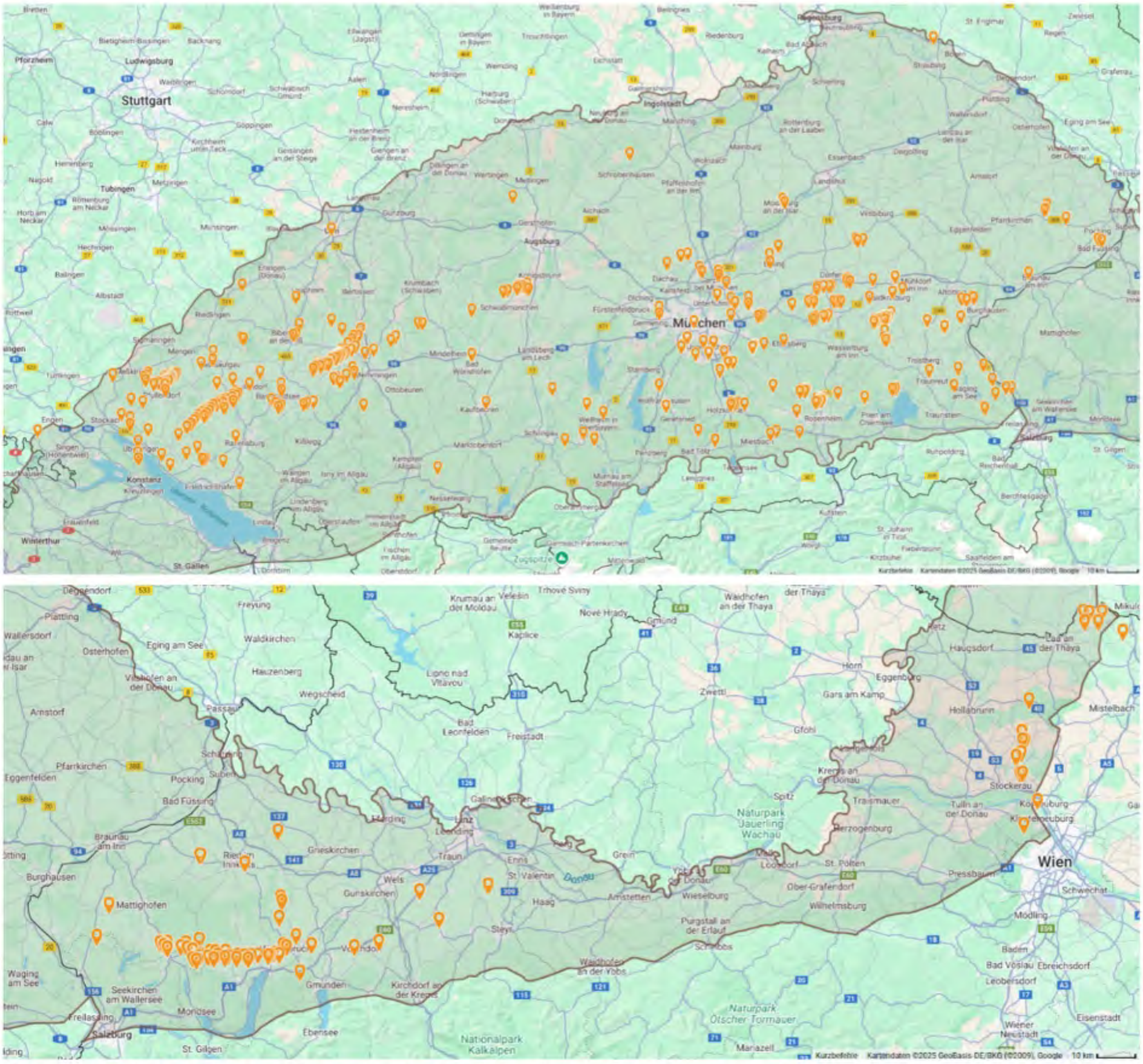


Figure 36: Wells suitable with certain restrictions for ATES in the Molasse Basin.

The low percentage of suitable wells (4.2%) and the high percentage (65.6%) of suitable, but uncertain wells for ATES (Figure 36) 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 hydrothermal energy production and too deep for ATES applications.

ATES	Molasse Basin		Molasse Basin - Germany		Molasse Basin - Austria	
	absolute	percentage	absolute	percentage	absolute	percentage
Total number of wells	2020	100	1354	100	666	100
Suitable	84	4.2	74	5.5	10	1.5
Uncertain	611	30.2	536	39.6	75	11.3
Not suitable	1325	65.6	744	54.9	581	87.2

Table 11: Absolute numbers and percentages of reusable wells for ATES in the Molasse Basin.

5.2 DBHE

From the input dataset of 2,020 wells (Figure 37), 398 (19.7%) are suitable (Figure 38), 470 (23.3%) are suitable with certain restrictions (Figure 39) and 1152 (57%) are not suitable for reuse as Deep Borehole Heat Exchanger (DBHE; Table 12).

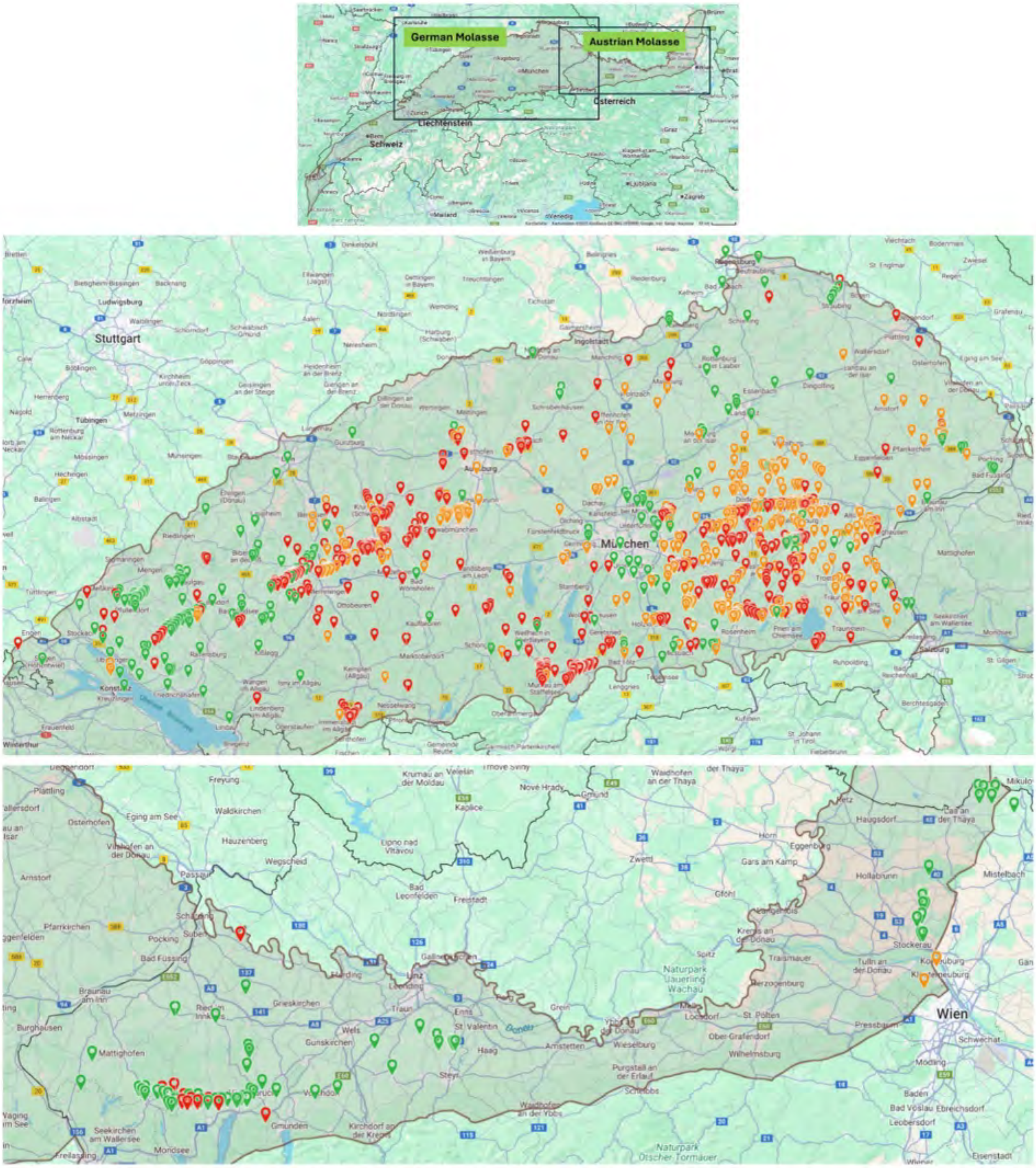


Figure 37: Maps of the repurpose potential in the Molasse Basin for DBHE.

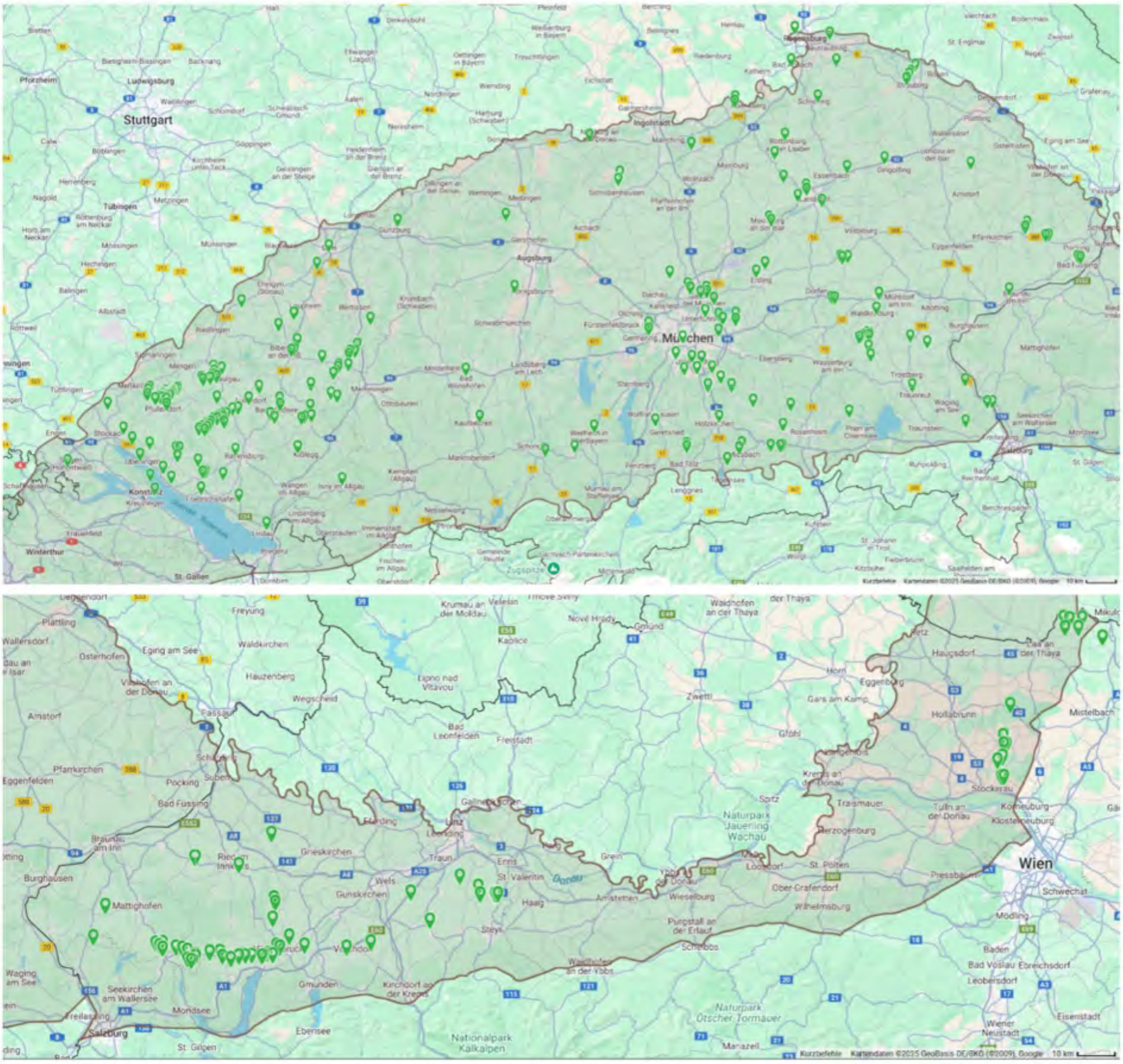


Figure 38: Suitable wells for reuse as DBHE in the Molasse Basin.

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, which is one of the pilot sites of TRANSGEO (Activity 2.3.2). With 11% of the wells suitable, this method shows high potential for Austria and its geological setting and well conditions (Table 12). Results are similar for Germany, DBHE is the most promising method to be employed with 24% of the boreholes being suitable and another 34.6% suitable with restrictions. Again, the Munich area, the wider area around Munich and the western part of the basin host most of the suitable wells (Figure 38) and the area east of Munich (eastern part of the basin) hosts most of the wells suitable, but with restrictions (Figure 39).

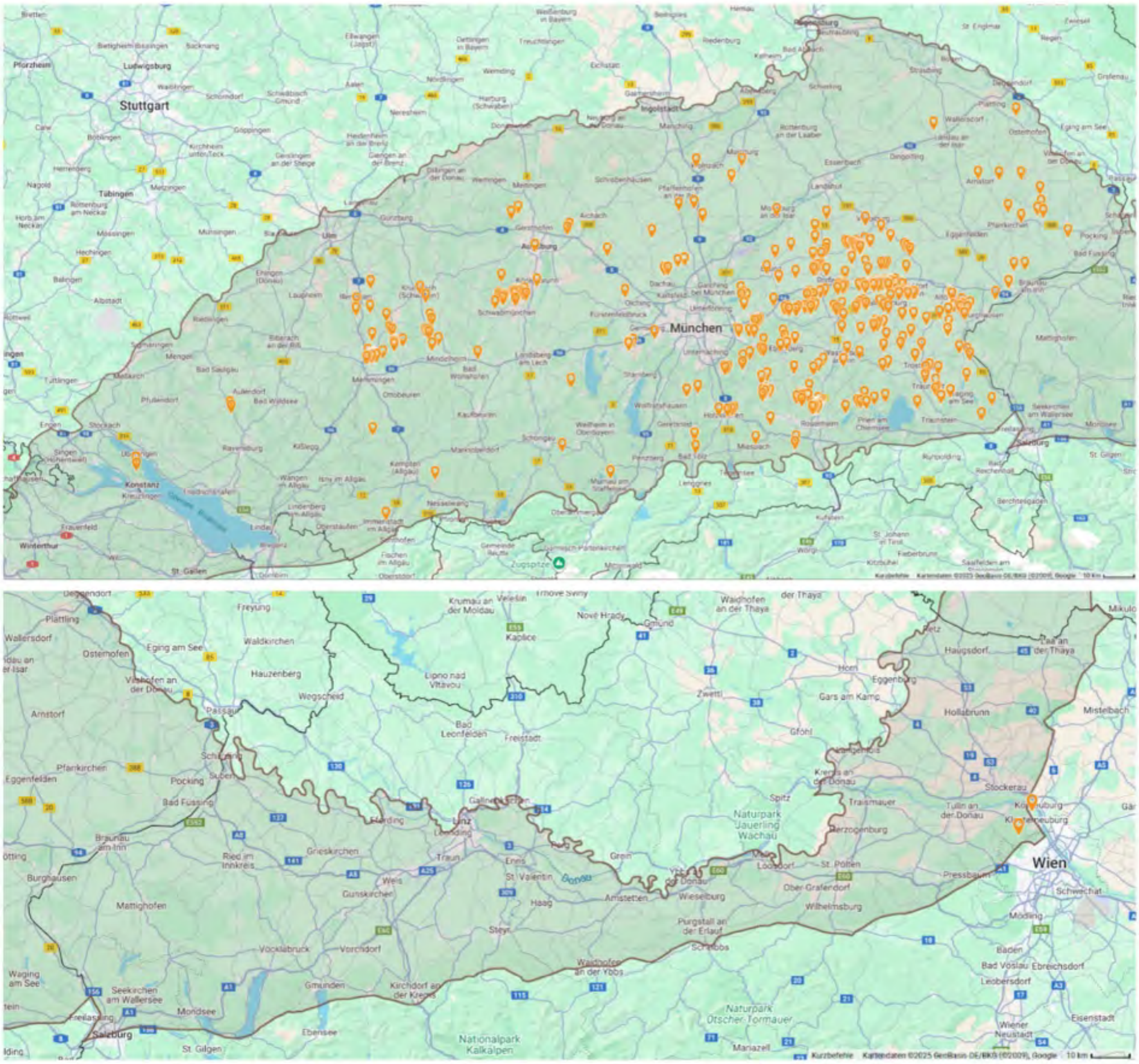


Figure 39: Suitable wells with restrictions for reuse as DBHE in the Molasse Basin.

Wells which are suitable but show unknown restrictions are 0.3% for DBHE in Austria (Figure 39). For Germany the percentages are higher as the date of drilling was not taken into account in the selection process, so even very old wells are included and have to be checked.

DBHE	Molasse Basin		Molasse Basin - Germany		Molasse Basin - Austria	
	absolute	percentage	absolute	percentage	absolute	percentage
Total number of wells	2020	100	1354	100	666	100
Suitable	398	19.7	325	24.0	73	11.0
Uncertain	470	23.3	468	34.6	2	0.3
Not suitable	1152	57.0	561	41.4	591	88.7

Table 12: Absolute numbers and percentages of reusable wells for DBHE in the Molasse Basin.

5.3 BTES

From the input dataset of 2,020 wells (Figure 40), 332 (16,4%) are suitable, 84 (4.2%) are suitable with certain restrictions and 1,604 (79.4%) are not suitable for reuse as Borehole Thermal Energy Storage (BTES; Table 13) in the Molasse Basin stretching over southern Germany and Austria.

Within the German part of the Molasse Basin the distribution of the suitable wells (19.8%) in the western part of the Basin and around Munich city, as well as to the northeast and south of Munich, is very similar to the ones suitable for DBHE applications. Nevertheless, even if, especially in the western part of the German MB, some of the potentially suitable wells are close to each other (less than 500 metres in some cases), BTES method is usually applied in arrays of wells (at least 3 according to the literature). Furthermore, it is understood that most of the wells are either abandoned or very old (<1990), which further complicates a potential reuse, if not only considering the market.

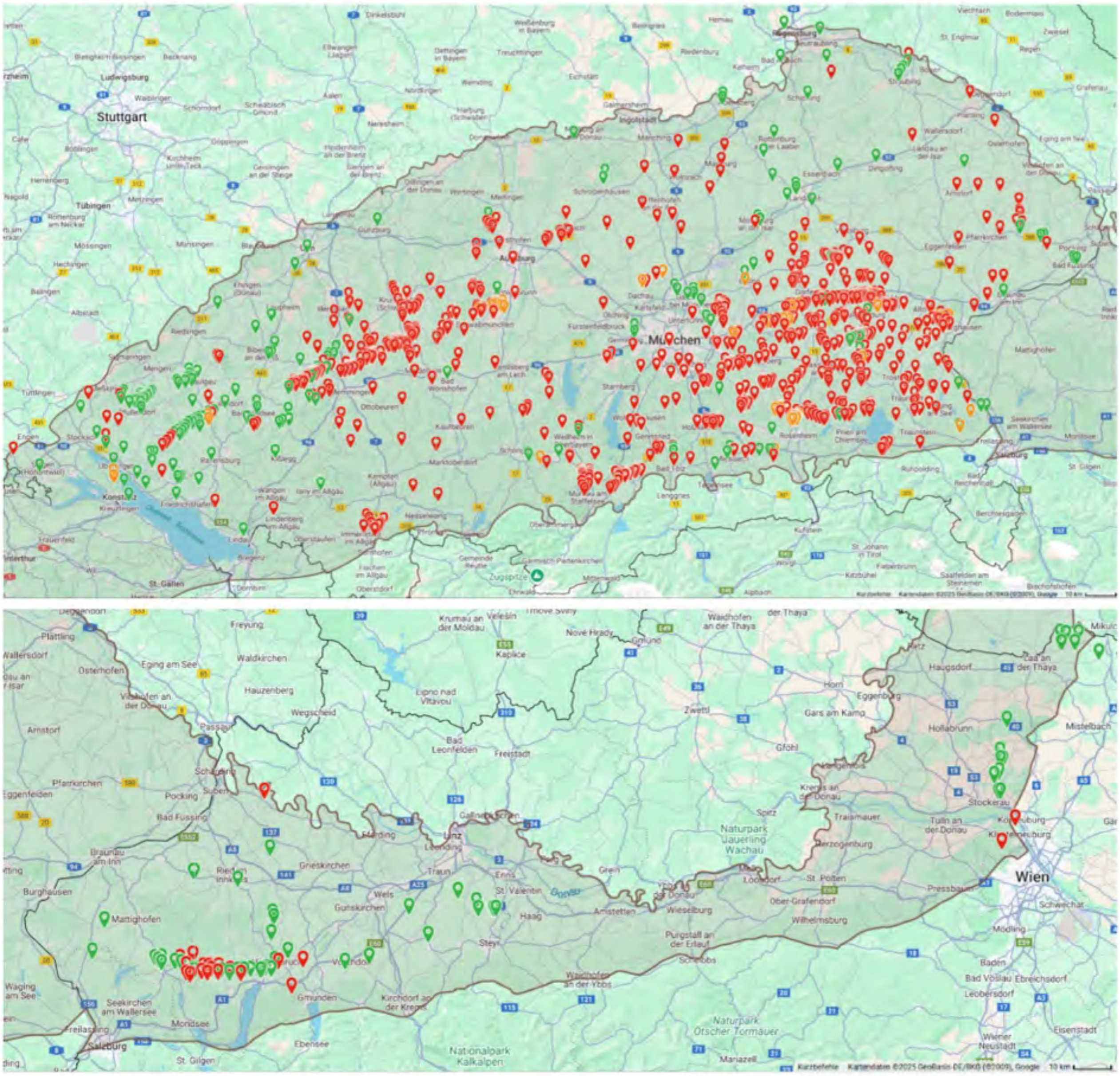


Figure 40: Map of the repurpose potential in the Molasse Basin for BTES. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

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 1000 m) and needs moderate temperature levels, the decision for suitability is mainly dependent on the positions of the wells according to the consumers.

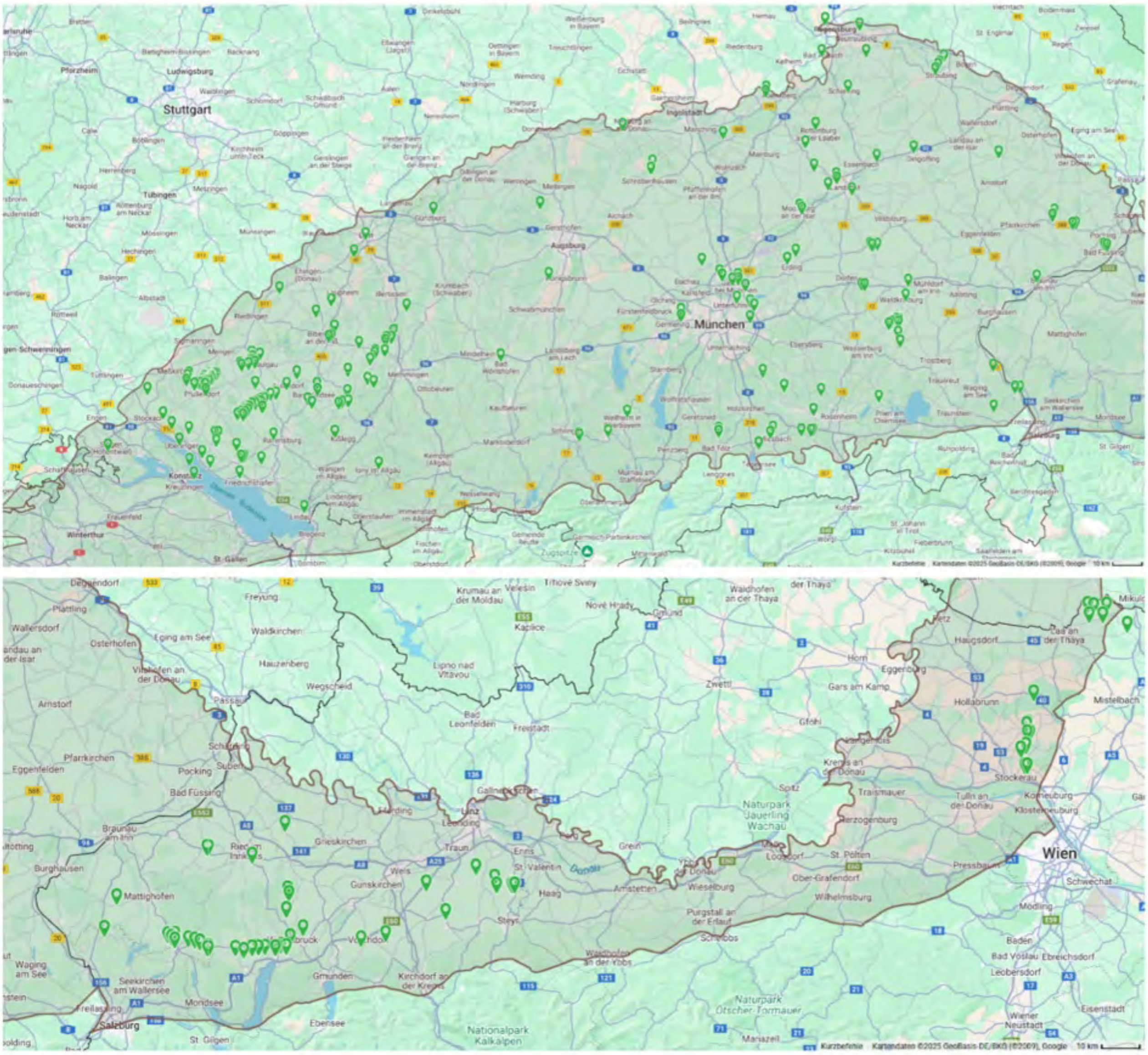


Figure 41: Wells suitable for BTES in the Molasse Basin.

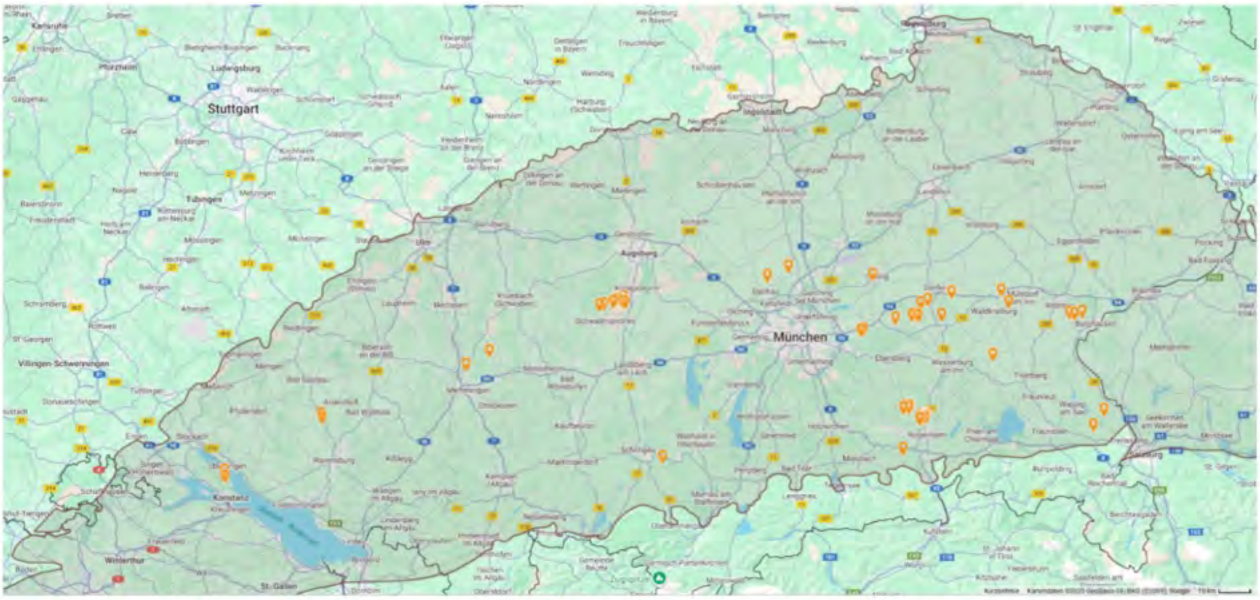


Figure 42: Wells suitable with certain restrictions for BTES in the Molasse Basin in Germany. In Austria there are no wells of this type.

BTES	Molasse Basin		Molasse Basin - Germany		Molasse Basin - Austria	
	absolute	percentage	absolute	percentage	absolute	percentage
Total number of wells	2020	100	1354	100	666	100
Suitable	332	16.4	268	19.8	64	9.6
Uncertain	84	4.2	84	6.2	0	0.0
Not suitable	1604	79.4	1002	74.0	602	90.4

Table 13: Absolute numbers and percentages of reusable wells for BTES in the Molasse Basin.

5.4 HE

From the input dataset of 2,020 wells (Figure 43), 251 (12.4%) are suitable, 939 (46.5%) are suitable with certain restrictions and 830 (41.1%) are not suitable for reuse as Hydrothermal Energy applications (Table 14) in the Molasse Basin area (Germany and Austria).

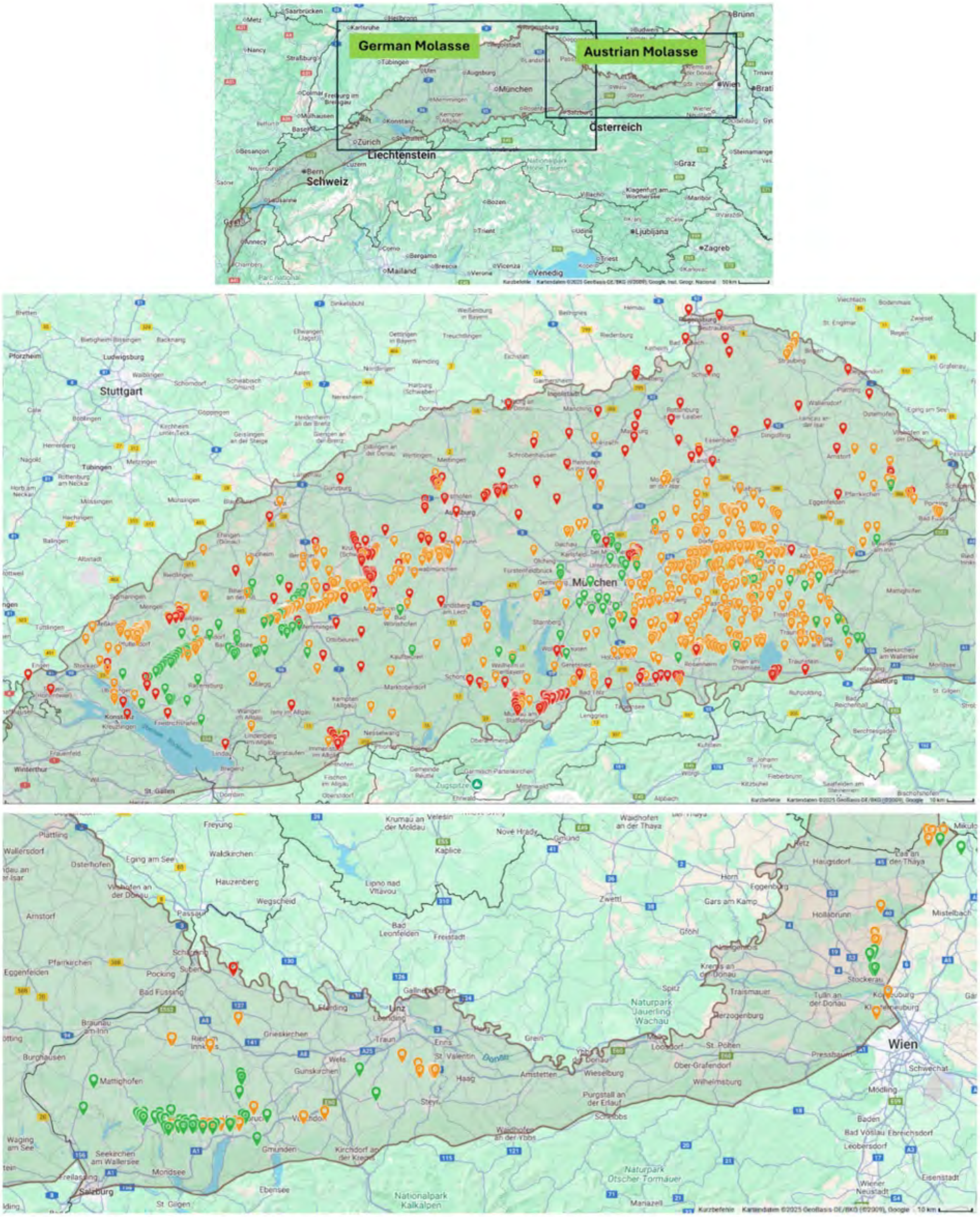


Figure 43: Map of the repurpose potential in the Molasse Basin for HE. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

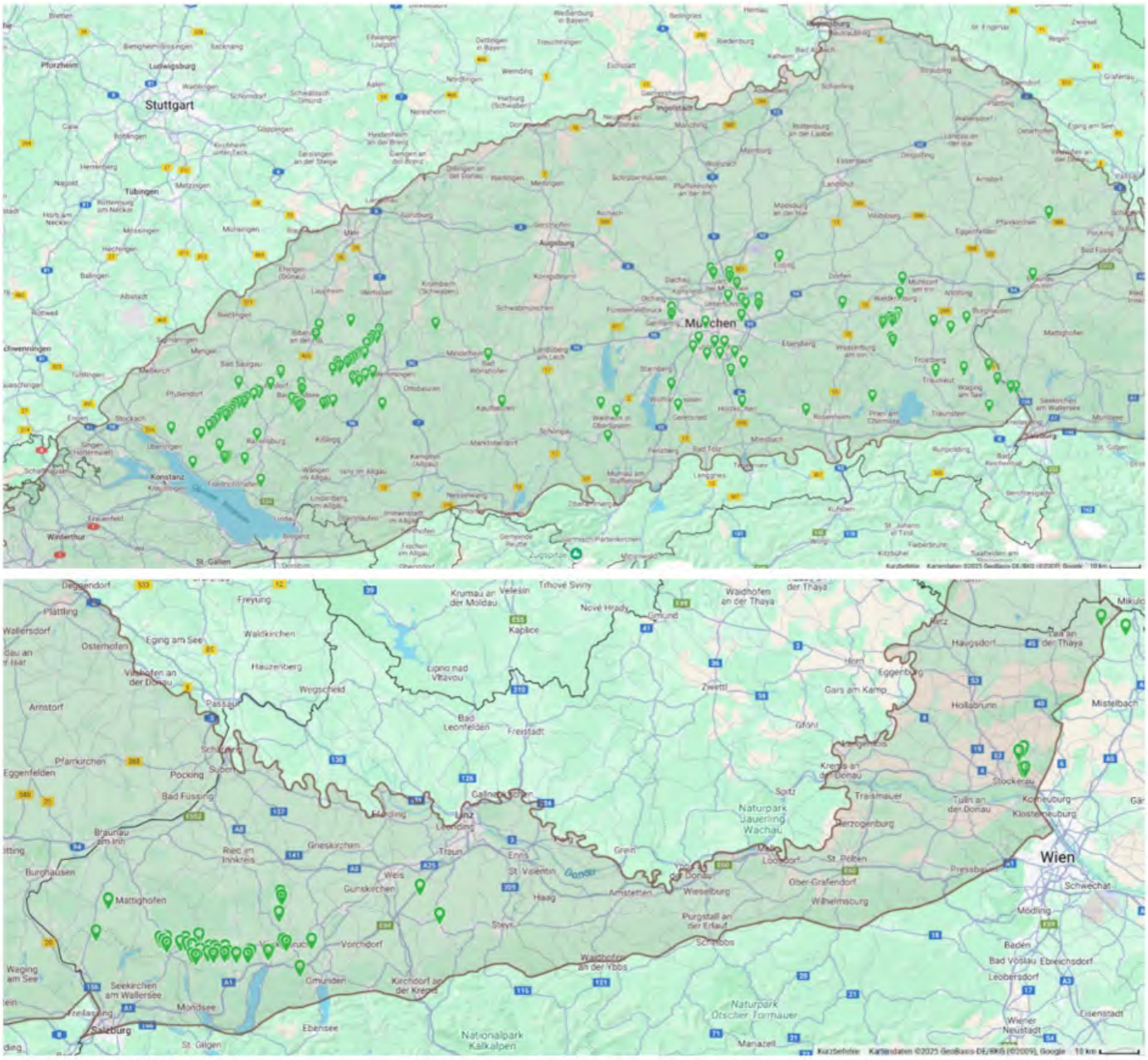


Figure 44: Wells suitable for HE in the Molasse Basin.

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 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 the German part of the basin, 14.8% of the wells are potentially suitable for HE applications and up to almost 67% could be suitable with some restrictions (Table 12, Fig. 47). Hydrothermal Energy applications are the most commonly used in Germany, including the German Molasse Basin (GMB). However, for reuse purposes within the GMB, they rank third, following DBHE and BTES applications. The suitable wells lie in the western part of the basin and within Munich city area and south-southeast of it.

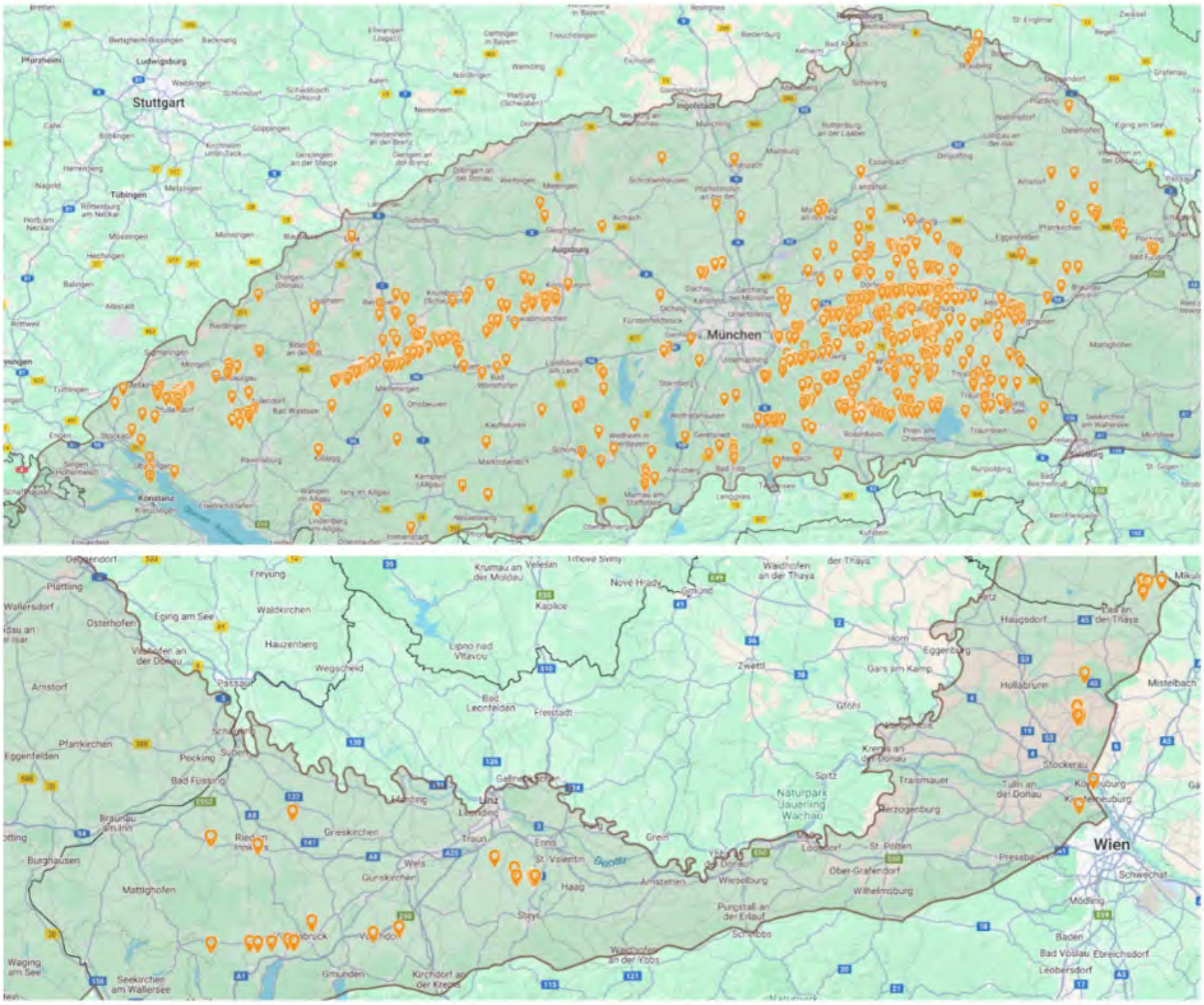


Figure 45: Wells suitable with certain restrictions for HE in the Molasse Basin.

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.

HE	Molasse Basin		Molasse Basin - Germany		Molasse Basin - Austria	
	absolute	percentage	absolute	percentage	absolute	percentage
Total number of wells	2020	100	1354	100	666	100
Suitable	251	12.4	201	14.8	50	7.5
Uncertain	939	46.5	904	66.8	35	5.3
Not suitable	830	41.1	249	18.4	581	87.2

Table 14: Absolute numbers and percentages of reusable wells for HE in the Molasse Basin.

5.5 EGS

From the input dataset of 2,020 wells (Figure 46), 22 (1.1%) are suitable, 170 (8.4%) are suitable with certain restrictions and 1,828 (90.5%) are not suitable for reuse as Enhanced Geothermal Systems (EGS; Table 15).

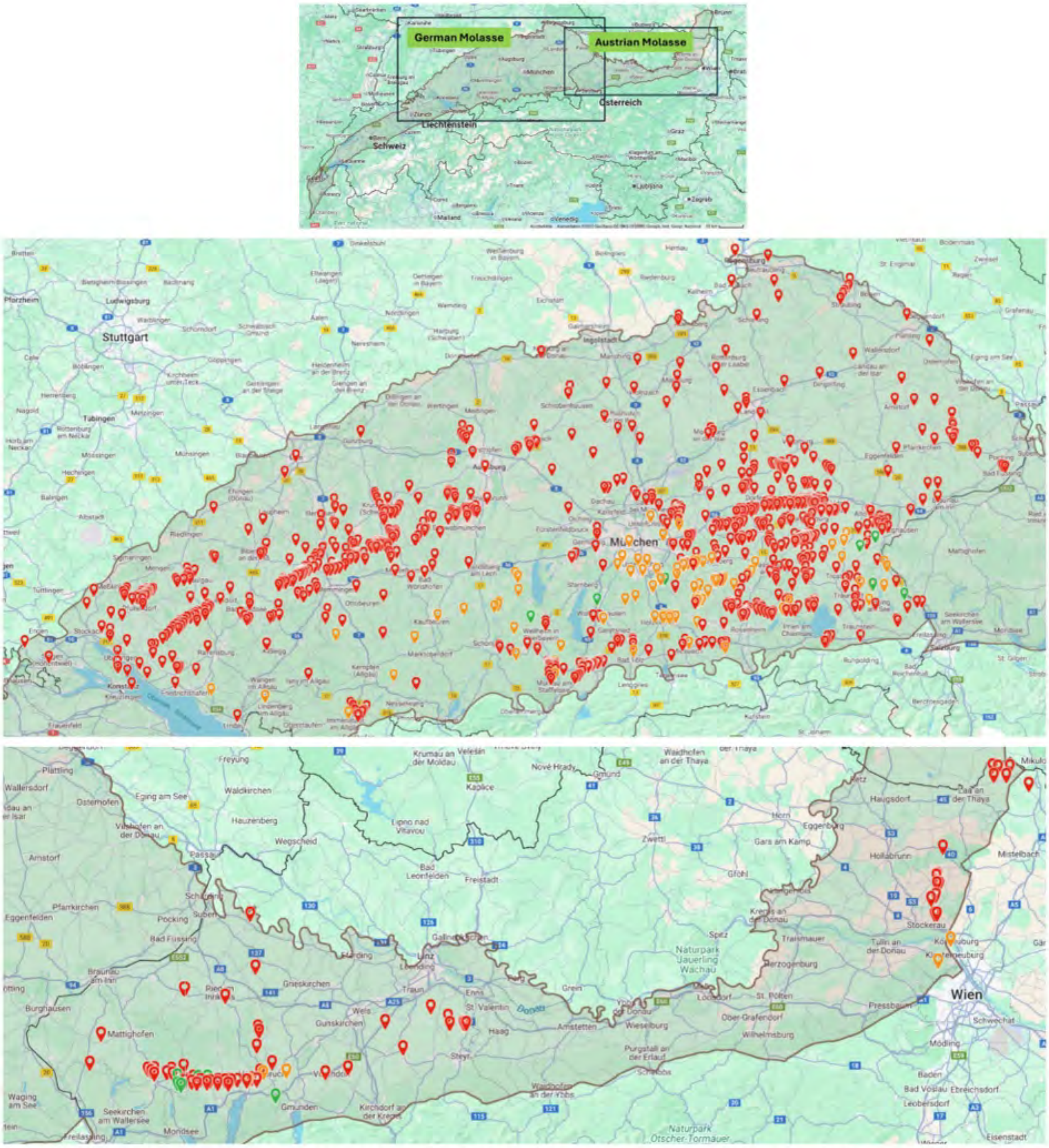


Figure 46: Map of the repurpose potential in the Molasse Basin for EGS. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

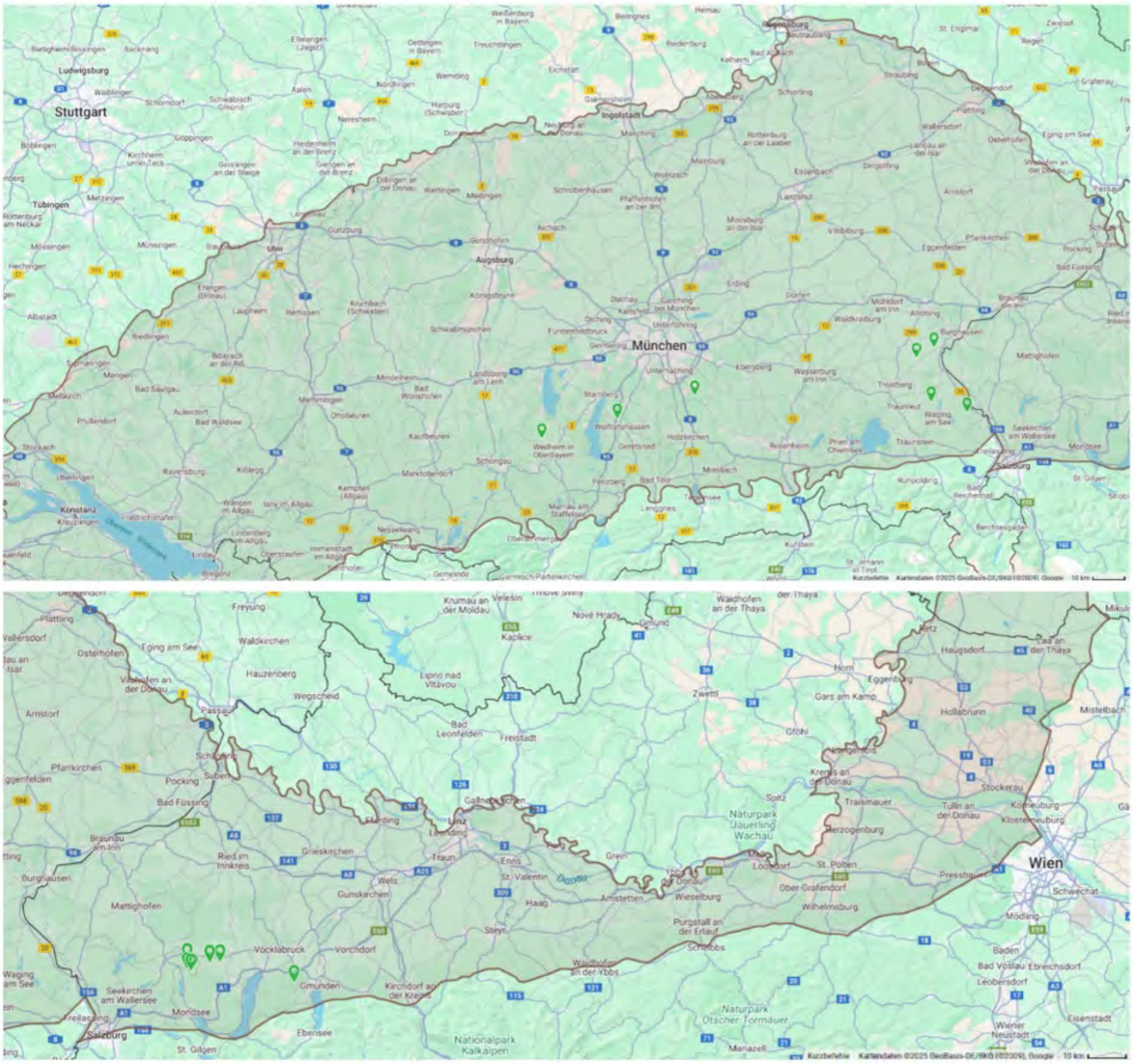


Figure 47: Wells suitable for EGS in the Molasse Basin.

In the Austrian part of the Molasse Basin 7 wells are reusable as EGS geothermal applications (Figure 47). They are situated in Upper Austria in the region of Attergau. These wells are mainly former exploration wells with a depth greater than 1000 m. In a similar way, 3 wells south of Munich and 4 at the eastern border of the basin are potentially suitable for EGS applications in the German part of the Molasse basin, corresponding to 1.1% of the wells.

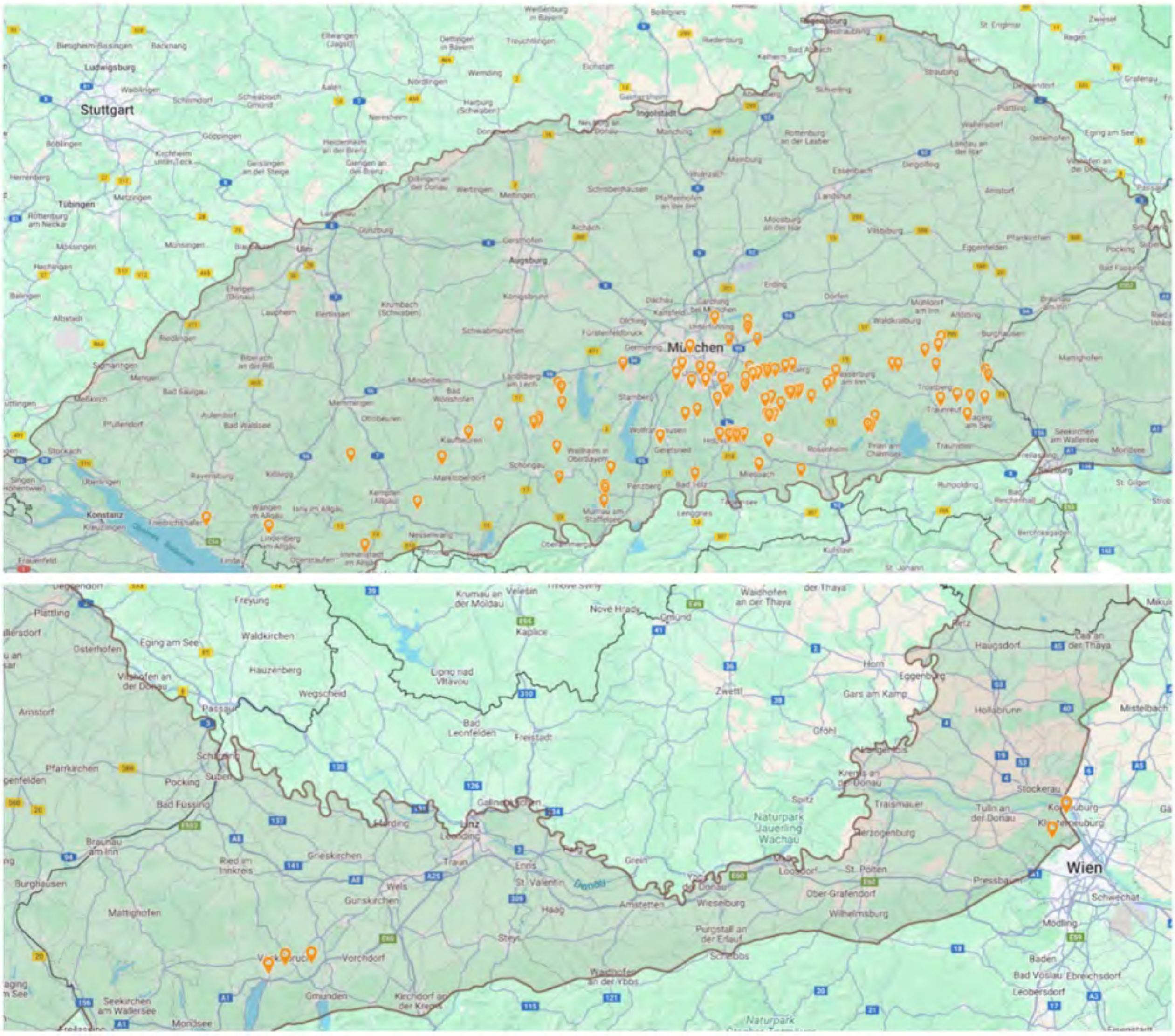


Figure 48: Wells suitable with certain restrictions for EGS in the Molasse Basin.

EGS	Molasse Basin		Molasse Basin - Germany		Molasse Basin - Austria	
	absolute	percentage	absolute	percentage	absolute	percentage
Total number of wells	2020	100	1354	100	666	100
Suitable	22	1.1	15	1.1	7	1.1
Uncertain	170	8.4	165	12.2	5	0.8
Not suitable	1828	90.5	1174	86.7	654	98.2

Table 15: Absolute numbers and percentages of reusable wells for EGS in the Molasse Basin.

5.6 Summary of the repurposing potential of the Molasse Basin in Germany and Austria

Molasse Basin	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute)	2020	2020	2020	2020	2020
Suitable	84	398	332	251	22
Uncertain	611	470	84	939	170
Not suitable	1325	1152	1604	830	1828

Table 16: Absolute numbers of reusable wells for the 5 TRANSGEO methods in the Molasse Basin.

Molasse Basin	ATES	DBHE	BTES	HE	EGS
Total of wells (percentage)	100	100	100	100	100
Suitable	4.2	19.7	16.4	12.4	1.1
Uncertain	30.2	23.3	4.2	46.5	8.4
Not suitable	65.6	57.0	79.4	41.1	90.5

Table 17: Percentages of reusable wells for the 5 TRANSGEO methods in the Molasse Basin.

The Table 16 and Table 17 show for the Molasse Basin that Deep Borehole Heat Exchangers (DBHE) appear to offer the greatest potential for repurposing existing wells, with almost 20% classified as suitable. Borehole Thermal Energy Storage (BTES) also shows some promise, although the majority of wells in this category are not suitable. Hydrothermal Energy (HE) is characterised by a high degree of uncertainty: while around 12% of wells are suitable, nearly 50% are uncertain, requiring more detailed investigations. By contrast, Aquifer Thermal Energy Storage (ATES) has only very limited applicability, and Enhanced Geothermal Systems (EGS) are almost entirely unsuitable, with more than 90% of the wells offering no potential for reuse.

Figure 49: Percentages of reusable wells for the five TRANSGEO methods in the Molasse Basin. The background colours of the charts indicate suitable wells (green), suitable wells with restrictions (yellow) and non-usable wells (red).

The comparison of results (Figure 49) of the Austrian and German part with the total percentages of the Molasse Basin show the uncertainties concerning well status and drilling year, both criteria to be queried by the tool automatically and user manually (e.g. drilling date). As described above the Austrian dataset is missing well status information totally as the German has around 50% with this information. In contrast, drilling dates are complete for Austria, but missing for many wells in Germany.

6 Vienna Basin (Austria)

The Vienna Basin stretches across northeastern Austria and into neighboring Slovakia and the Czech Republic, encompassing major urban centers such as Vienna, which enhances its strategic relevance for geothermal energy development. Geologically, it is a deep sedimentary basin formed 20 Million years ago and filled with successions of mainly sand- and siltstones overlying a complex basement of calcareous and crystalline rocks (Decker et al., 2005; Salcher et al., 2012).

Similar to the Molasse Basin, the basin hosts several aquifers and hydrocarbon reservoirs (oil and gas) at different levels (Wessely, 2006). Their exploration resulted in intense exploration and drilling of wells in the area. Nowadays the amount of wells in the Austrian part of the Vienna Basin is 3750 (Sachsenhofer et al., 2024).

OMV Austria is the main operator in the area followed by ADX. OMV owns most of the wells in the area and only around 24 are owned by ADX (Bundesministerium für Finanzen, 2025).

The Vienna Basin dataset for this repurpose study consists of 3357 wells with published data owned by OMV Austria (Figure 50). It is important to note that, due to publication rights, well status information is missing from the Austrian dataset. As a result, the number of wells available for geothermal repurposing does not equal the total of active wells in Austria. A final request for a well's availability must be made to the well owner.

Using the IT tool, wells drilled before 1990 were filtered out, based on the consideration that the average lifespan of an oil and gas well is approximately 30 to 40 years (Planète Énergies, 2015; IOGP, 2018; OGA, 2018). There are 300 wells available in our database drilled later than 1990. While older wells can be valuable candidates for repurposing, those drilled too long ago may no longer exist in usable condition — they may have been fully decommissioned, removed from records, or permanently sealed, making them inaccessible for geothermal conversion. Therefore, this filtering step helps to exclude wells that are likely beyond their operational lifespan and no longer suitable for reuse, ensuring the focus remains on viable, repurposable infrastructure.

The following sections will provide a detailed description of the repurposing potential for each targeted methodology.

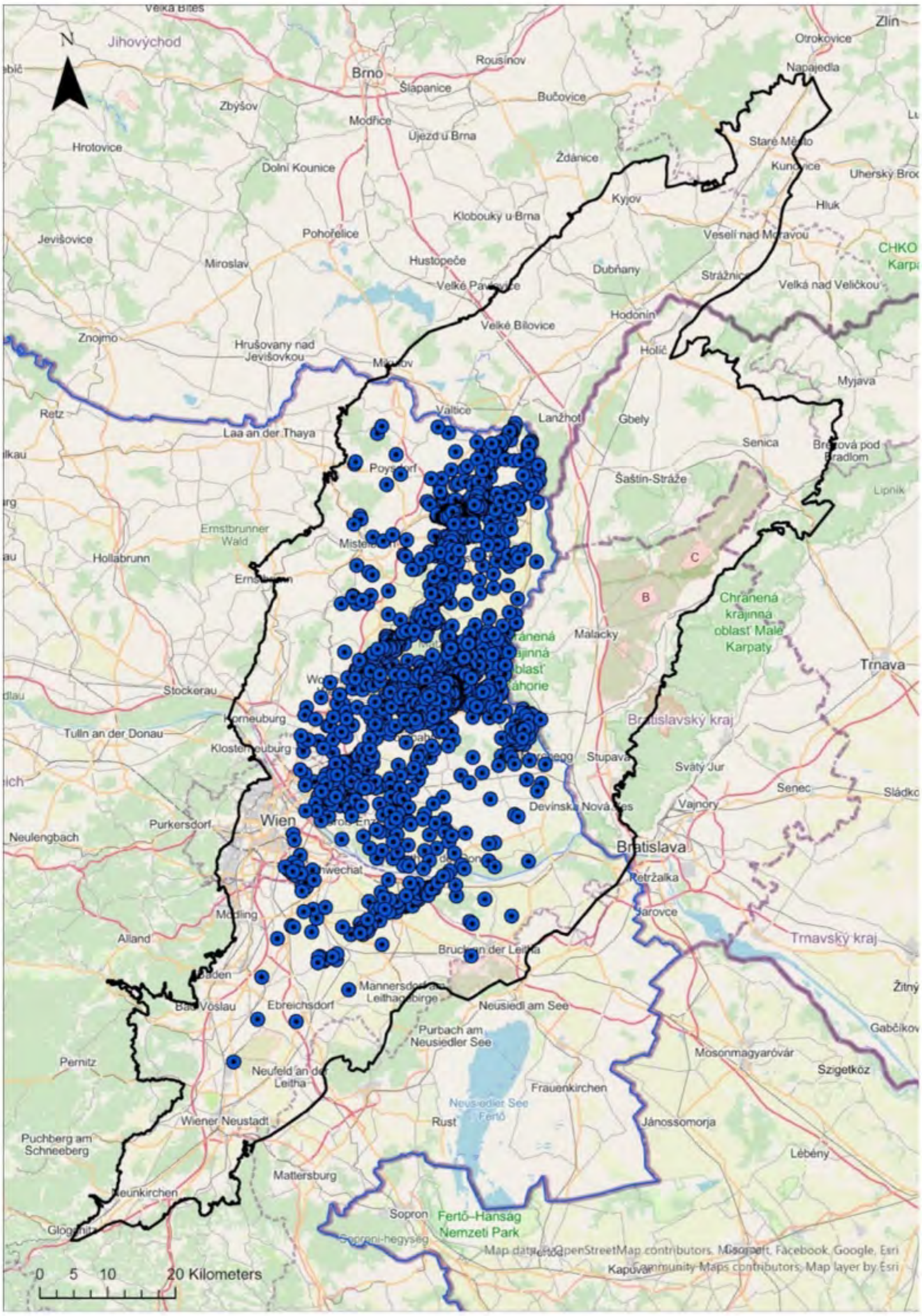


Figure 50: Map of the contour of the Vienna basin with the Austrian wells.

6.1 ATES

This section presents the results from the well assessment tool evaluating the repurposing potential of existing wells in the Vienna Basin for Aquifer Thermal Energy Storage (ATES); only wells drilled **after 1990** were included in this analysis following the filtering step described earlier.

Table 18 provides a quantitative overview: Out of 3,357 total wells assessed, 12 (0.4%) are classified as suitable for repurposing. 288 wells (8.6%) fall into the uncertain category, indicating a moderate but notable number that could become viable with further exploration. The majority, 3,057 wells (91.1%), are not suitable for ATES repurposing under current criteria.

Vienna Basin	ATES (absolute)	ATES (percentage)
Totals of wells	3357	100
Suitable	12	0.4
Uncertain	288	8.6
Not suitable	3057	91.1

Table 18: Absolute numbers and percentages of reusable wells for ATES in the Vienna Basin.

Figure 51 shows the spatial distribution of the wells that are categorised based on their suitability for ATES repurposing:

- **Green flags** indicate wells that are suitable for repurposing without restrictions.
- **Orange flags** represent wells with uncertain status, requiring further investigation or data.
- **Red flags** are wells deemed not suitable for repurposing.

Figure 52 highlights only the **suitable wells**, clearly showing clusters of potential ATES infrastructure, particularly in areas with favorable subsurface conditions.

Figure 53 displays wells that could be **conditionally suitable**, where some limitations or missing data must be addressed before confirming their reuse potential.

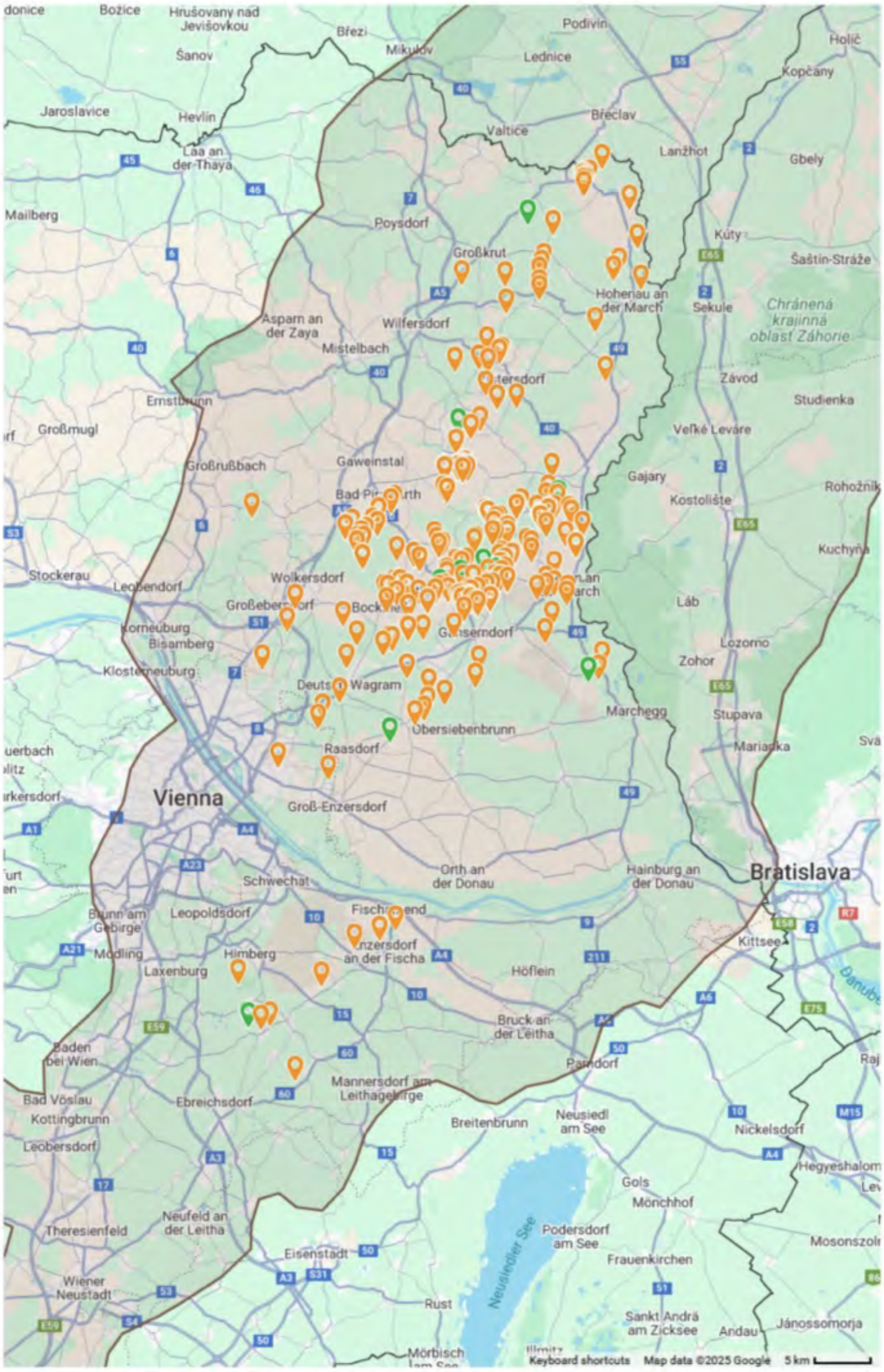


Figure 51: Map of the repurpose potential for ATES within the contour of the Vienna basin (grey area).

Figure 52: Suitable wells for ATES in the Vienna Basin (grey area).

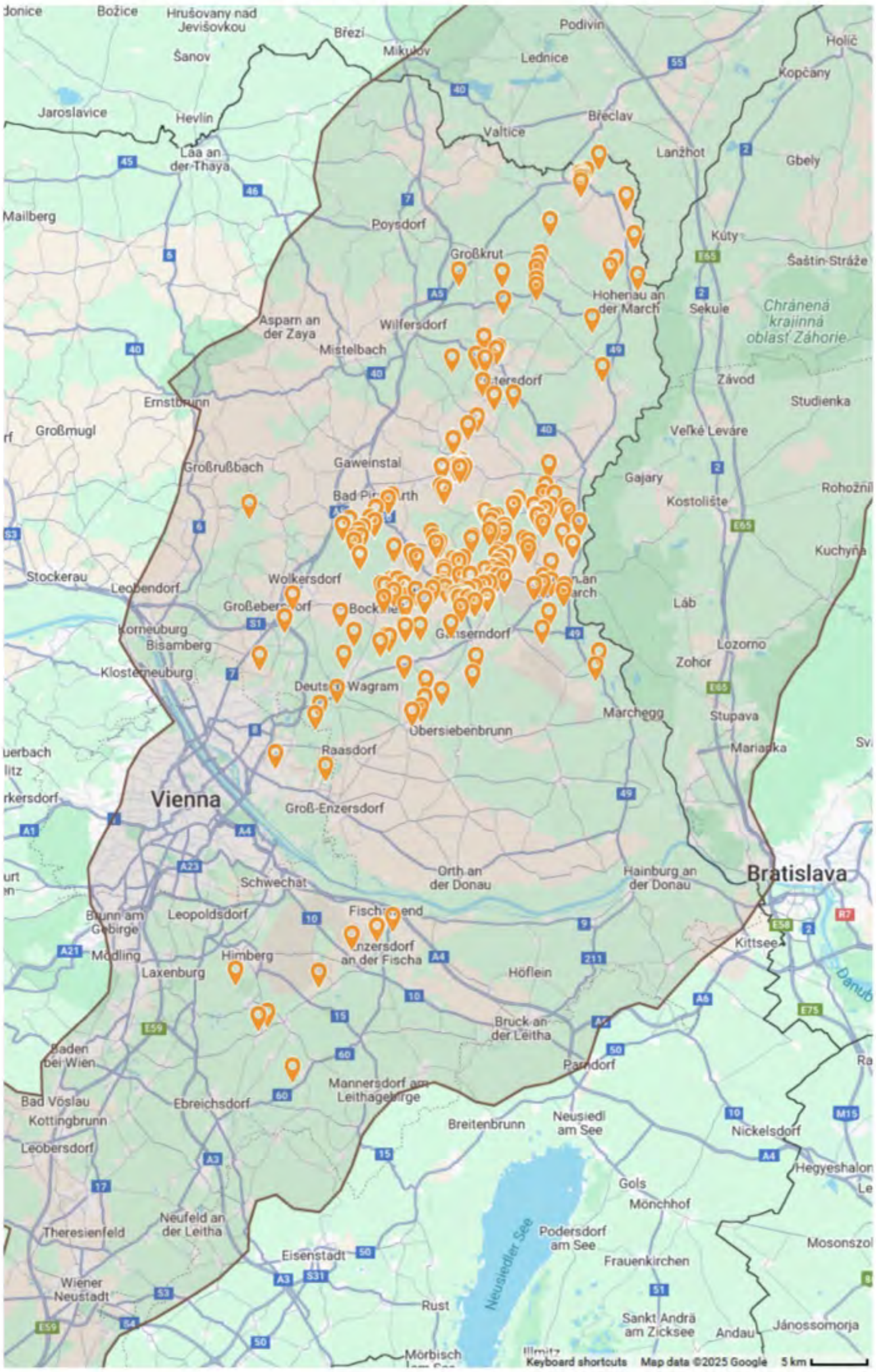


Figure 53: Suitable wells with certain restrictions for ATES in the Vienna Basin (grey area).

6.2 DBHE

This section presents the results from the IT tool assessing the repurposing potential of existing wells in the Vienna Basin for Deep Borehole Heat Exchanger (DBHE); only wells drilled **after 1990** were included in this analysis following the filtering step described earlier.

Table 19 provides a quantitative overview: Out of **3,357** total wells assessed, **255 wells** (7.6%) are classified as suitable for repurposing. **8 wells** (0.2%) fall into the uncertain category, indicating a moderate but notable number that could become viable with further exploration. The majority, **3,094 wells** (92.2%), are not suitable for DBHE repurposing under current criteria.

Vienna Basin	DBHE (absolute)	DBHE (percentage)
Totals of wells	3357	100
Suitable	255	7.6
Uncertain	8	0.2
Not suitable	3094	92.2

Table 19: Absolute numbers and percentages of reusable wells for DBHE in the Vienna Basin.

Figure 54 shows the spatial distribution of the wells that are categorised based on their suitability for DBHE repurposing:

- **Green flags** indicate wells that are suitable for repurposing without restrictions.
- **Orange flags** represent wells with uncertain status, requiring further investigation or data.
- **Red flags** are wells deemed not suitable for repurposing.

Figure 55 highlights only the **suitable wells**, clearly showing clusters of potential DBHE infrastructure, particularly in areas with favorable subsurface conditions.

Figure 56 displays wells that could be **conditionally suitable**, where some limitations or missing data must be addressed before confirming their reuse potential.

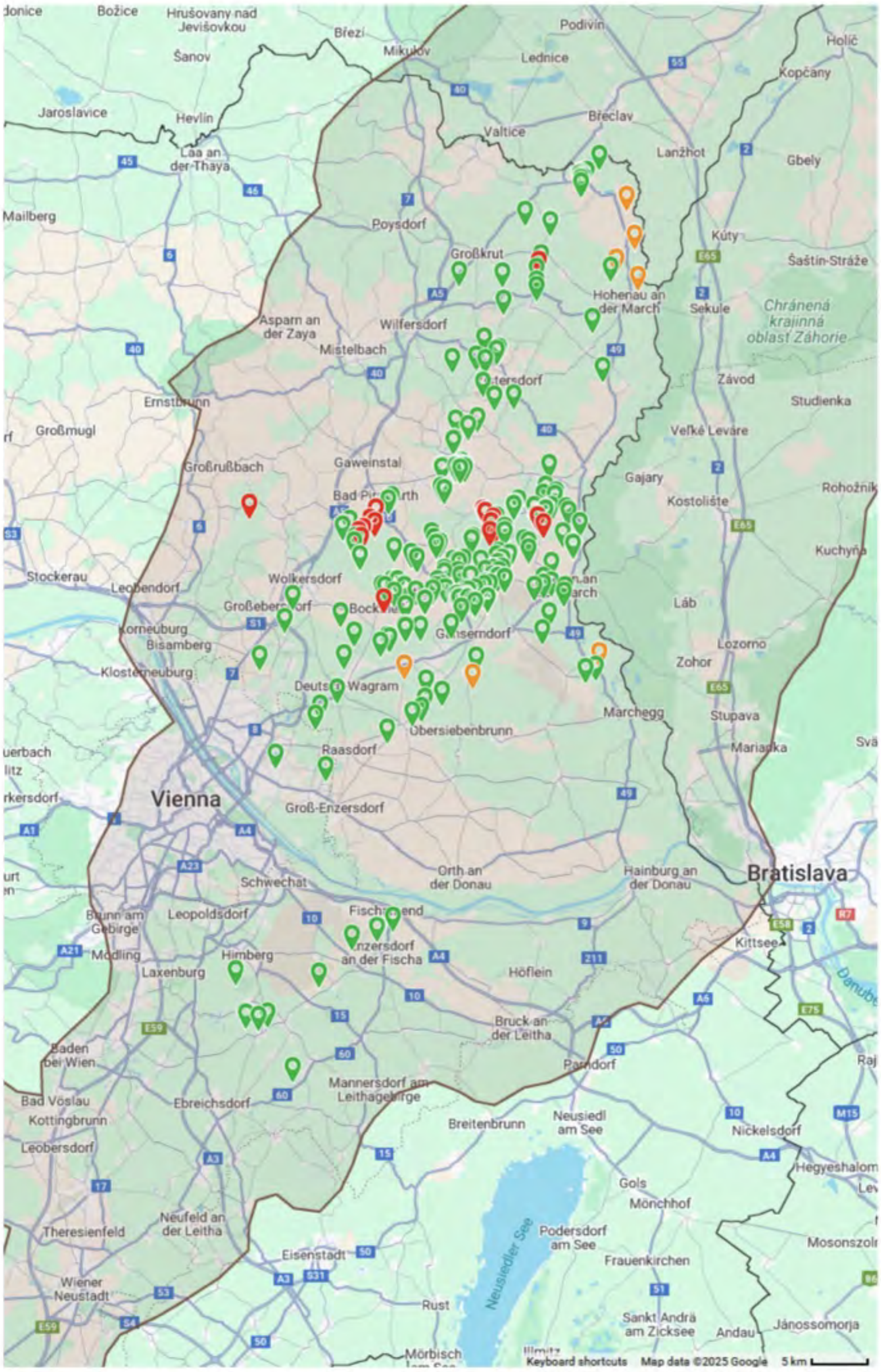


Figure 54: Map of the repurpose potential for DBHE within the contour of the Vienna basin (grey area).

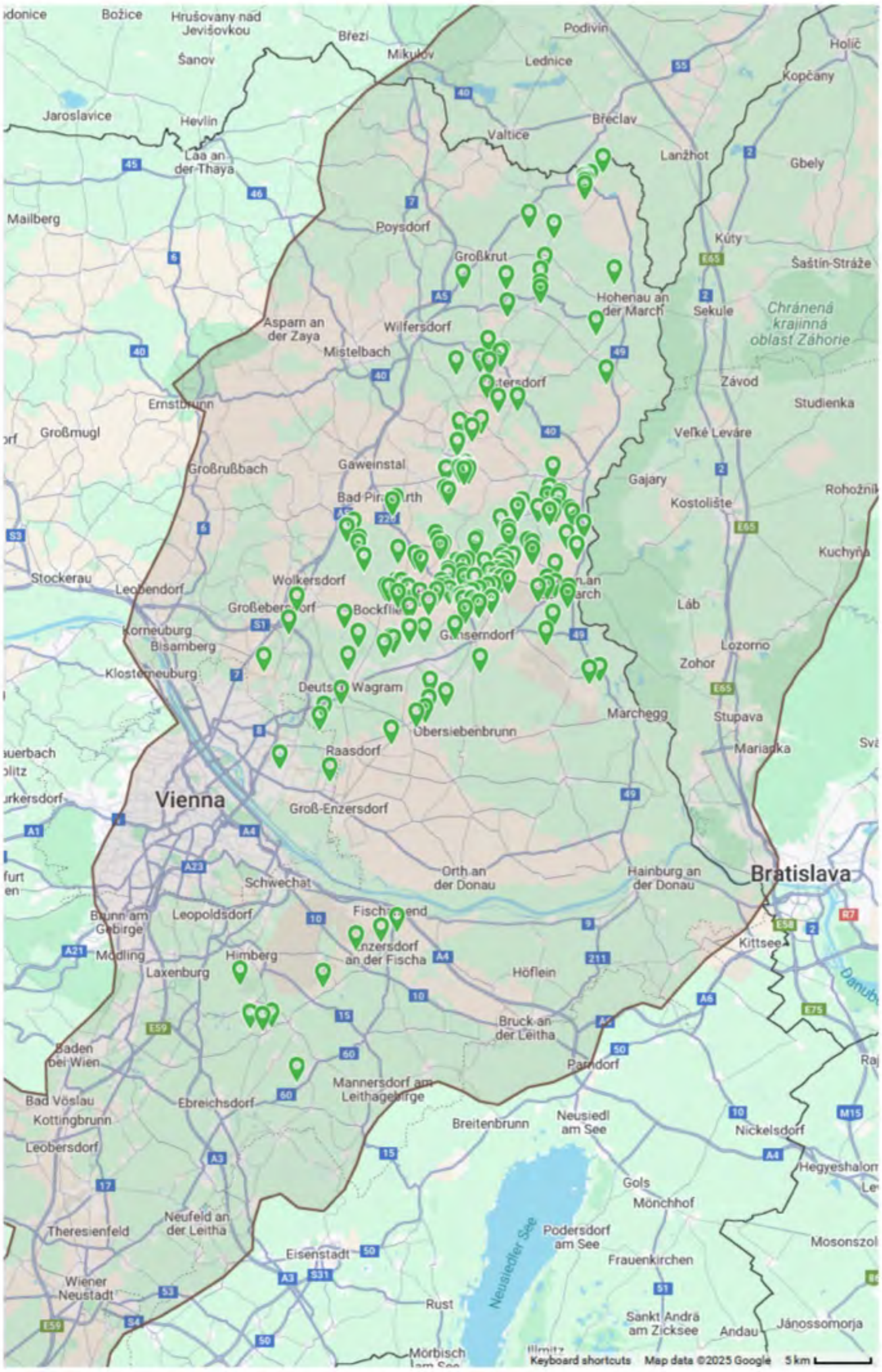


Figure 55: Suitable wells for DBHE in the Vienna Basin (grey area).

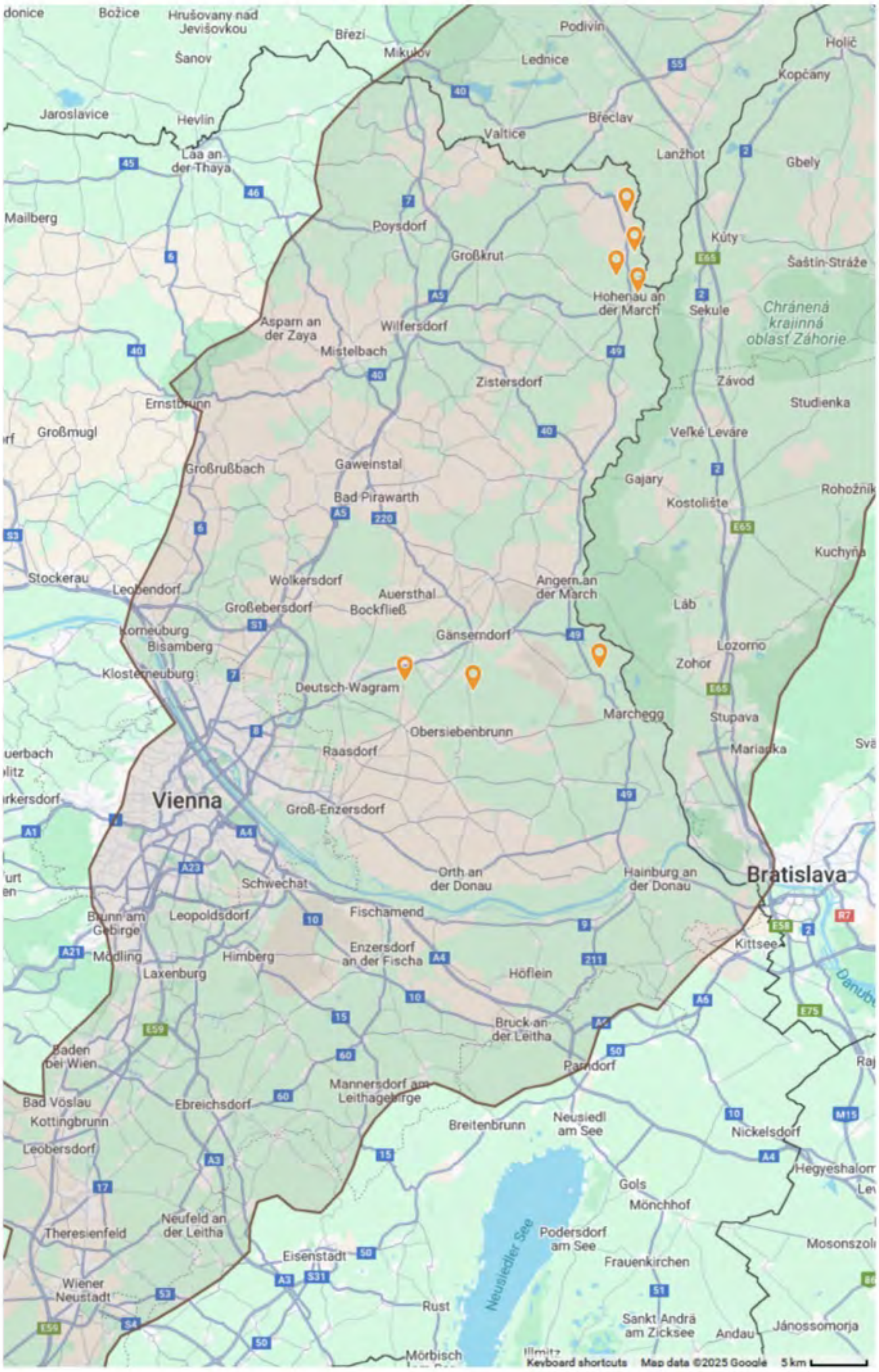


Figure 56: Suitable wells with certain restrictions for DBHE in the Vienna Basin (grey area).

6.3 BTES

This section presents the results from the IT tool assessing the repurposing potential of existing wells in the Vienna Basin for Borehole Thermal Energy Storage (BTES); only wells drilled **after 1990** were included in this analysis following the filtering step described earlier.

Table 20 provides a quantitative overview: Out of **3,357** total wells assessed, **234** (7%) are classified as suitable for repurposing. **8 wells** (0.2%) fall into the uncertain category, indicating a moderate but notable number that could become viable with further exploration. The majority, **3,115 wells** (92.8%), are not suitable for BTES repurposing under current criteria.

Vienna Basin	BTES (absolute)	BTES (percentage)
Totals of wells	3357	100
Suitable	234	7
Uncertain	8	0.2
Not suitable	3115	92.8

Table 20: Absolute numbers and percentages of reusable wells for BTES in the Vienna Basin.

Figure 57 shows the spatial distribution of the wells that are categorised based on their suitability for BTES repurposing:

- **Green flags** indicate wells that are suitable for repurposing without restrictions.
- **Orange flags** represent wells with uncertain status, requiring further investigation or data.
- **Red flags** are wells deemed not suitable for repurposing.

Figure 58 highlights only the **suitable wells**, clearly showing clusters of potential BTES infrastructure, particularly in areas with favorable subsurface conditions.

Figure 59 displays wells that could be **conditionally suitable**, where some limitations or missing data must be addressed before confirming their reuse potential.

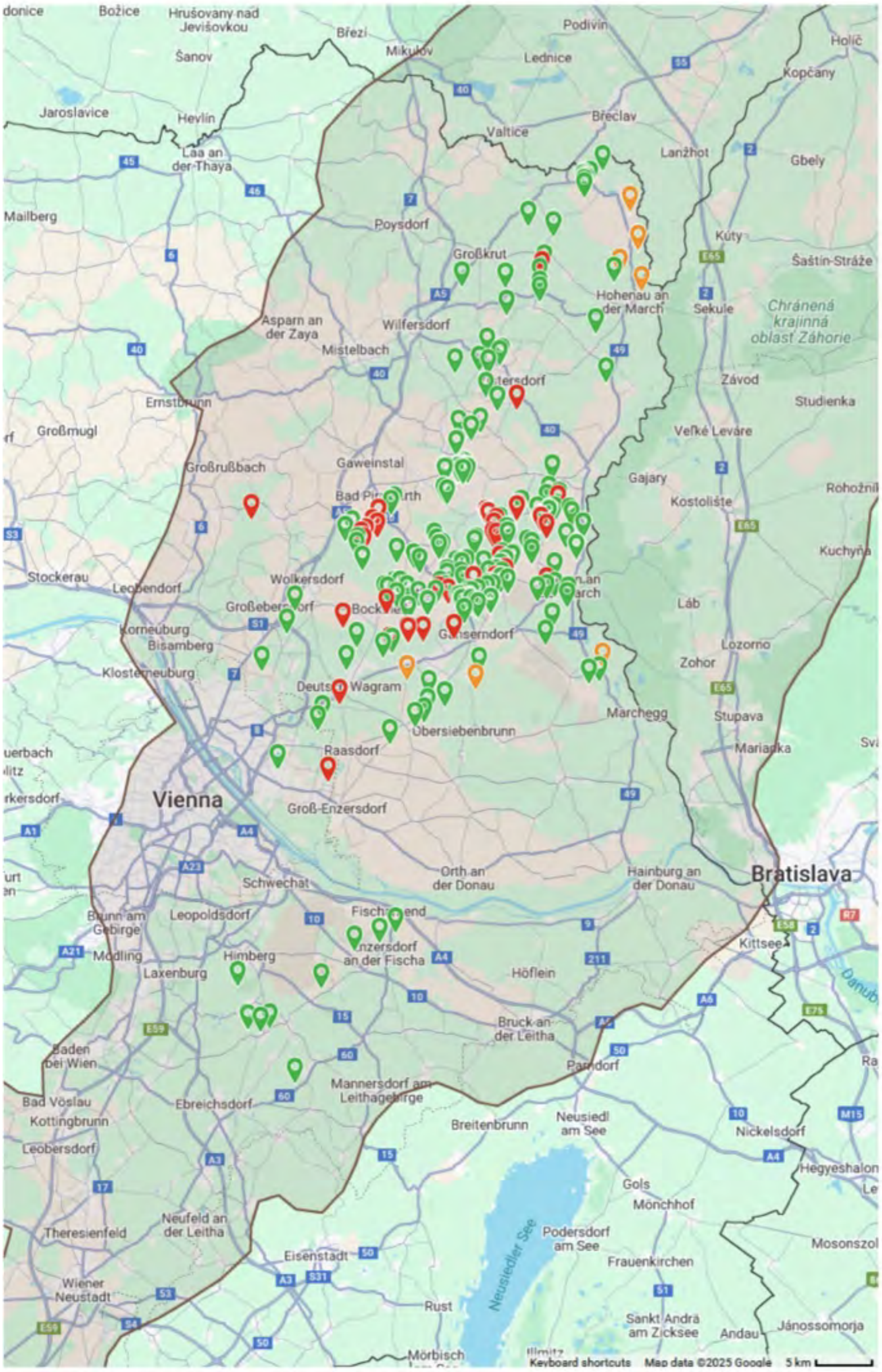


Figure 57: Map of the repurpose potential for BTES within the contour of the Vienna basin (grey area).

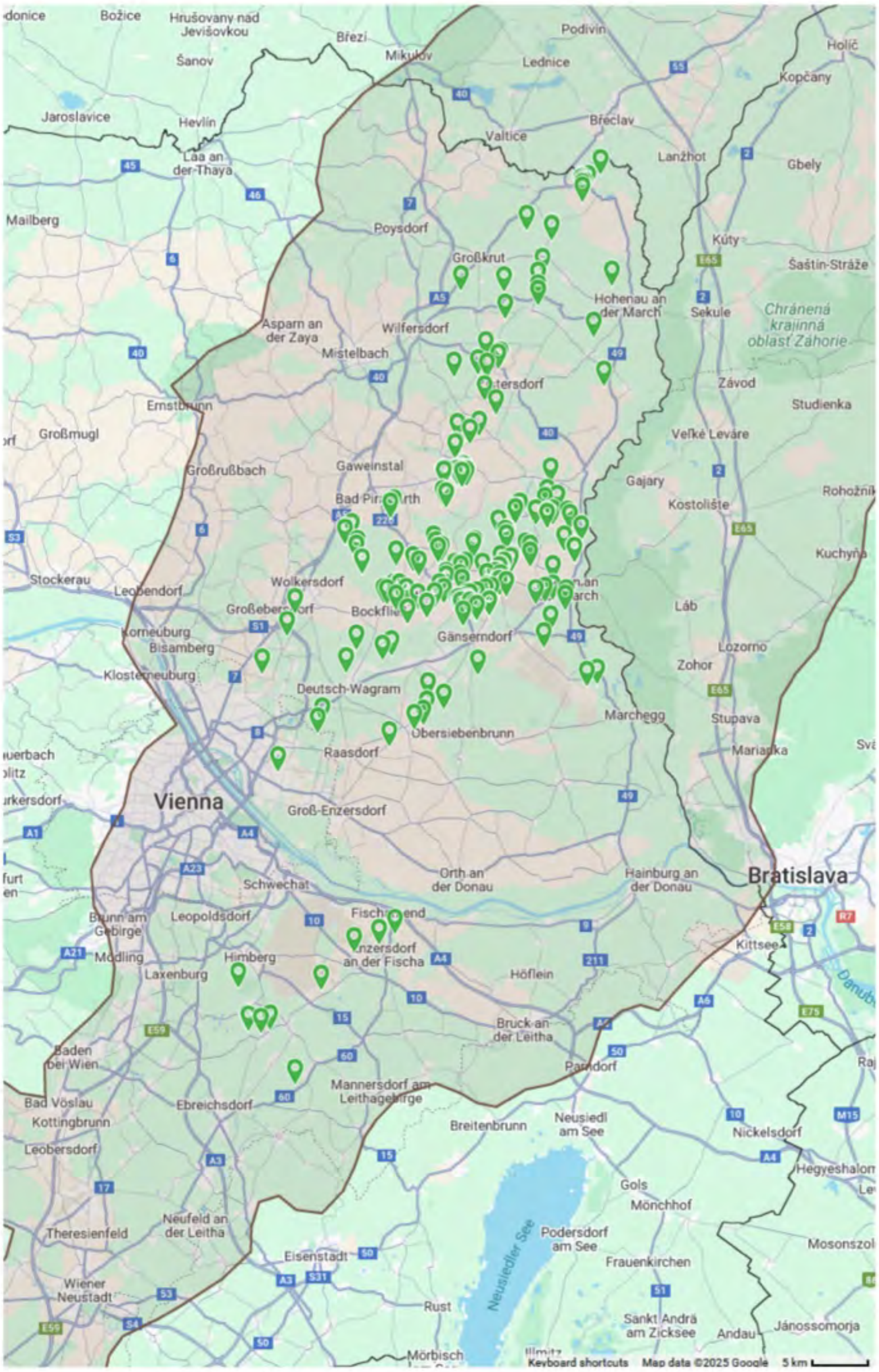


Figure 58: Suitable wells for BTES in the Vienna Basin (grey area).

Figure 59: Suitable wells with certain restrictions for BTES in the Vienna Basin (grey area).

6.4 HE

This section presents the results from the IT tool assessing the repurposing potential of existing wells in the Vienna Basin for Hydrothermal Energy (HE); only wells drilled **before 1990** were included in this analysis following the filtering step described earlier.

Table 21 provides a quantitative overview: Out of **3,357** total wells assessed, **191** (5.7%) are classified as suitable for repurposing. **104 wells** (3.1%) fall into the uncertain category, indicating a moderate but notable number that could become viable with further exploration. The majority, **3,062 wells** (91.2%), are not suitable for HE repurposing under current criteria.

Vienna Basin	HE (absolute)	HE (percentage)
Totals of wells	3357	100
Suitable	191	5.7
Uncertain	104	3.1
Not suitable	3062	91.2

Table 21: Absolute numbers and percentages of reusable wells for HE in the Vienna Basin.

Figure 60 shows the spatial distribution of the wells that are categorised based on their suitability for HE repurposing:

- **Green flags** indicate wells that are suitable for repurposing without restrictions.
- **Orange flags** represent wells with uncertain status, requiring further investigation or data.
- **Red flags** are wells deemed not suitable for repurposing.

Figure 61 highlights only the **suitable wells**, clearly showing clusters of potential HE infrastructure, particularly in areas with favorable subsurface conditions.

Figure 62 displays wells that could be **conditionally suitable**, where some limitations or missing data must be addressed before confirming their reuse potential.

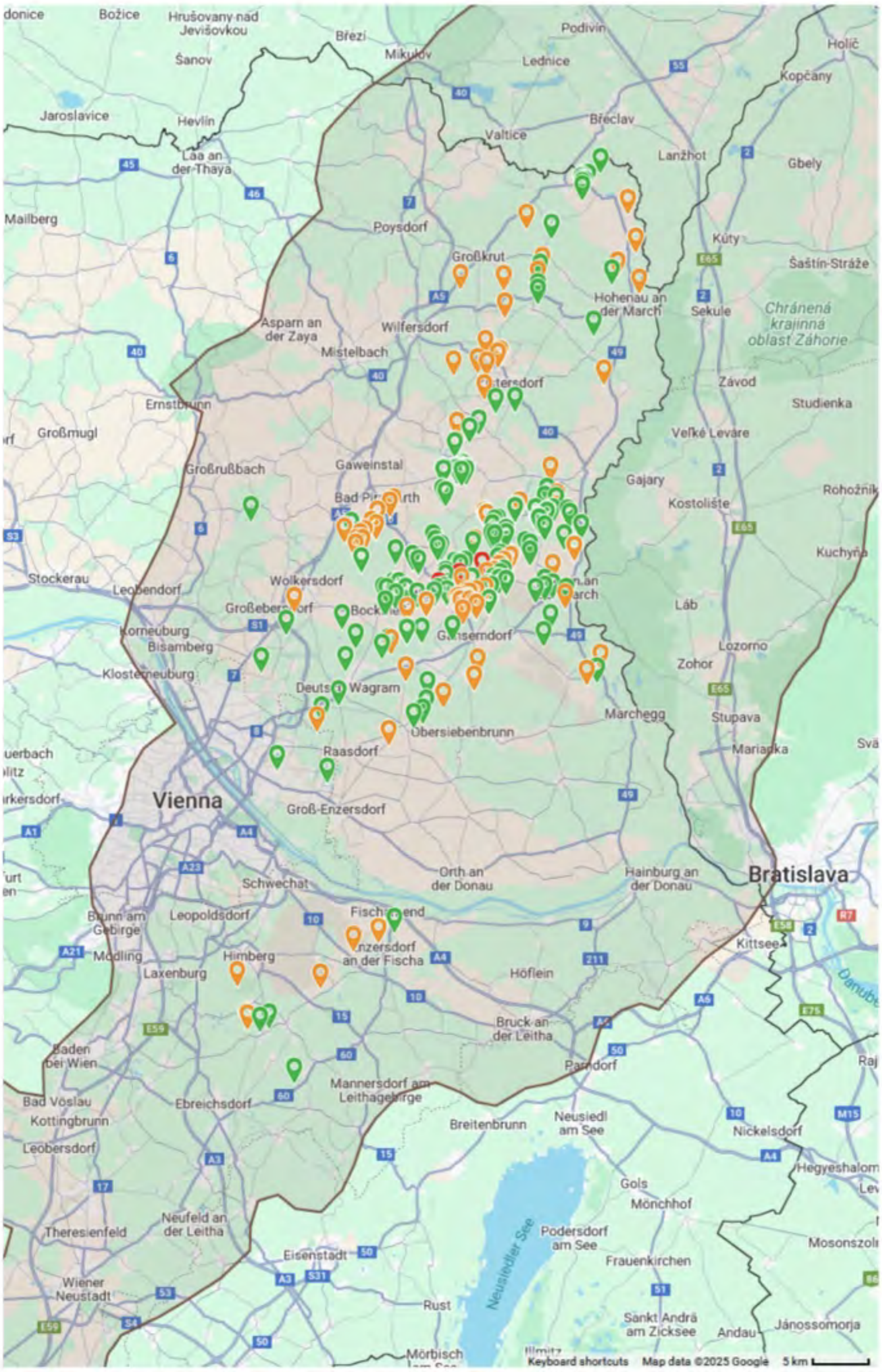


Figure 60: Map of the repurpose potential for HE within the contour of the Vienna basin (grey area).

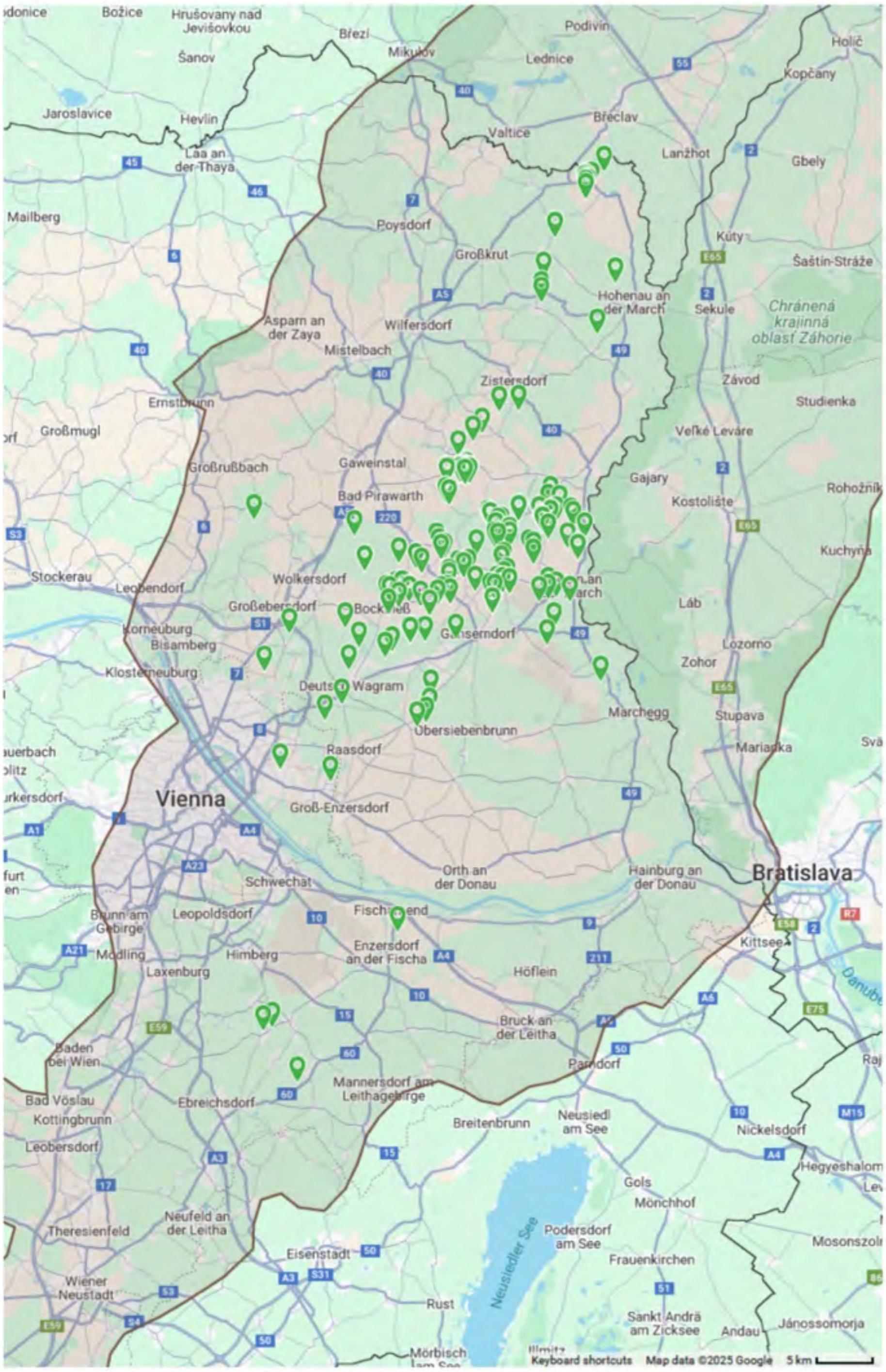


Figure 61: Suitable wells for HE in the Vienna Basin (grey area).

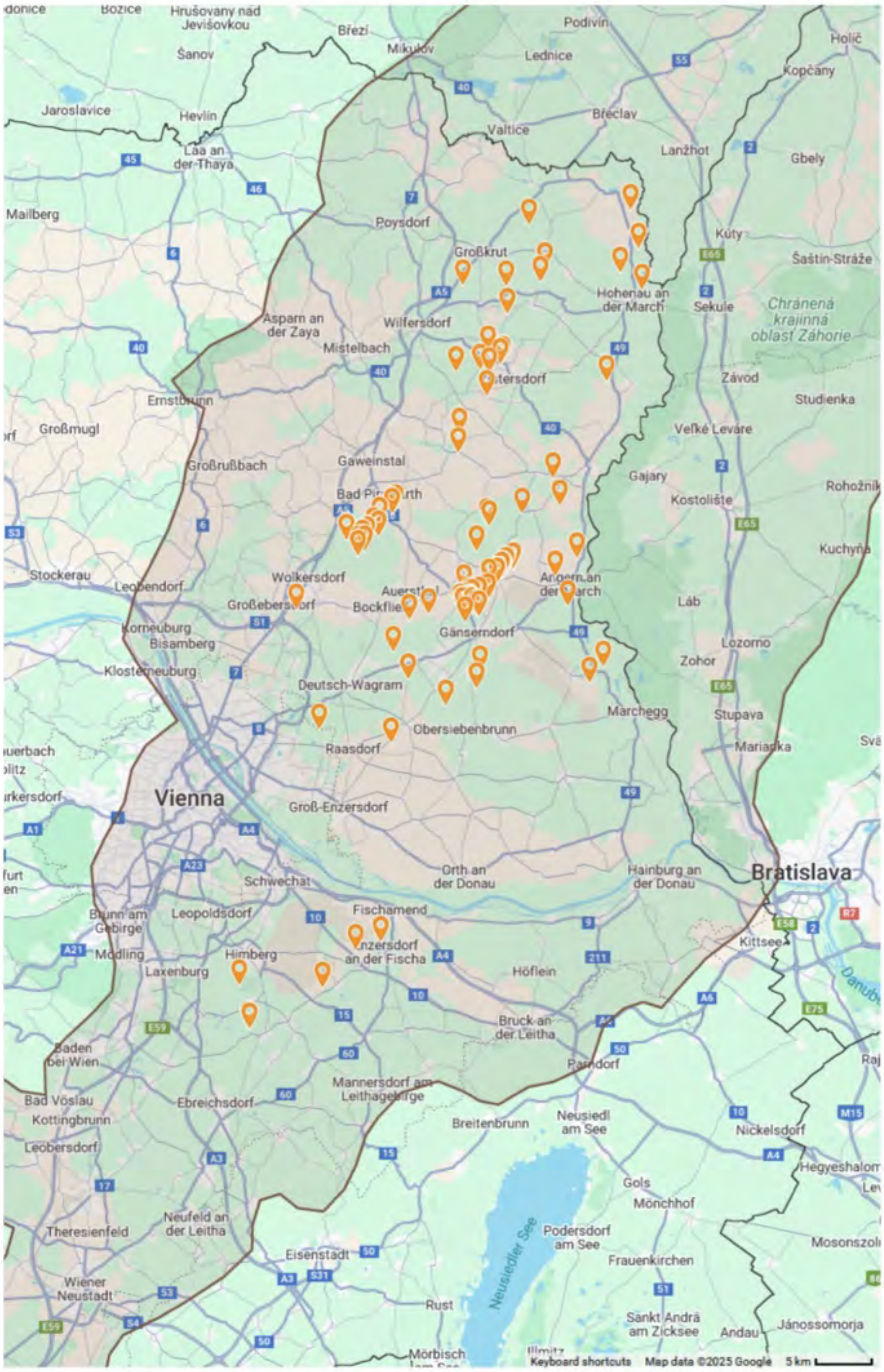


Figure 62: Suitable wells with certain restrictions for HE in the Vienna Basin (grey area).

6.5 EGS

This section presents the results from the IT tool assessing the repurposing potential of existing wells in the Vienna Basin for Enhanced Geothermal Systems (EGS); only wells drilled **after 1990** were included in this analysis following the filtering step described earlier.

Table 22 provides a quantitative overview: Out of **3,357** total wells assessed, only **20** (0.6%) are classified as suitable for repurposing. Only **2 wells** (0.1%) fall into the uncertain category, indicating a moderate but notable number that could become viable with further exploration. Almost the entirety, **3,335 wells** (99.3%), are not suitable for EGS repurposing under current criteria.

Vienna Basin	EGS (absolute)	EGS (percentage)
Totals of wells	3357	100
Suitable	20	0.6
Uncertain	2	0.1
Not suitable	3335	99.3

Table 22: Absolute numbers and percentages of reusable wells for EGS in the Vienna Basin.

Figure 63 shows the spatial distribution of the wells that are categorised based on their suitability for EGS repurposing:

- **Green flags** indicate wells that are suitable for repurposing without restrictions.
- **Orange flags** represent wells with uncertain status, requiring further investigation or data.
- **Red flags** are wells deemed not suitable for repurposing.

Figure 64 highlights only the **suitable wells**, clearly showing clusters of potential EGS infrastructure, particularly in areas with favorable subsurface conditions.

Figure 65 displays wells that could be **conditionally suitable**, where some limitations or missing data must be addressed before confirming their reuse potential.

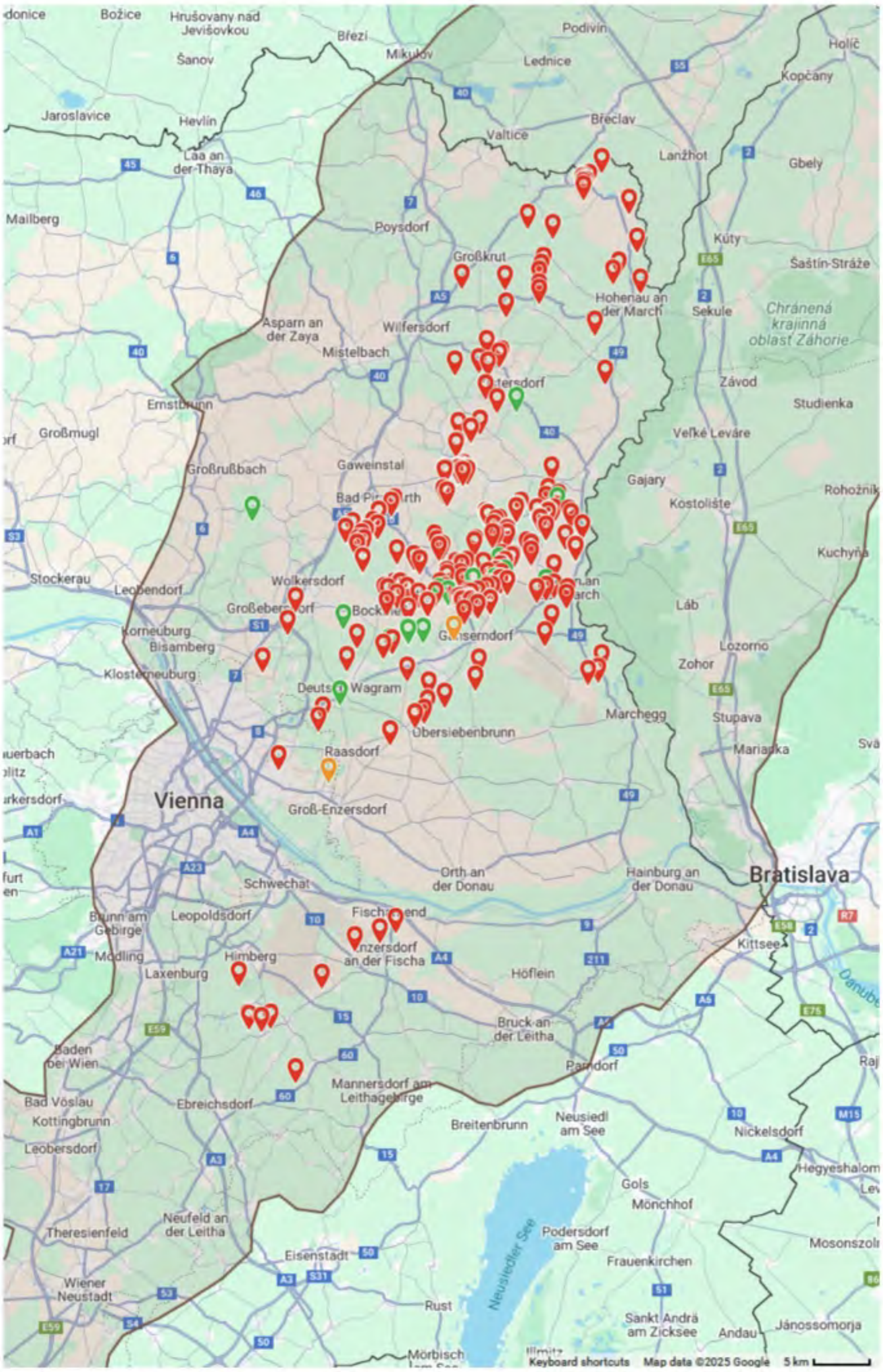


Figure 63: Map of the repurpose potential for EGS within the contour of the Vienna basin (grey area).

Figure 64: Suitable wells for EGS in the Vienna Basin (grey area).

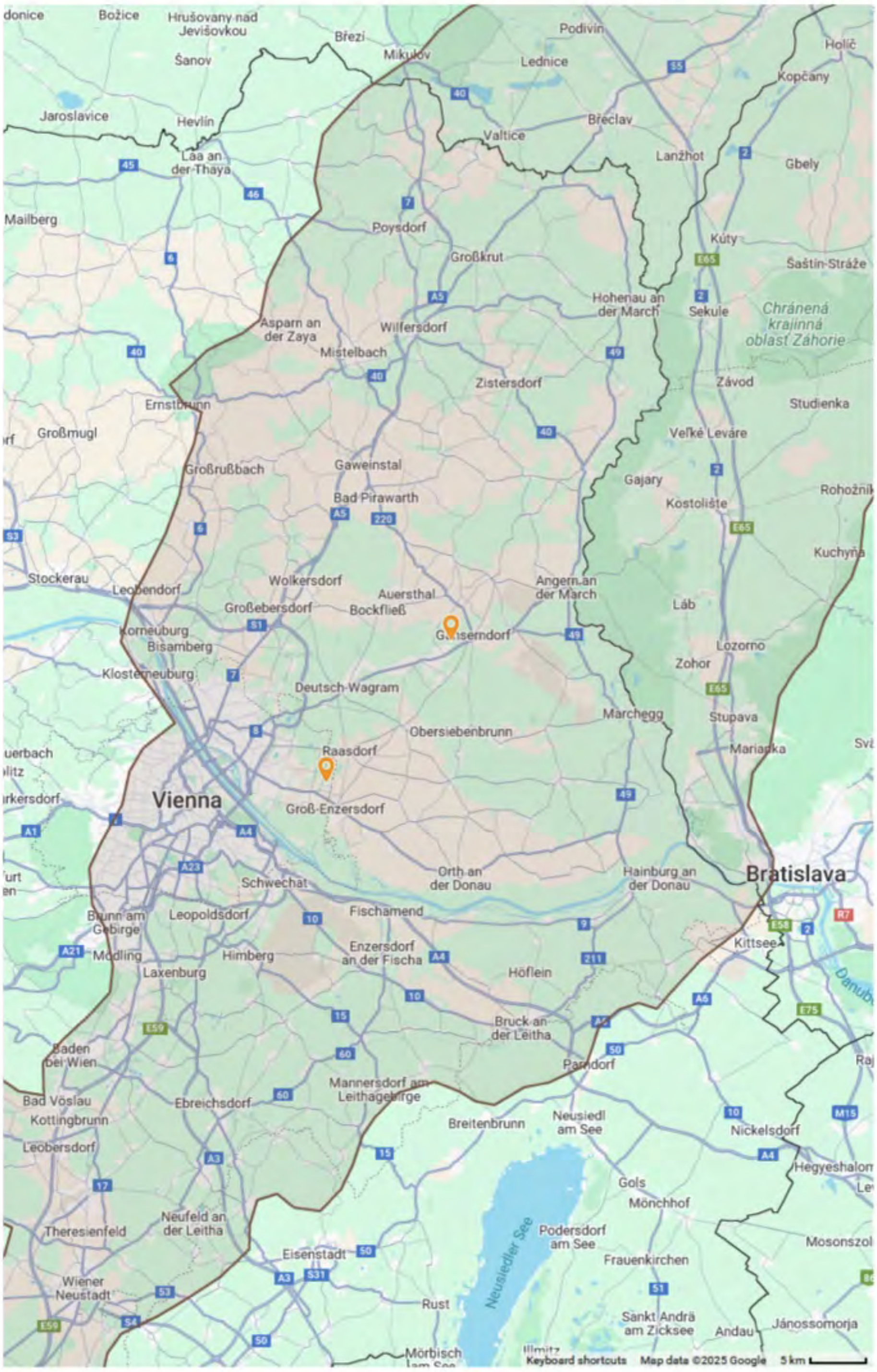


Figure 65: Suitable wells with certain restrictions for EGS in the Molasse Basin (grey area).

6.6 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 five geothermal methods: Aquifer Thermal Energy Storage (ATES), Deep Borehole Heat Exchangers (DBHE), Borehole Thermal Energy Storage (BTES), Hydrothermal Energy (HE), and Enhanced Geothermal Systems (EGS).

Exact resulting numbers and percentages are shown in Table 23 and Table 24, respectively.

Vienna Basin	ATES	DBHE	BTES	HE	EGS
Totals of wells	3357	3357	3357	3357	3357
Suitable	12	255	234	191	20
Uncertain	288	8	8	104	2
Not suitable	3057	3094	3115	3062	3335

Table 23: Absolute numbers of reusable wells for 5 geothermal methods in the Vienna Basin.

Vienna Basin	ATES	DBHE	BTES	HE	EGS
Suitable	0.4	7.6	7.0	5.7	0.6
Uncertain	8.6	0.2	0.2	3.1	0.1
Not suitable	91.1	92.2	92.8	91.2	99.3

Table 24: Percentages of reusable wells for 5 geothermal methods in the Vienna Basin.

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%; Table 24). The low percentages of suitable wells result from the filtering step in the IT tool, which only considered wells drilled after 1990. This cutoff aligns with the average lifespan of oil and gas wells (30-40 years; Planète Énergies, 2015; IOGP, 2018; OGA, 2018), ensuring the analysis focuses on wells still viable for geothermal conversion.

Despite the small fraction of suitable wells, the potential energy gains are significant (TRANSGEO Deliverable 1.1.6): 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.

7 Pannonian Basin (Slovenia - Croatia - Hungary)

In the TRANSGEO project the Pannonian Basin (PB) encompasses three countries (Slovenia, Croatia, Hungary), each with its own specifics regarding for example geological nomenclature, well data details, different approach to the well selection for the database, etc. The well assessment of the Pannonian Basin was therefore done for each country separately as described in the respective subchapters.

Pannonian Basin, as the largest Miocene-Quaternary basin within the Alpine-Carpathian-Dinaridic orogenic system (Prelogović et al., 1998). According to Royden and Horváth (1988) as well as Cvetković et al. (2019), the tectonic evolution of the PB started by the Cretaceous-Paleogene collision of the Adria Microplate and the European foreland. In the Early to Late Miocene, European plate roll-back subduction induced lithospheric extension and back-arc-type extension in the PB.

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 partially 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, Árgyelán et al., 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 meters (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 Algyő hydrocarbon field (Révész, 1980). Researchers identified the cyclicity and repetition of delta lobes, which were 10 to 30 meters 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 six major depositional environments (I-VI) and seven related formations (Sztanó et al., 2025). 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-center turbidite systems (Sztanó et al., 2013; Vlček et al., 2024), although slope-toe turbidites and deltas are also predominantly sandy. These three 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).

7.1 Croatian part of Pannonian Basin

The Croatian part of the Pannonian Basin (CPB) is well known for its higher-than-average geothermal gradient with good potential for geothermal energy exploitation.

It is divided into four main depressions: 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 and borders the Drava Depression to the north. The Drava depression covers most of the CPB and extends over the territory of the Drava River, bounded by the state border with Hungary in the north and reaching the border with the Republic of Serbia in the east. The southern part of the Drava depression borders the mountains from Medvednica to Krndija. The Slavonija-Srijem depression is located east of the town of Slavonski Brod and extends to the borders of Serbia and Bosnia-Herzegovina, making it the smallest of all depressions in the CPB (Malvić and Velić, 2011).

Hydrocarbon production in Croatia began in the second half of the 20th century, and since then more than 4,000 oil and gas wells have been drilled. Most of the currently known geothermal field locations in the CPB were discovered during these exploration and exploitation activities. Currently, around 900 wells are active within various hydrocarbon exploitation fields, serving as production, injection or measurement wells. Most of these wells are operated by INA d.d. as the concession holder, while the wells located outside the exploitation and exploration areas, as well as the data from all drilled wells, are the property of the Republic of Croatia.

However, in the last decade, hydrocarbon exploration licenses have been granted not only to INA but also to Aspect Croatia Kft and Vermilion Zagreb Exploration d.o.o. In parts of these new exploration areas there have been confirmed positive findings of hydrocarbons and new exploitation licences are expected in the future.

When it comes to geothermal licences, there are currently (June 2025) 24 active exploration licences awarded to various investors, ranging from larger energy companies invested in exploring electricity production to local public companies who are interested in developing geothermal projects for heating purposes. There are also 13 active exploitation licences in various stages of project development, with one licence for operating ORC power plant, two licenses for active greenhouse vegetable production and three licences for heating operations. Through the National Recovery and Resilience Plan (NRRP) the Croatian Hydrocarbon Agency (CHA) is carrying out a project to activate the geothermal potential in

Croatia. The project also aims to reduce the risk of future geothermal energy projects, as high initial investment costs have been recognised as a major risk for investors at EU level. In the first step of the project, six areas of interest were designated as preliminary exploration areas for further investigation through in depth analysis of existing data (seismic, MT, from previously drilled wells where available etc.). Out of those six areas, four were chosen to have an exploratory well drilled and tested with the intention of reducing the geological risk for future development. 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. For more details on geothermal licences in Croatia refer to TRANSGEO Deliverable D3.2.1., Chapter 2.

Since 2018, geothermal exploration has increased, and concessions for geothermal exploration areas have been granted to various companies to develop projects, mainly for power production. Therefore, the existing wells for potential repurpose are currently under concession and were not part of the database for Croatia. 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, as 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 recorded during their drilling phase. The information regarding well completion (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, using the IT Tool, gives a good assessment of the reuse potential of the 115 wells in the Croatian database, for the five reuse technologies. The results of the well assessment reuse potential in Croatia are presented as maps of three main areas of hydrocarbon exploitation fields according to respective reuse technology.

7.1.1 ATES

Of the 115 wells of the Croatian dataset, the well assessment tool results with none of them deemed compliant/suitable for Aquifer Thermal Energy Storage reuse. However, 98 of them are categorised as uncertain due to certain restrictions, therefore each well should be further examined to evaluate its possible ATES reuse. Some of the criteria that categorised wells as uncertain are minimum casing diameter, reservoir thickness, TVD/MD. In some cases, the overall uncertain category was assigned because reservoir thickness for a well was too small for certain layers, while for other layers was compliant. Therefore, the uncertain category has to be checked in more detail if any well is of interest. The remaining 17 wells are designated as rejected/not suitable for ATES reuse. Figure 66, Figure 67 and Figure 68 show the potential for ATES reuse for selected wells.

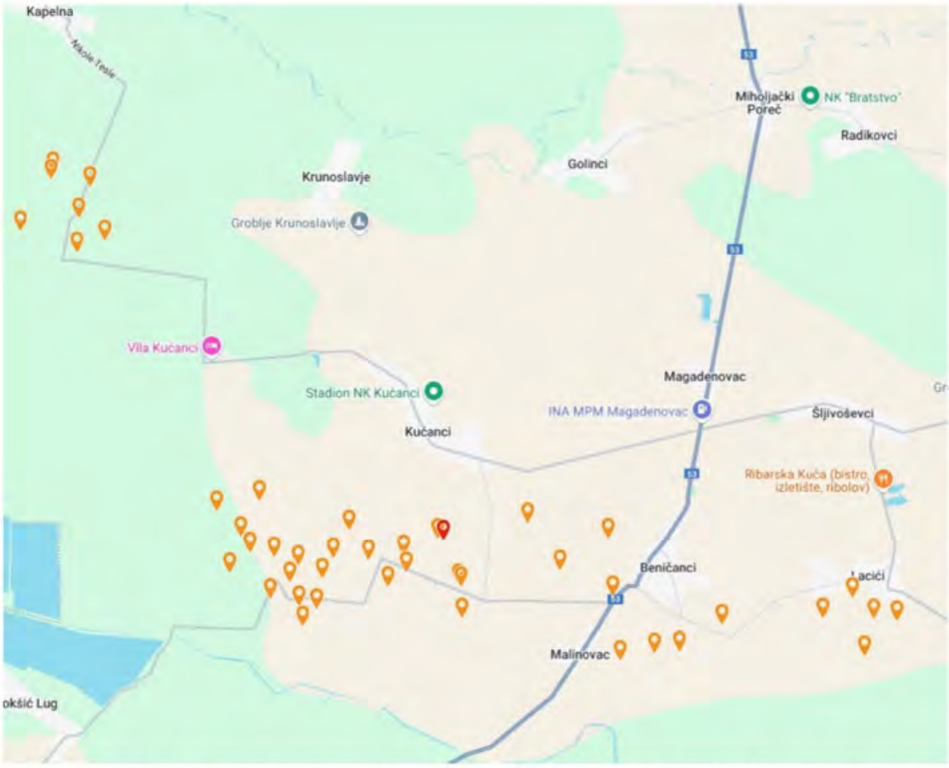


Figure 66: Map of the repurpose potential in the Croatian part of Pannonian Basin for ATES - area of exploitation fields Beničanci, Obod, Kučanci-Kapelna.

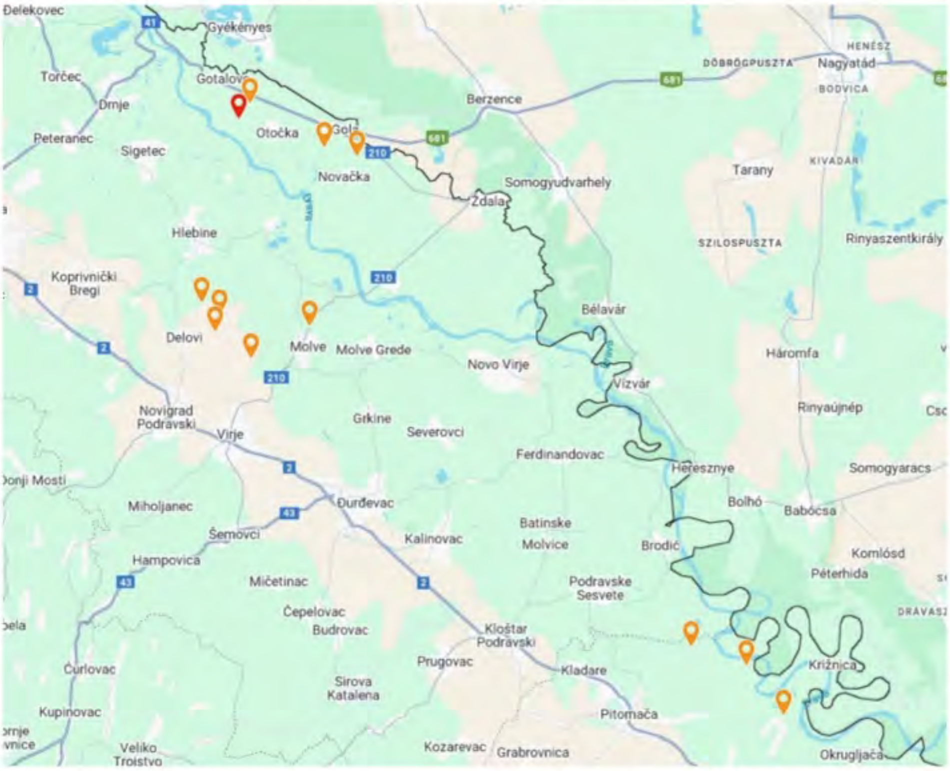


Figure 67: Map of the repurpose potential in the Croatian part of the Pannonian Basin for ATES - area of exploitation fields Molve, Gola and Stari Gradac.

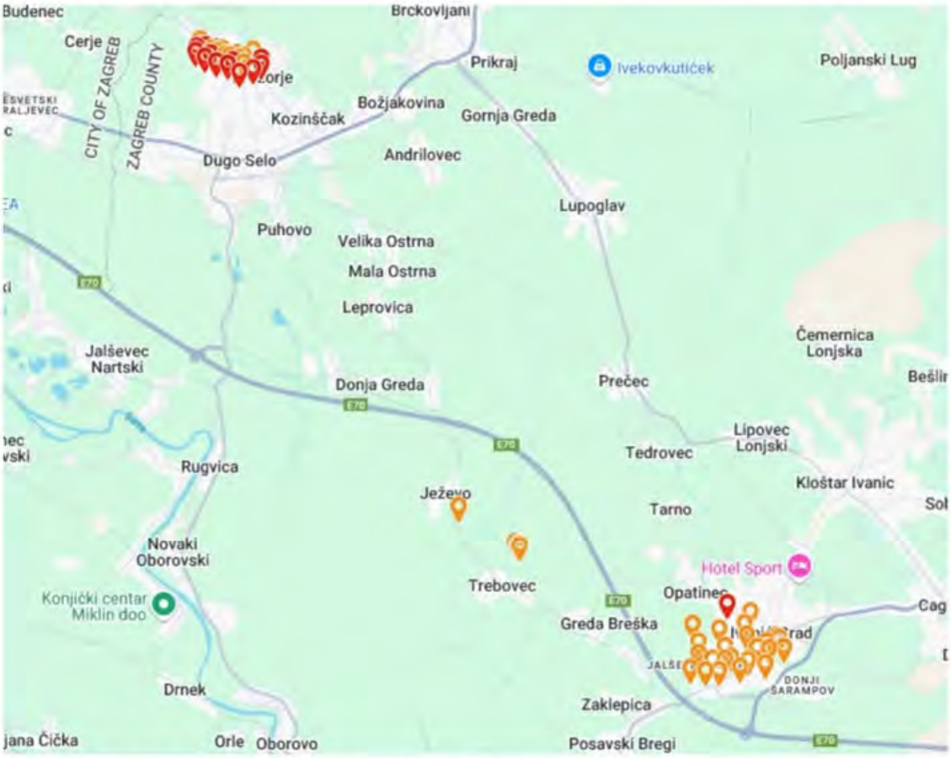


Figure 68: Map of the repurpose potential in the Croatian part of Pannonian Basin for ATES - area of exploitation fields Ivanić, Ježevo and Dugo Selo.

Pannonian Basin (Croatia)	ATES (absolute)	ATES (percentage)
Totals of wells	115	100
Suitable	0	0.0
Uncertain	98	85.2
Not suitable	17	14.8

Table 25: Absolute numbers and percentages of reusable wells for ATES in the Pannonian Basin (Croatian part).

7.1.2 DBHE

For Deep Borehole Heat Exchanger well reuse out of the 115 wells, 24 of them are designated as compliant/suitable, while 83 of them are categorised as uncertain due to certain restrictions. Therefore, each well should be further examined to evaluate the possibility for DBHE reuse. Some of the criteria that categorised wells as uncertain are well status, TVD/MD, etc. The remaining 8 wells are designated as rejected/not suitable for DBHE reuse. Figure 69, Figure 70 and Figure 71 show the potential for DBHE reuse for selected wells.

Figure 69: Map of the repurpose potential in the Croatian part of Pannonian Basin for DBHE - area of exploitation fields Beničanci, Obod, Kučanci-Kapelna.

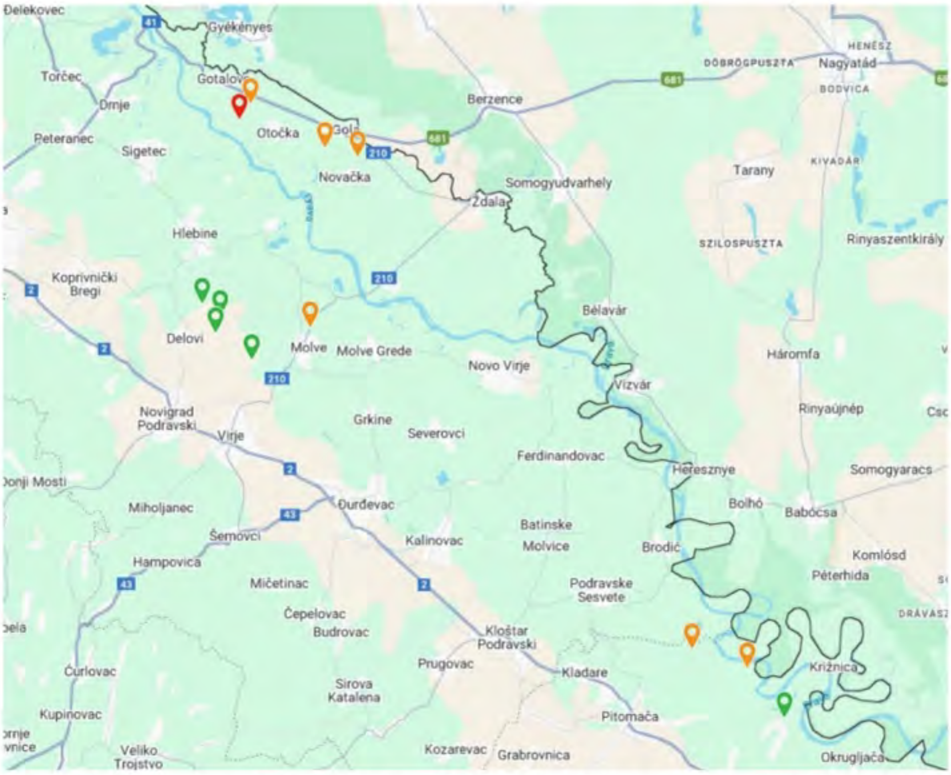


Figure 70: Map of the repurpose potential in the Croatian part of Pannonian Basin for DBHE - area of exploitation fields Molve, Gola and Stari Gradac.

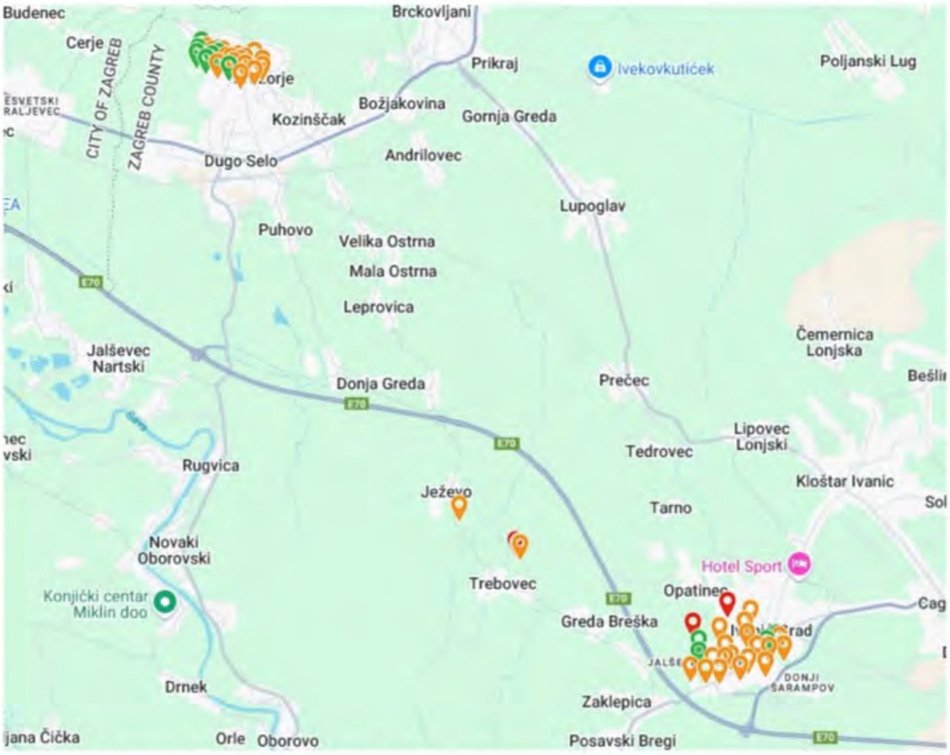


Figure 71: Map of the repurpose potential in the Croatian part of Pannonian Basin for DBHE - area of exploitation fields Ivanić, Ježevo and Dugo Selo.

Pannonian Basin (Croatia)	DBHE (absolute)	DBHE (percentage)
Totals of wells	115	100
Suitable	24	20.9
Uncertain	83	72.2
Not suitable	8	7.0

Table 26: Absolute numbers and percentages of reusable wells for DBHE in the Pann. Basin (Croatian part).

7.1.3 BTES

For Borehole Thermal Energy Storage well reuse out of the 115 wells, 14 of them are designated as compliant/suitable. 48 of them are categorised as uncertain due to certain restrictions. Therefore, each well should be further examined to evaluate the possibility for BTES reuse. Some of the criteria that categorised wells as uncertain are well status and TVD/MD. The remaining 53 wells are designated as rejected/not suitable for BTES reuse, usually due to higher bottom hole temperatures and large distance to potential consumers (industrial access, agricultural access, distance to municipality). Figure 72, Figure 73 and Figure 74 show the potential for BTES reuse for selected wells.

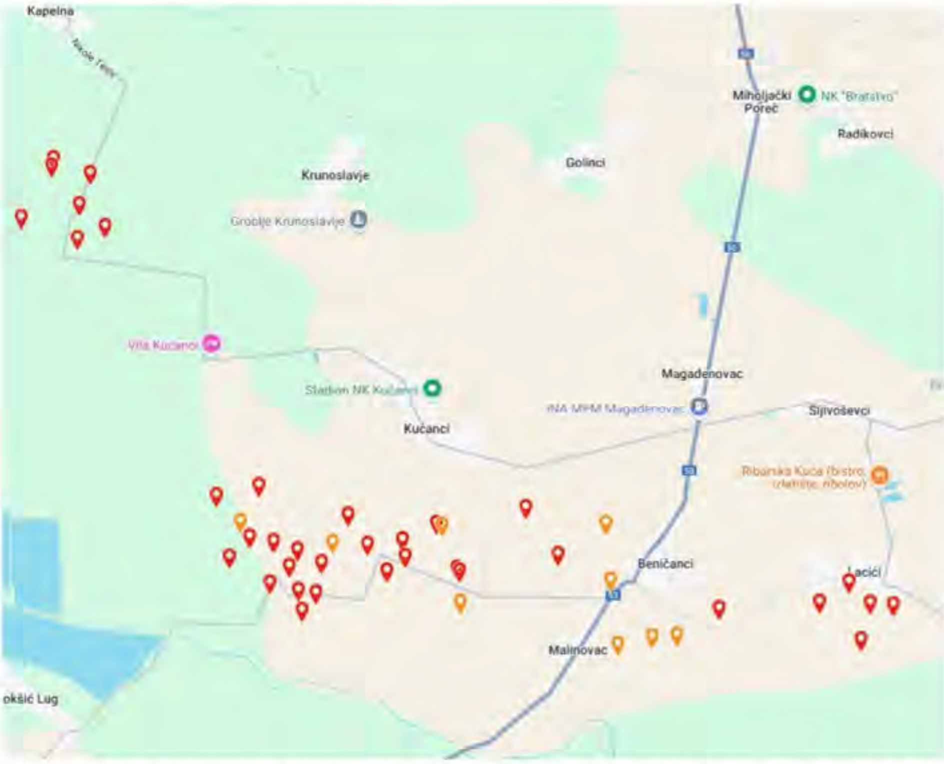


Figure 72: Map of the repurpose potential in the Croatian part of Pannonian Basin for BTES - area of exploitation fields Beničanci, Obod, Kučanci-Kapelna.

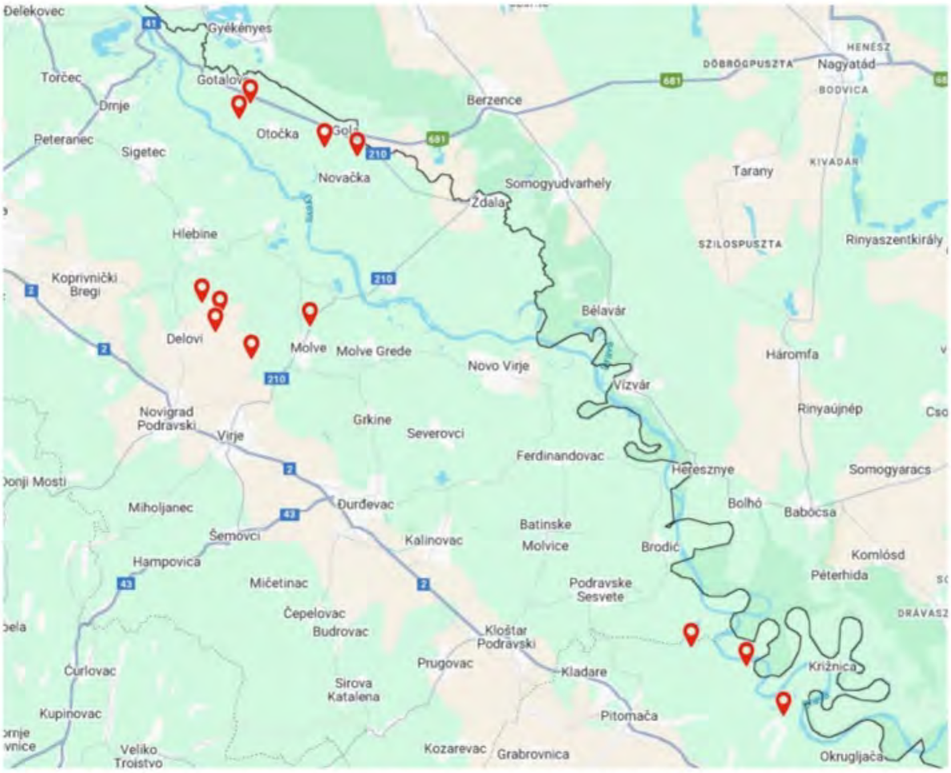


Figure 73: Map of the repurpose potential in the Croatian part of Pannonian Basin for BTES - area of exploitation fields Molve, Gola and Stari Gradac.

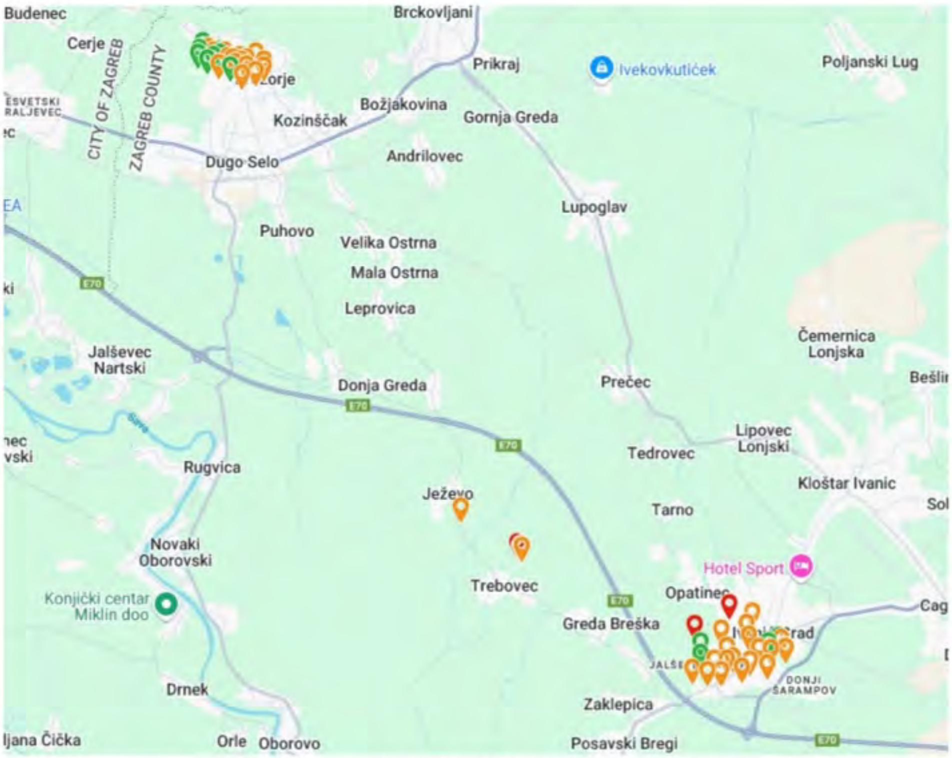


Figure 74: Map of the repurpose potential in the Croatian part of Pannonian Basin for BTES - area of exploitation fields Ivanić, Ježevo and Dugo Selo.

Pannonian Basin (Croatia)	BTES (absolute)	BTES (percentage)
Totals of wells	115	100
Suitable	14	12.2
Uncertain	48	41.7
Not suitable	53	46.1

Table 27: Absolute numbers and percentages of reusable wells for BTES in the Pann. Basin (Croatian part).

7.1.4 HE

In the case of Hydrothermal Energy well reuse, out of the 115 wells 17 of them are designated as compliant/suitable. 83 of them are categorised as uncertain due to certain restrictions. Therefore, each well should be further examined to evaluate the possibility for HE reuse. Some of the criteria that categorised wells as uncertain are well status, minimum casing diameter, etc. The remaining 15 wells are designated as rejected/not suitable for HE reuse. Figure 75, Figure 76 and Figure 77 show the potential for HE reuse for selected wells.

Figure 75: Map of the repurpose potential in the Croatian part of Pannonian Basin for HE - area of exploitation fields Beničanci, Obod, Kučanci-Kapelna.

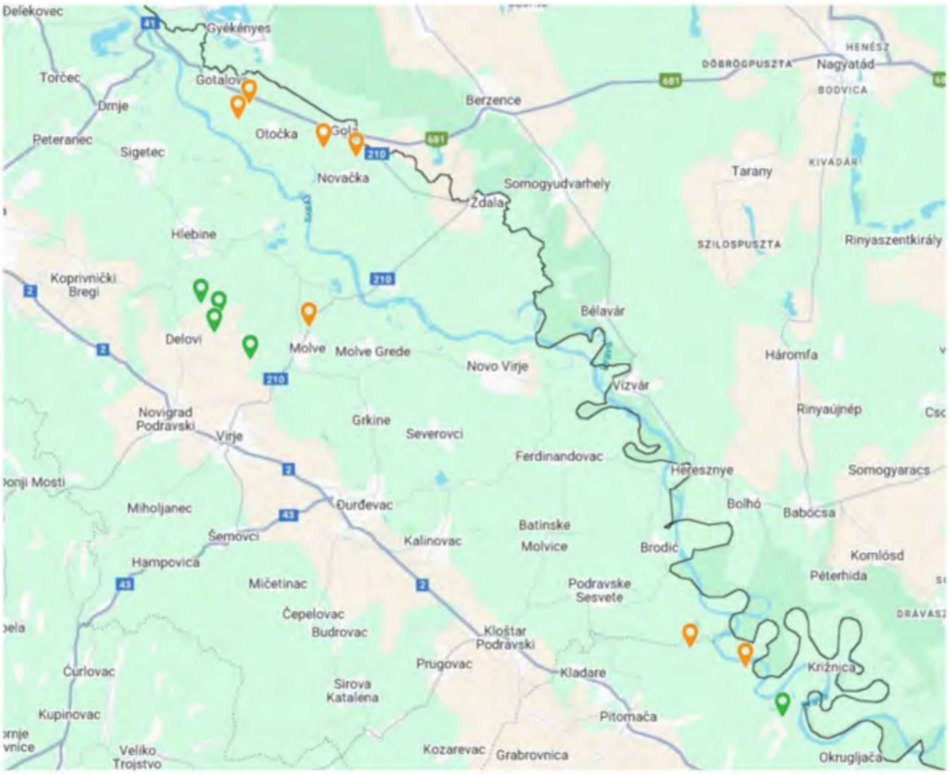


Figure 76: Map of the repurpose potential in the Croatian part of Pannonian Basin for HE - area of exploitation fields Molve, Gola and Stari Gradac.

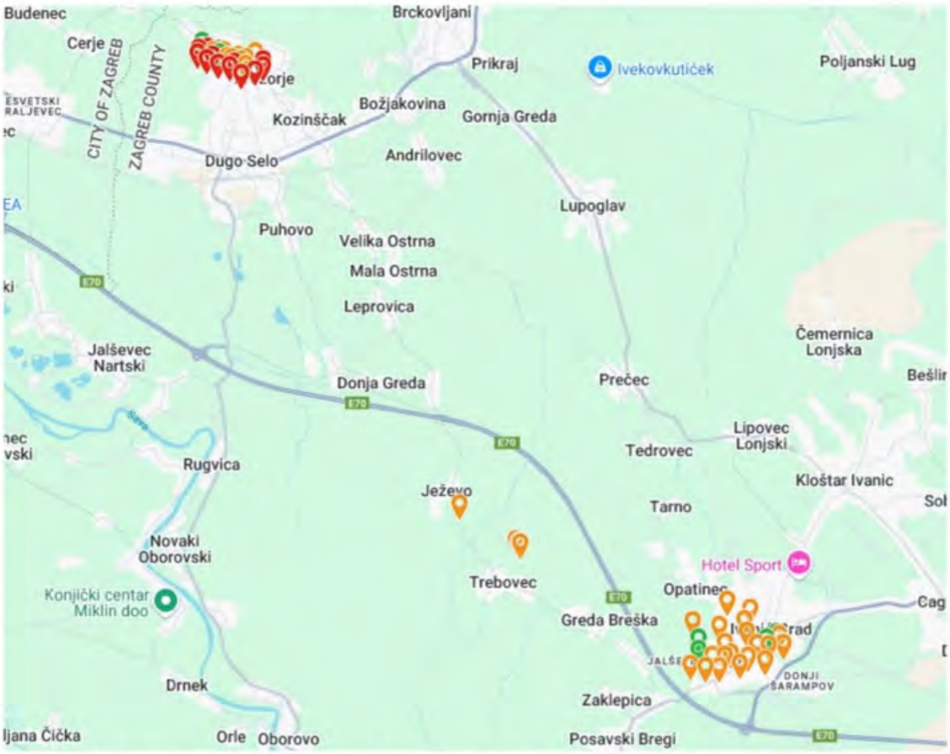


Figure 77: Map of the repurpose potential in the Croatian part of Pannonian Basin for HE - area of Ivanić, Ježevo and Dugo Selo.

Pannonian Basin (Croatia)	HE (absolute)	HE (percentage)
Totals of wells	115	100
Suitable	17	14.8
Uncertain	83	72.2
Not suitable	15	13.0

Table 28: Absolute numbers and percentages of reusable wells for HE in the Pann. Basin (Croatian part).

7.1.5 EGS

In the case of Enhanced Geothermal System well reuse, out of the 115 wells only 10 of them are designated as compliant/suitable, while 41 of them are categorised as uncertain due to certain restrictions. Therefore, each well should be further examined to evaluate the possibility for EGS reuse. The reason the well is categorised as uncertain is mainly due to the large distance to potential consumers (industrial access, agricultural access, distance to municipality), etc. The remaining 64 wells are designated as rejected/not suitable for EGS reuse, especially due to insufficient bottomhole temperature. Figure 78, Figure 79 and Figure 80 show the potential for EGS reuse for selected wells.

Figure 78: Map of the repurpose potential in the Croatian part of Pannonian Basin for EGS - area of exploitation fields Beničanci, Obod, Kučanci-Kapelna.

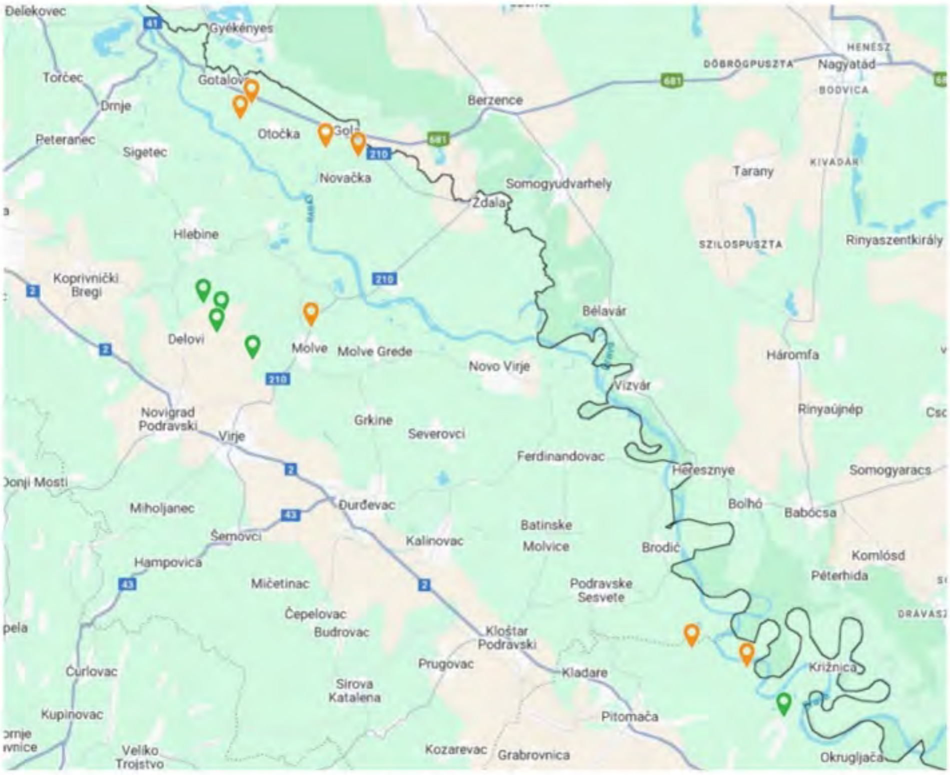


Figure 79: Map of the repurpose potential in the Croatian part of Pannonian Basin for EGS - area of exploitation fields Molve, Gola and Stari Gradac.

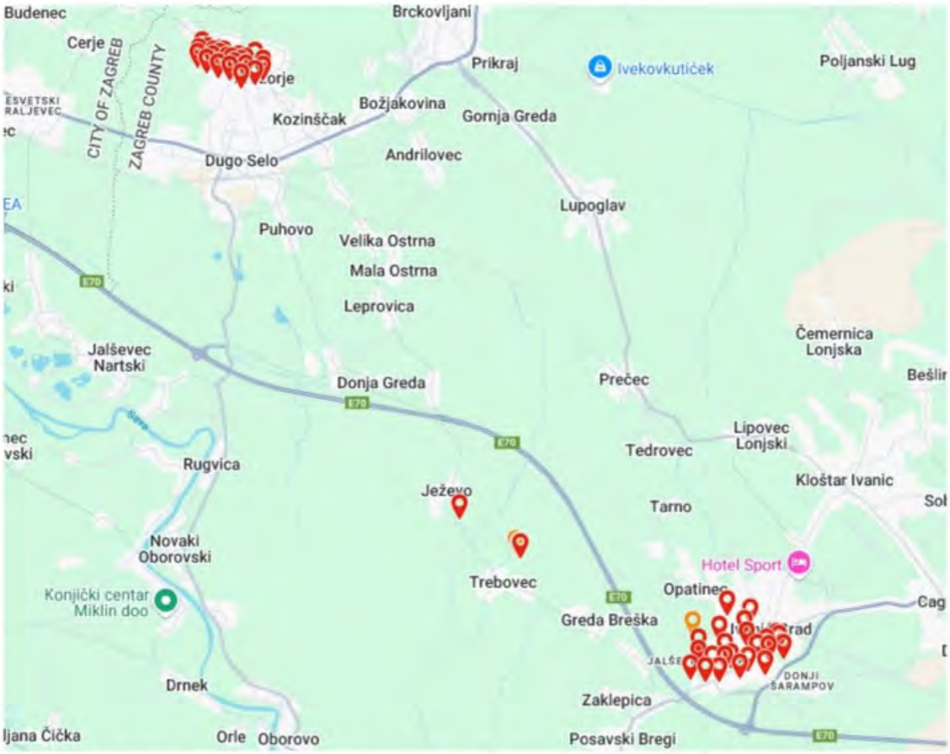


Figure 80: Map of the repurpose potential in the Croatian part of Pannonian Basin for EGS - area of exploitation fields Ivanić, Ježevo and Dugo Selo.

Pannonian Basin (Croatia)	EGS (absolute)	EGS (percentage)
Totals of wells	115	100
Suitable	10	8.7
Uncertain	41	35.7
Not suitable	64	55.6

Table 29: Absolute numbers and percentages of reusable wells for EGS in the Pannonian Basin (Croatian part).

7.1.6 Summary of the repurposing potential of the Pannonian Basin (Croatian part)

For the Croatian part of the Pannonian Basin, the results of the well assessment reuse potential for different geothermal technologies are presented in Table 30 and Table 31.

Pannonian Basin (Croatia)	ATES	DBHE	BTES	HE	EGS
Total of wells (absolute)	115	115	115	115	115
Suitable	0	24	14	17	10
Uncertain	98	83	48	83	41
Not suitable	17	3	53	15	64

Table 30: Absolute numbers of reusable wells for 5 geothermal technologies in the Croatian part of the Pannonian Basin.

Pannonian Basin (Croatia)	ATES	DBHE	BTES	HE	EGS
Total of wells (percentage)	115	115	115	115	115
Suitable	0.0	20.9	12.2	14.8	8.7
Uncertain	85.2	72.2	41.7	72.2	35.7
Not suitable	14.8	7.0	46.1	13.0	55.6

Table 31: Percentages of reusable wells for 5 geothermal technologies in the Croatian part of the Pannonian Basin.

The highest number of suitable wells was identified for DBHE (20.9%), followed by HE (14.8%), BTES (12.2%), and EGS (8.7%), while no suitable wells were recorded for ATES. For the uncertain category, the largest shares were recorded for ATES (85.2%), DBHE (72.2%), HE (72.2%), followed by BTES (41.7%) and EGS (35.7%), indicating that additional analyses could help clarify their potential for geothermal use. Regarding the non-suitable category, the highest percentages were found for EGS (55.6%), followed by BTES (46.1%), HE (13.0%), DBHE (6.9%), and ATES (14.8%).

7.2 Hungarian part of Pannonian Basin

The geothermal reservoirs of the Pannonian Basin (PB) 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 due to the favourable geological conditions.

With the exception of mountainous areas, the country's surface is covered by Neogene sediments ranging in thickness from 100 meters to 8 kilometers. The thickness of the sediments is greatest in the Little 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 a regional water system, 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 m^3/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. It is generally typical beneath pelitic and marly sediments, as the development of overpressure is primarily a consequence of the compaction of these formations. However, the production of overpressure reservoirs, being considered closed systems, always requires water reinjection. Saline water is common beneath the thick Lower Pannonian marls, as a remnant of the former seawater. 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 usually 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 basin, 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 (e.g. Fábiánsebestyén). High overpressure hinders the water production.

In summary, most hydrocarbon exploration drilling is directed at the Lower Pannonian and deeper layers, so the **Neogene aquifers** have been explored and intersected. From a geological point of view, abandoned wells in these areas may be suitable for conversion into geothermal wells, however, many technical and geological problems still need to be solved. The main concerns are the condition of the wells, well integrity problems, sand production, gas content, and salt content.

Carbonate rocks are also target areas and are often reached by drilling for oil (e.g., Andráshida-Nagylengyel, Mélykút-Pusztamérges, and Nagyszénás-Fábiánsebestyén areas). (Mádlné et al, 2008). The main problems in deeper carbonates are salt content, hydrocarbon content and overpressure. There is great potential for the reuse of abandoned hydrocarbon wells, especially if preparations for well reuse begin before 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 for various customer groups, such as municipalities, agricultural companies, and industrial users. There are 8,354 oil and gas 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 companies, as well as 2,334 abandoned wells, of which 2,258 are deeper than 400 m, in the asset management of the Mining Property Utilization Nonprofit Public Ltd. (BVH) in the PB (see Figure 81). 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; gas vs. geothermal wells). Therefore, the actual number of wells is approximately 10,000. Based on preliminary assessment and consultation, BVH submitted 177 wells from the 2,334 abandoned wells it manages, which we integrated into the database.

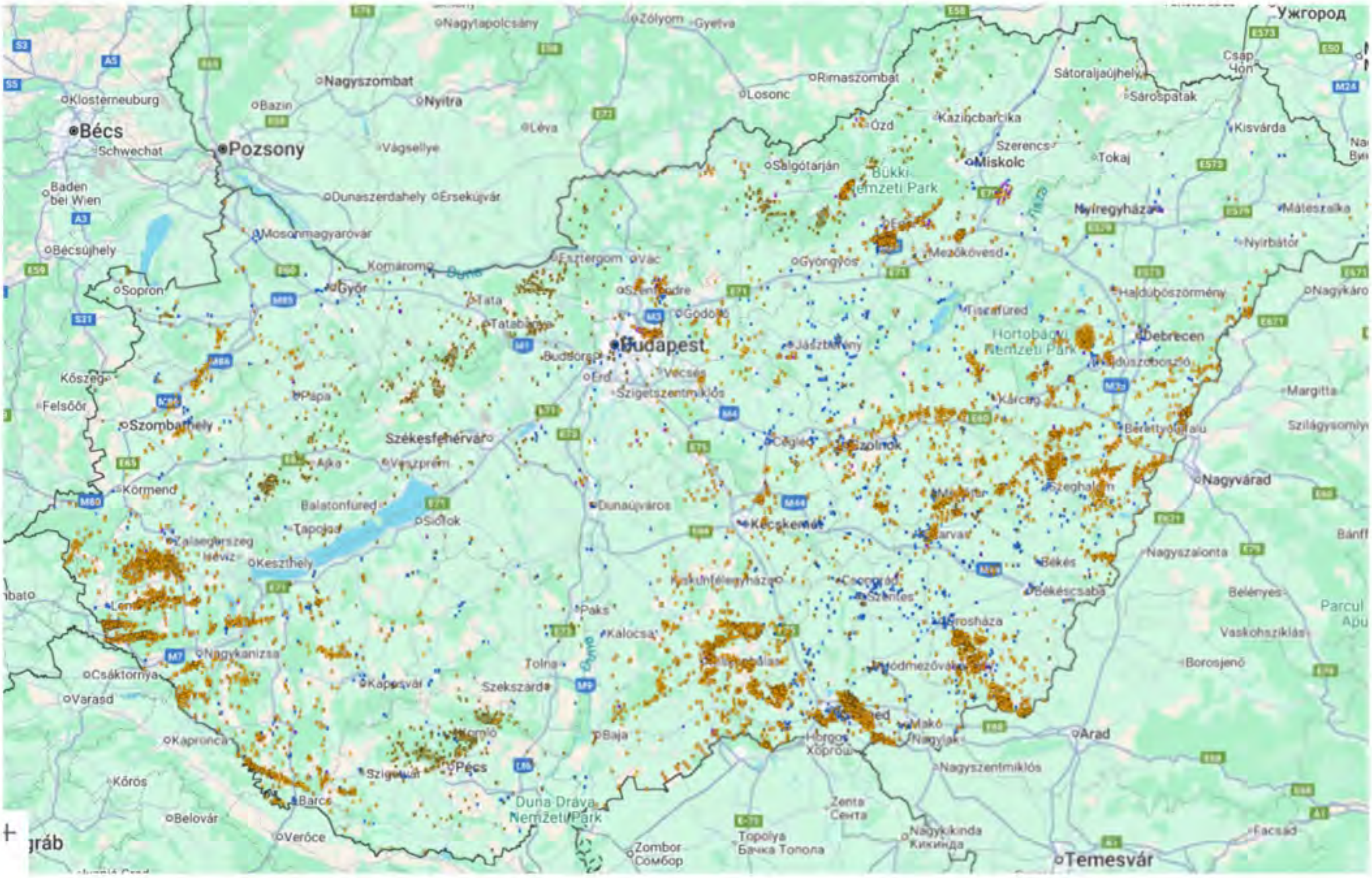


Figure 81: Wells deeper than 400 m in the Pannonian Basin, Hungary. Orange: hydrocarbon wells, brown: other exploration and coal wells, blue: thermal, purple: abandoned wells.

7.2.1 ATES

From the input dataset of 177 wells (Figure 82), 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 (Table 32).

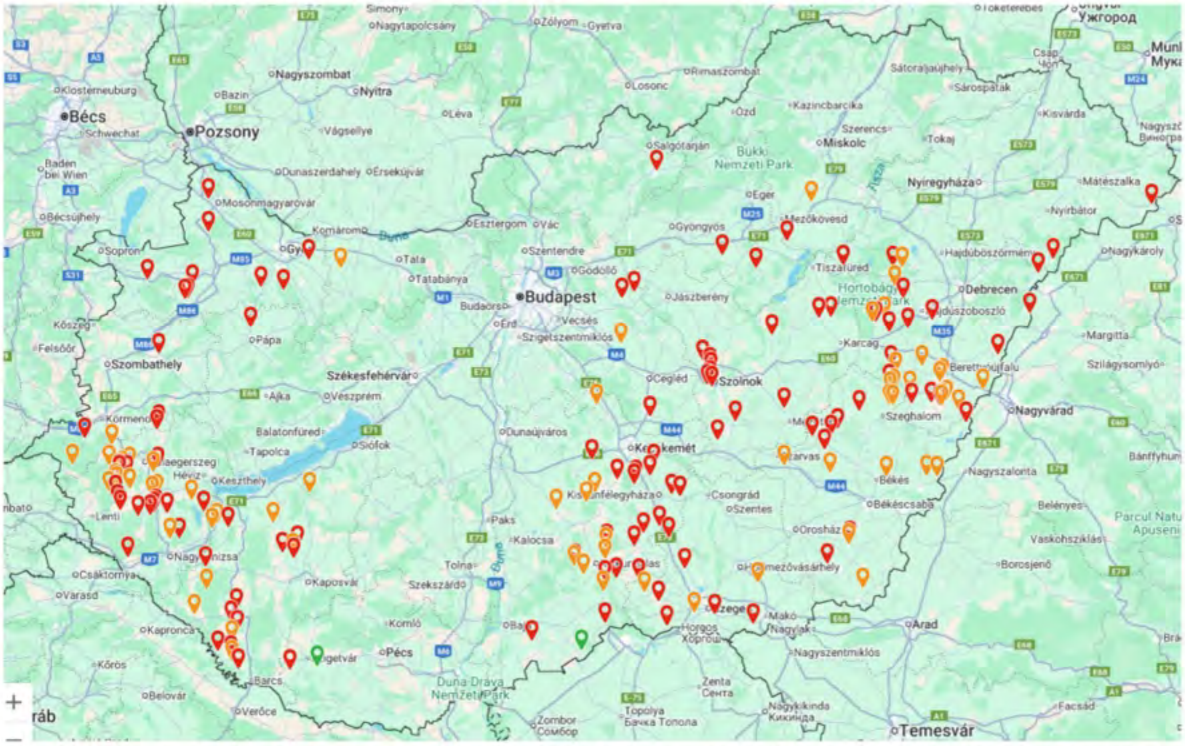


Figure 82: Map of the repurpose potential in the Pannonian Basin (Hungarian part) for ATES. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

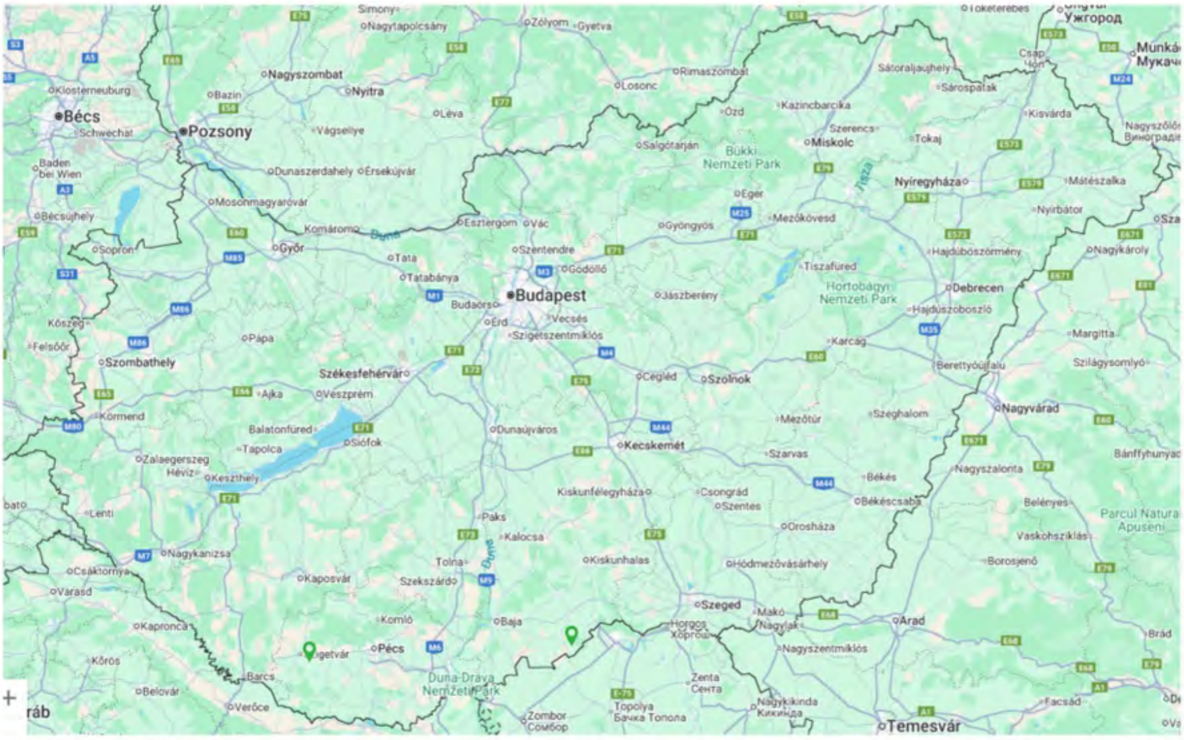


Figure 83: Wells suitable for ATES.

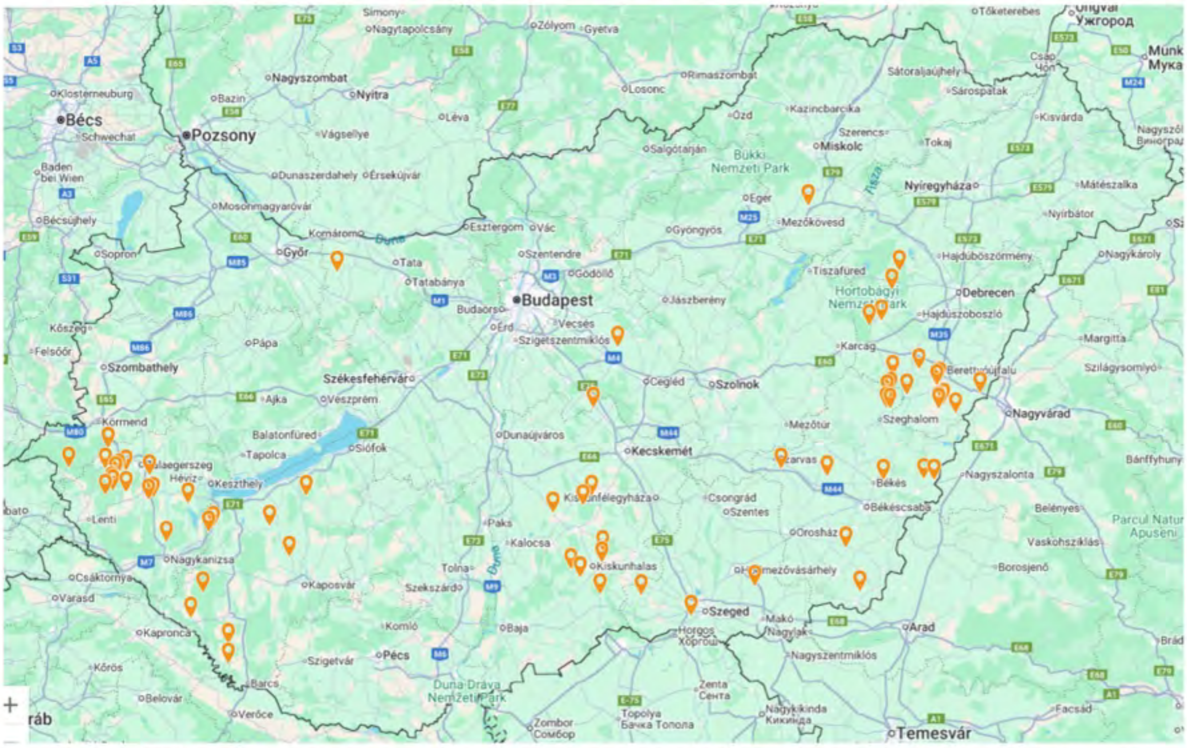


Figure 84: Wells suitable with certain restrictions for ATES in the Pannonian Basin (Hungarian part).

The low percentage of suitable wells (1.1%) and the high percentage (36.7%) of suitable, but uncertain wells for ATES are subject to further investigation, as shallow aquifers are not currently integrated into the database, despite their existence. The main aquifer in the Pannonian Basin dataset is the Upper Pannonian sandstones in the Hungarian Great Plain and the Zala Basin's sediments.

Pannonian Basin (Hungary)	ATES (absolute)	ATES (percentage)
Totals of wells	177	100
Suitable	2	1.1
Uncertain	65	36.7
Not suitable	110	62.2

Table 32: Absolute numbers and percentages of reusable wells for ATES in the PB (Hungarian part).

7.2.2 DBHE

From the input dataset of 177 wells (Figure 85), 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 (Table 33).

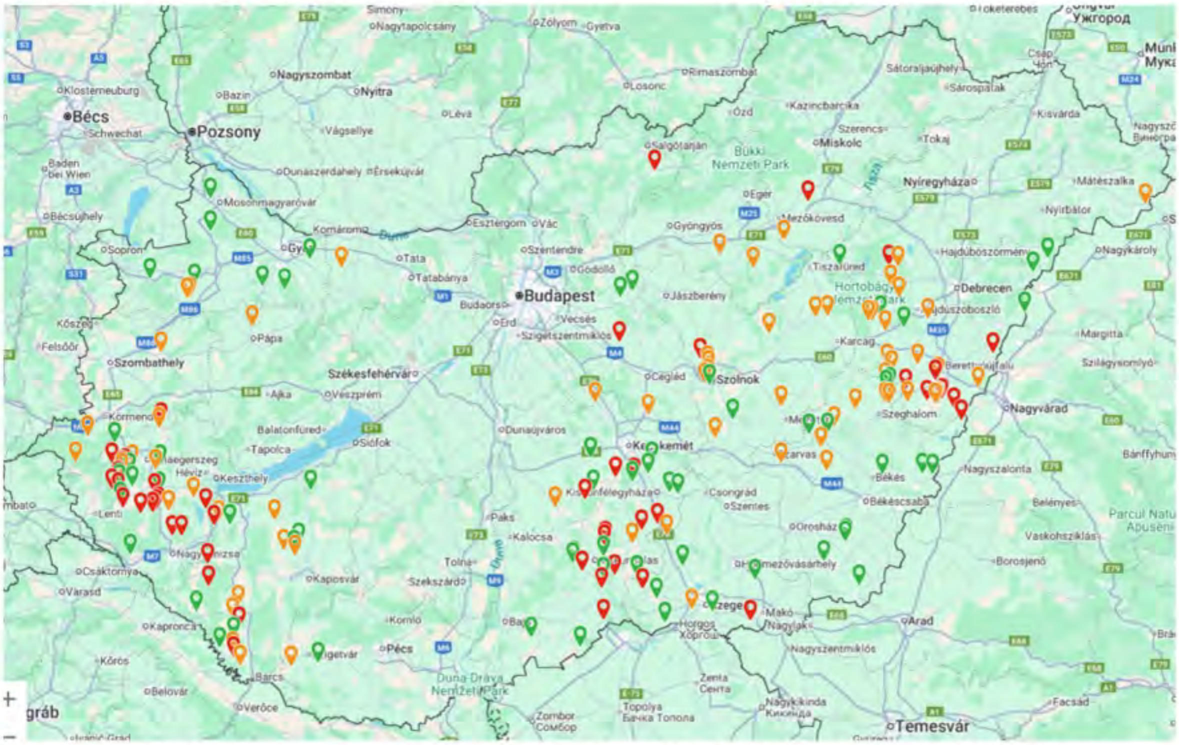


Figure 85: Map of the repurpose potential in the Pannonian Basin (Hungarian part) for DBHE.

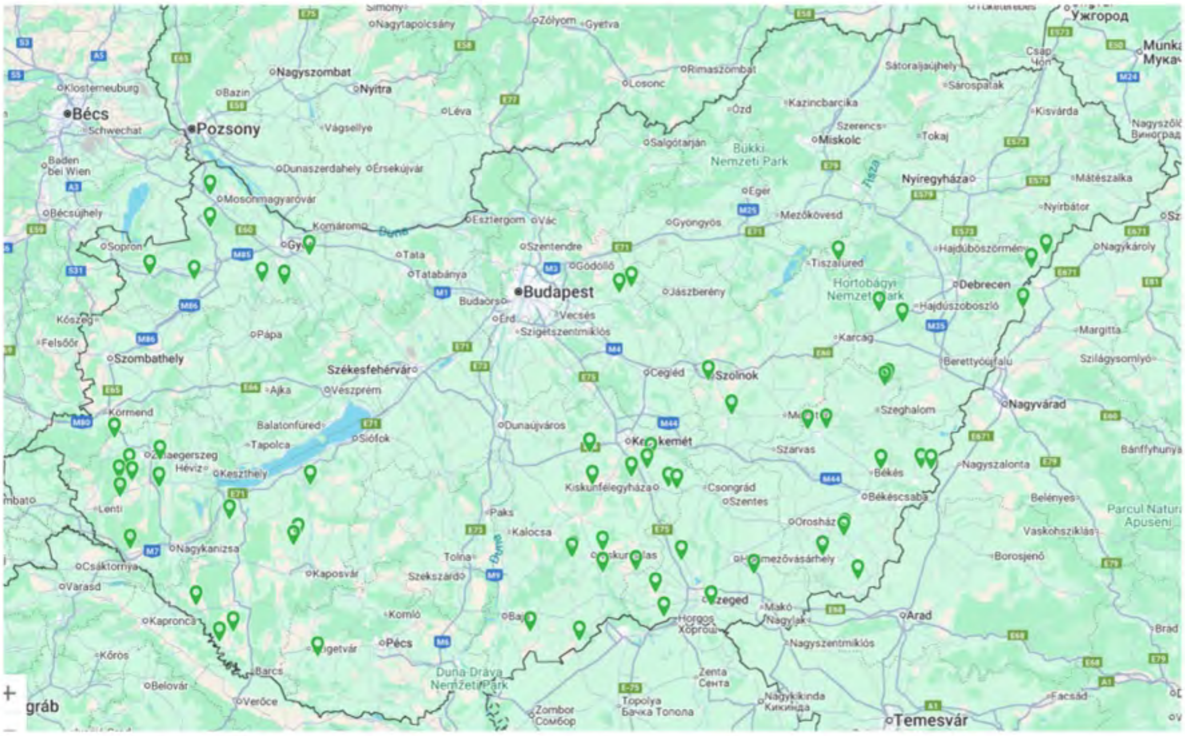


Figure 86: Suitable wells for reuse as DBHE in the Pannonian Basin (Hungarian part).

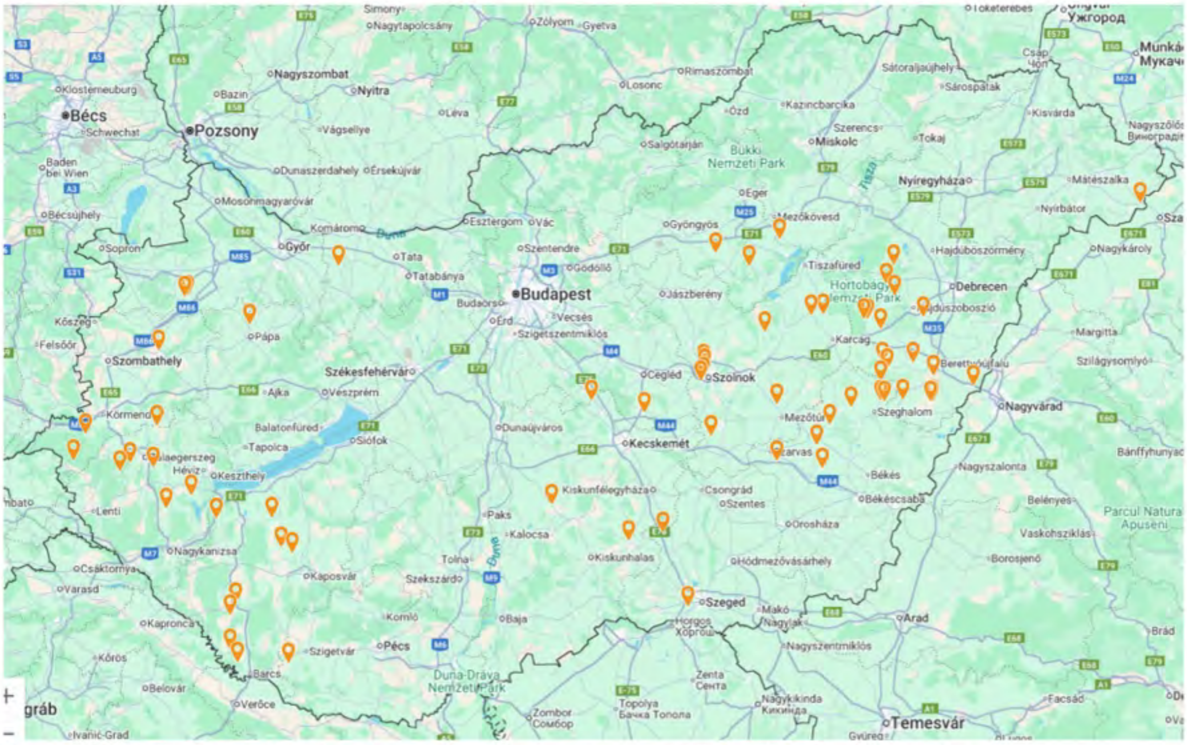


Figure 87: Suitable wells with restrictions for reuse as DBHE in the PB (Hungarian part).

Pannonian Basin (Hungary)	DBHE (absolute)	DBHE (percentage)
Totals of wells	177	100
Suitable	63	35.6
Uncertain	66	37.3
Not suitable	48	27.1

Table 33: Absolute numbers and percentages of reusable wells for DBHE in the PB (Hungarian part).

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.

7.2.3 BTES

From the input dataset of 177 wells (Figure 88), 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 (Table 34).

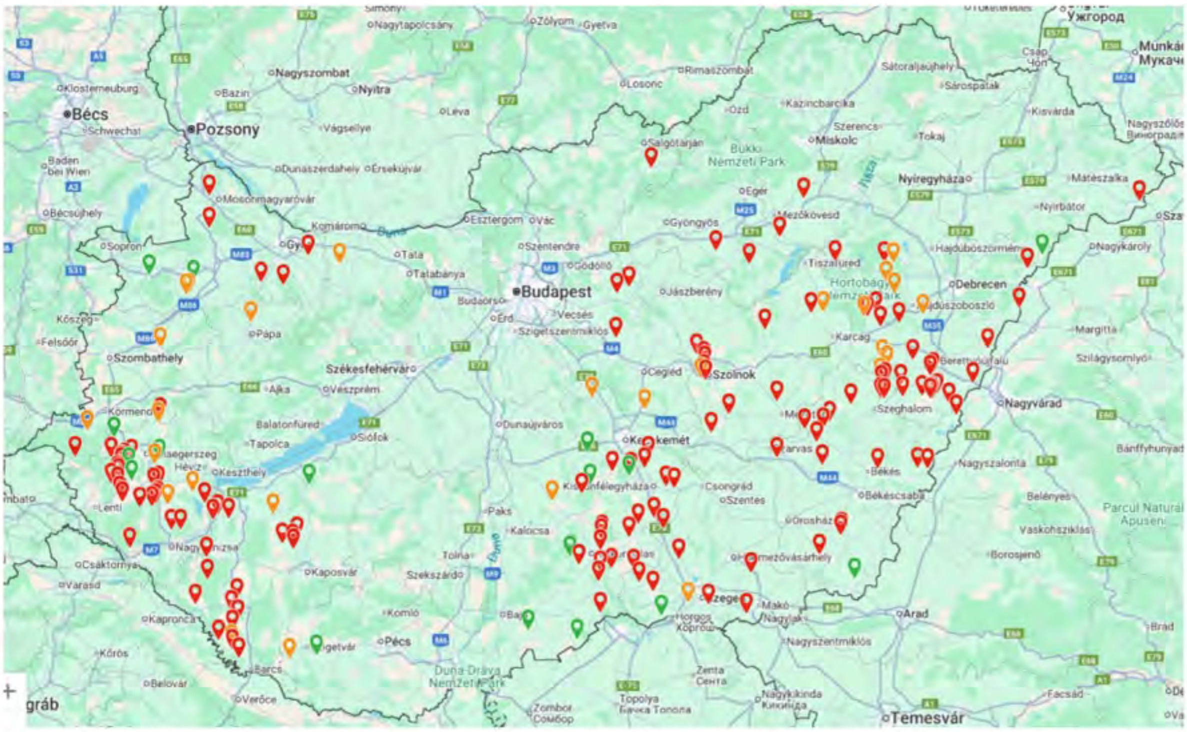


Figure 88: Map of the repurpose potential in the Pannonian Basin (Hungarian part) for BTES. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

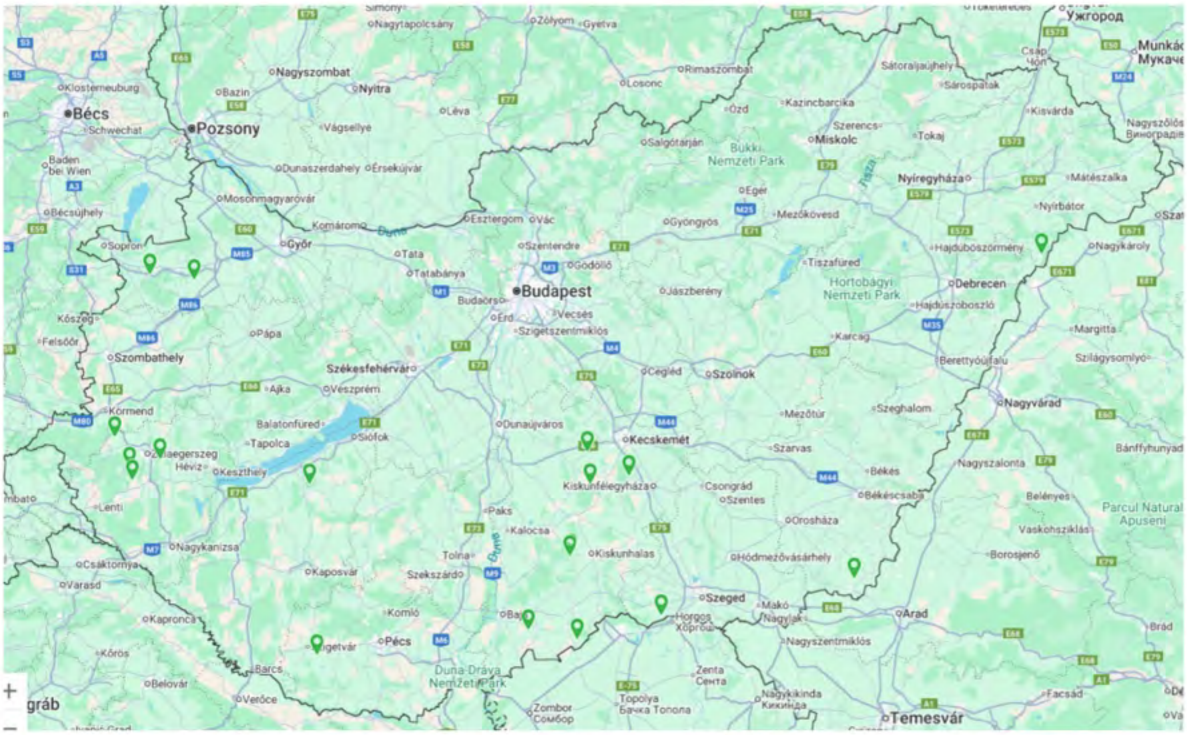


Figure 89: Wells suitable for BTES in the Pannonian Basin (Hungarian part).

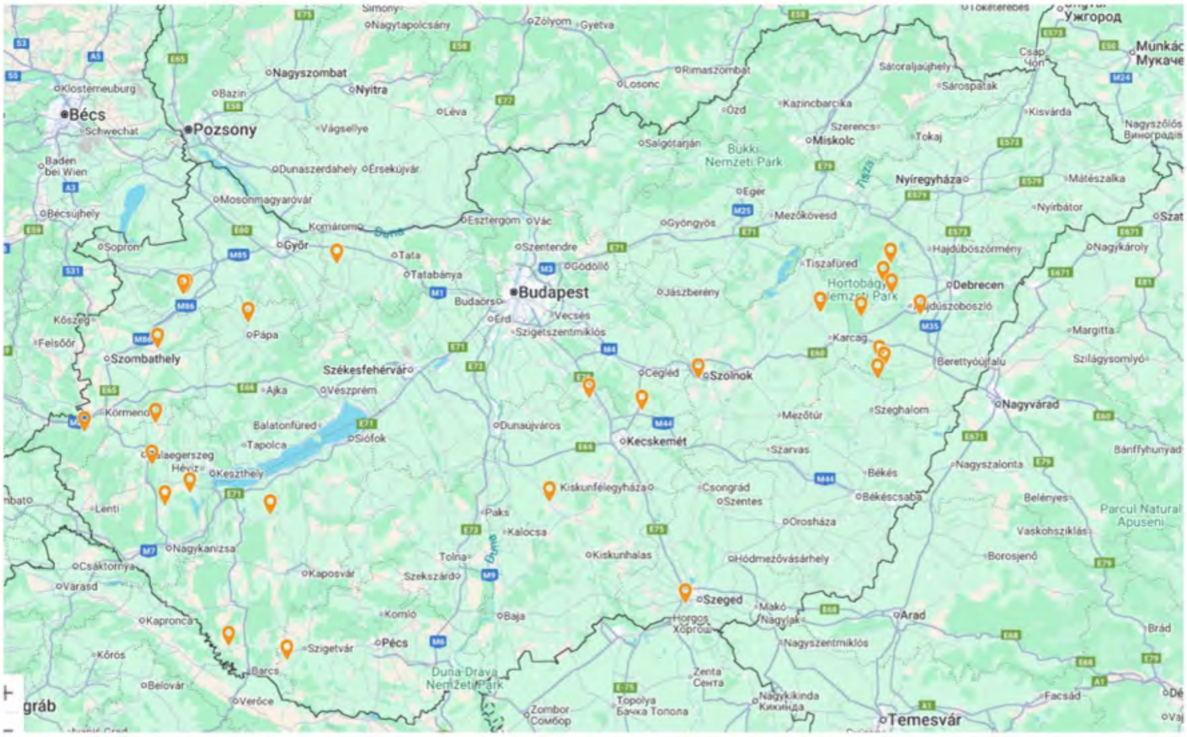


Figure 90: Wells suitable with certain restrictions for BTES in the PB (Hungarian part).

Pannonian Basin (Hungary)	BTES (absolute)	BTES (percentage)
Totals of wells	177	100
Suitable	18	10.2
Uncertain	27	15.2
Not suitable	132	74.6

Table 34: Absolute numbers and percentages of reusable wells for BTES in the PB (Hungarian part).

In most cases, BTES cannot be considered due to excessively high temperatures.

7.2.4 HE

From the input dataset of 177 wells (Figure 91), 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 applications (Table 35).

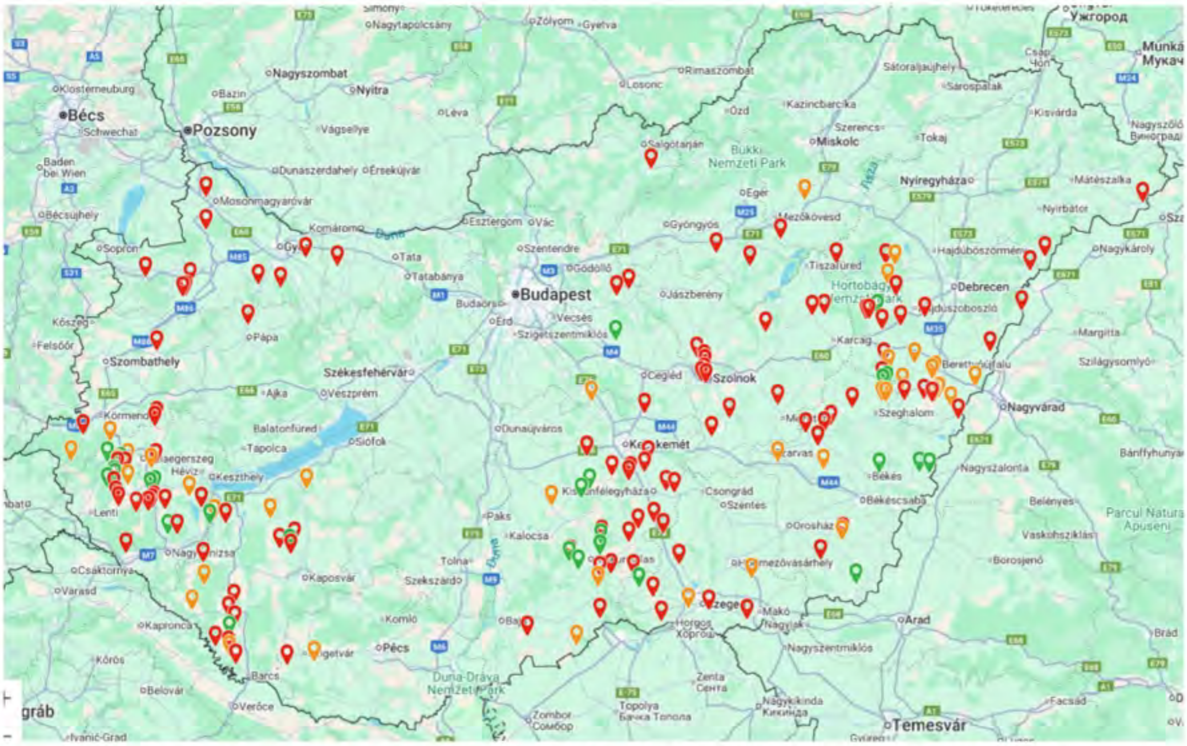


Figure 91: Map of the repurpose potential in the Pannonian Basin (Hungarian part) for HE. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

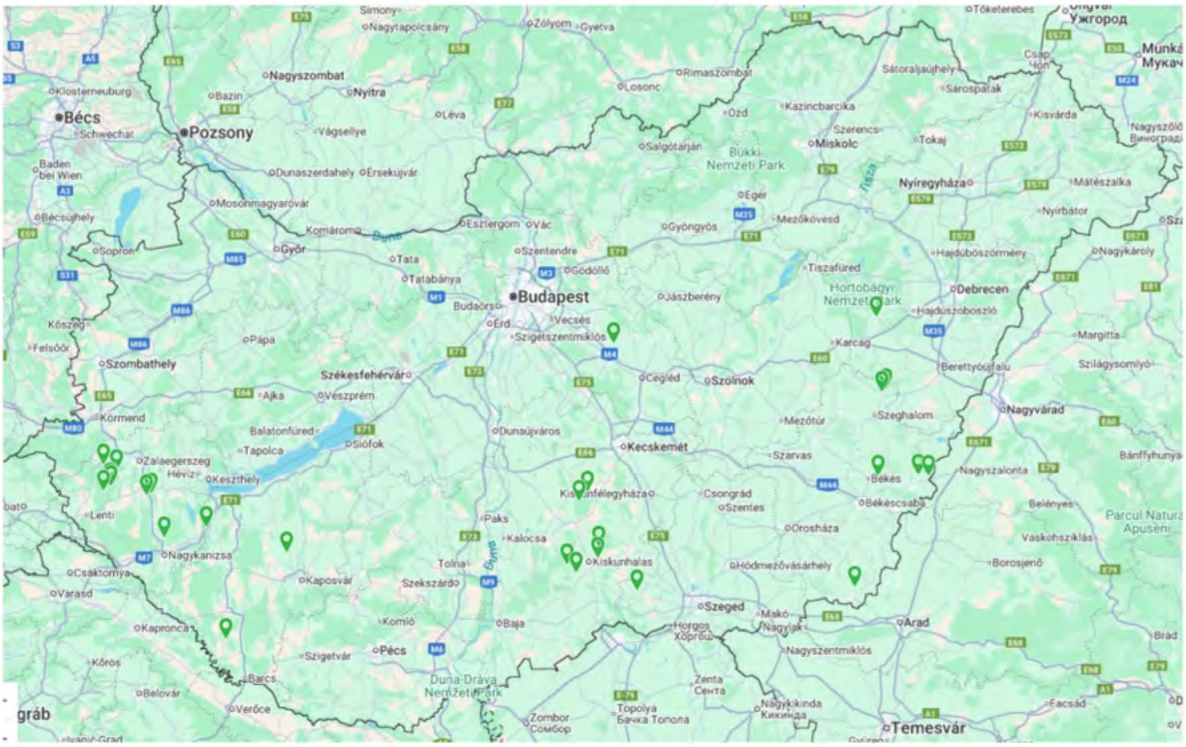


Figure 92: Wells suitable for HE in the Pannonian Basin (Hungarian part).

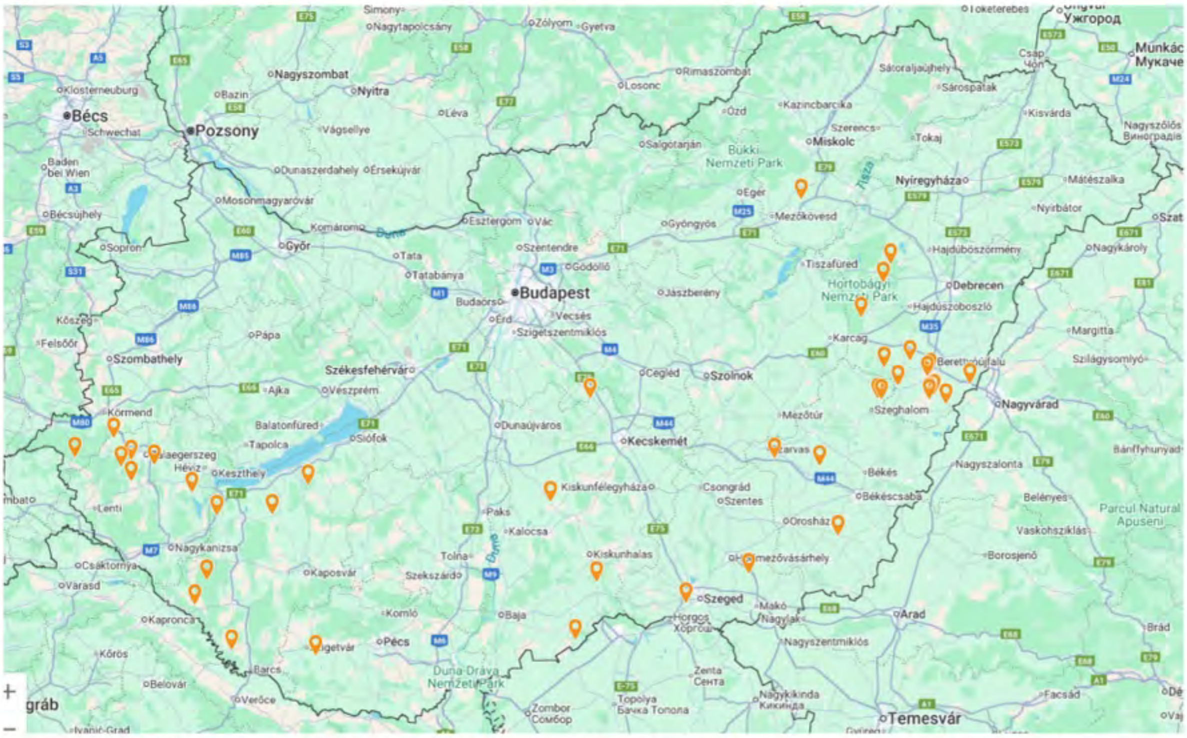


Figure 93: Wells suitable with certain restrictions for HE in the Pannonian Basin (Hungarian part).

Pannonian Basin (Hungary)	HE (absolute)	HE (percentage)
Totals of wells	177	100
Suitable	26	14.7
Uncertain	40	22.6
Not suitable	111	62.7

Table 35: Absolute numbers and percentages of reusable wells for HE in the PB (Hungarian part).

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.

7.2.5 EGS

From the input dataset of 177 wells (Figure 94), 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 (Table 36).

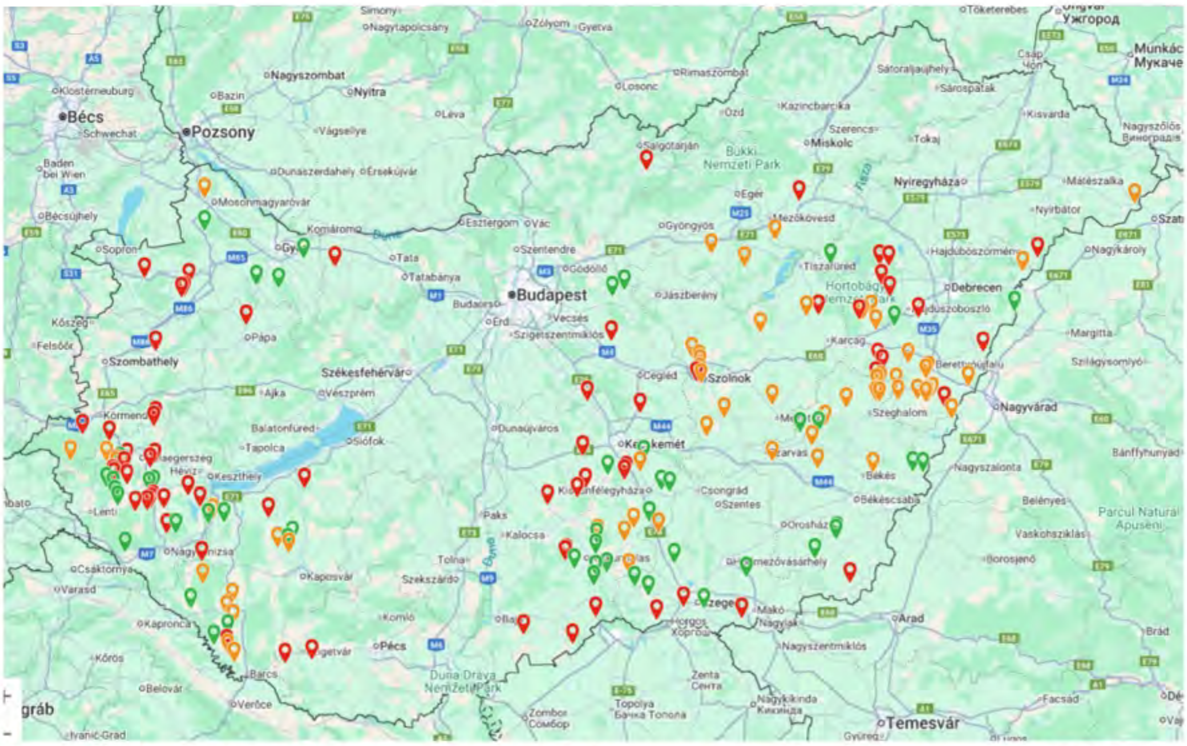


Figure 94: Map of the repurpose potential in the Pannonian Basin (Hungarian part) for EGS. Green: wells suitable; orange: wells suitable, with certain restrictions; red: wells are not suitable.

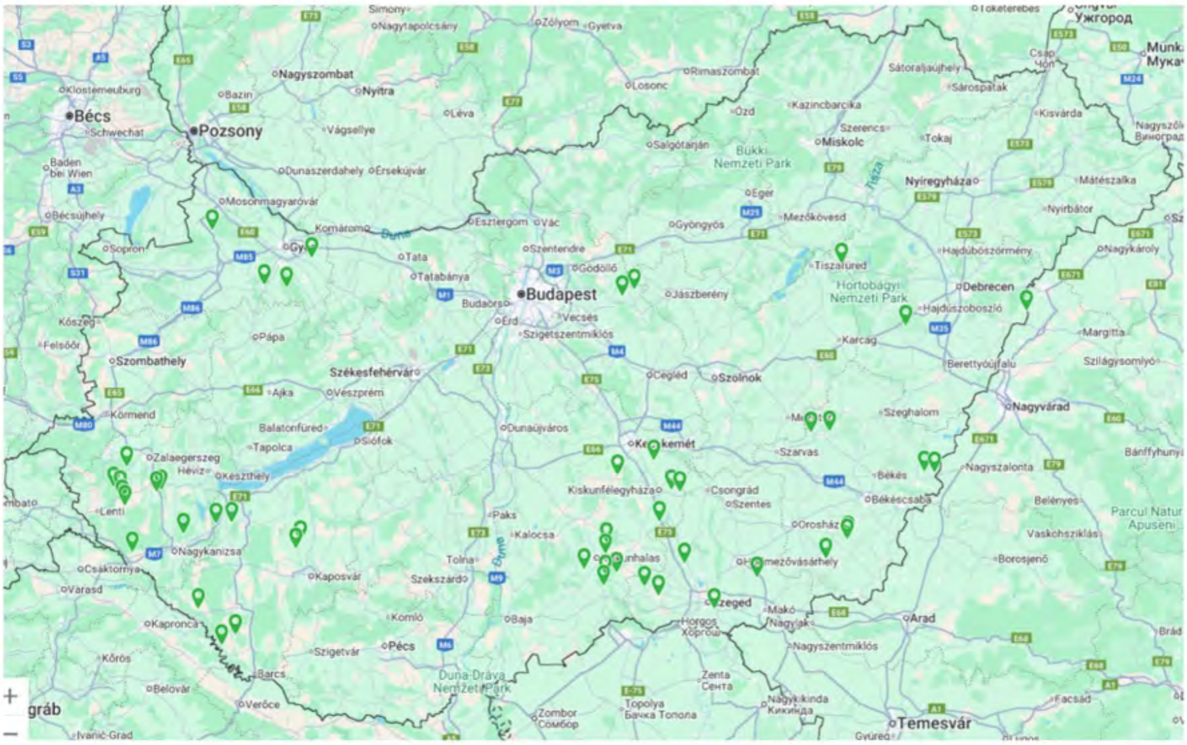


Figure 95: Wells suitable for EGS in the Pannonian Basin (Hungarian part).

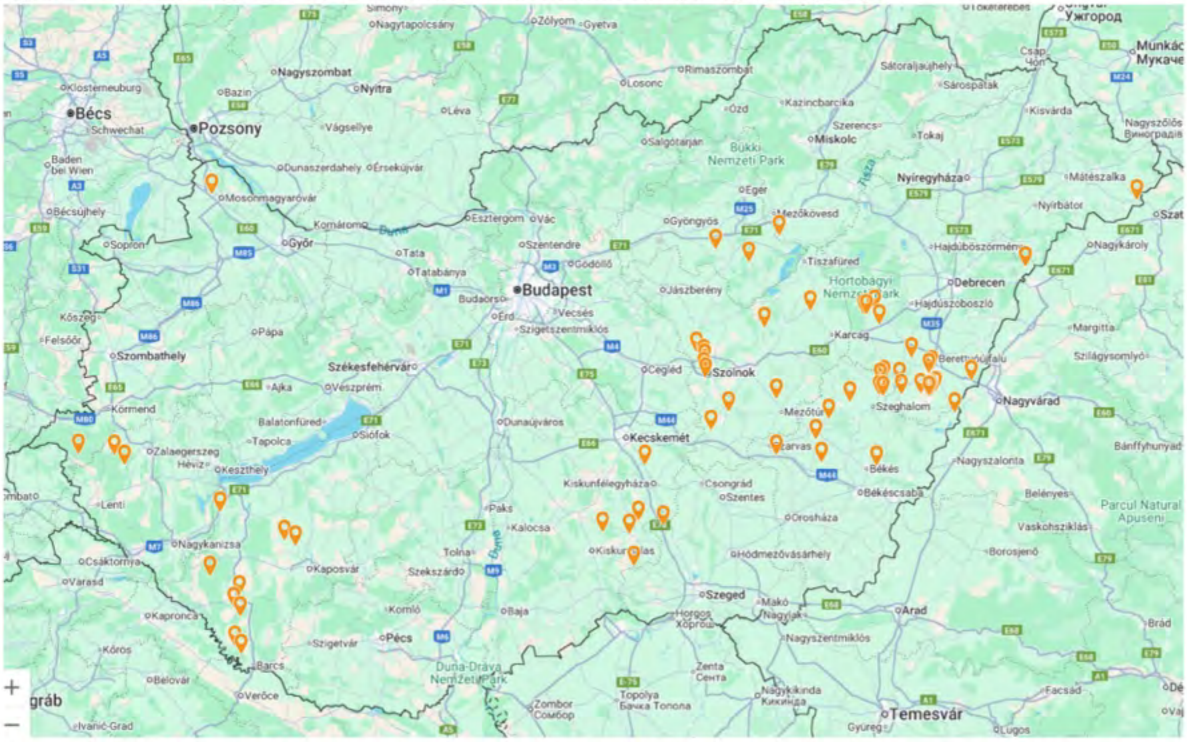


Figure 96: Wells suitable with certain restrictions for EGS in the Pannonian Basin (Hungarian part).

Pannonian Basin (Hungary)	EGS (absolute)	EGS (percentage)
Totals of wells	177	100
Suitable	48	27.1
Uncertain	61	34.5
Not suitable	68	38.4

Table 36: Absolute numbers and percentages of reusable wells for EGS in the PB (Hungarian part).

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.

7.2.6 Summary of the repurposing potential of the Pannonian Basin (Hungarian part)

A total of 624 wells were evaluated by BVH after which 177 wells were selected as potentially suitable and inserted to the database and thus into the IT tool. The preliminary assessment of the 177 wells based on the IT tool yielded the following results (Table 37):

Pannonian Basin (Hungary)	ATES	DBHE	BTES	HE	EGS
Total number of wells	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 %

Table 37: Absolute numbers and percentages of reusable wells for the 5 TRANSGEO methods in the Pannonian Basin, Hungary.

In the case of HE projects, the flow rate range between 10 l/s and 100 l/s is marked as uncertain (yellow), 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. There are overlaps between these wells. Taking into account the table of 177 wells, 63 wells were suitable for DBHE, 26 for HE, and 48 for EGS. Of course, there are overlaps between these wells. Of the 177 wells, a total of 137 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 we can count on 63 DBHE, 45 HE, and 6 EGS projects.

The modified assessment of the 177 wells yielded the following results (Table 38):

Pannonian Basin (Hungary)	**DBHE**	**HE**	**EGS**
Total of wells (absolute)	177 / 100 %	177 / 100 %	177 / 100 %
Suitable	63 / 10.1 %	45 / 7.2 %	6 / 1 %

Table 38: Of the 177 wells included in the database, the number of wells deemed suitable based on detailed analysis.

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 °C) offer significant potential. Such temperatures occur even at depths of 2500-3000 m in most aquifers of the PB, as well as in Mesozoic carbonatic bedrock.

The following average values can be used to calculate the heat production potential of wells: DBHE: 250 kWth; HE: 1.5 MWth, EGS: 3 MWth. 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 MWe and 5 MWe can be expected.

In order to do a more global analysis of geothermal potential from existing wells in Hungary (Table 39), assume that all wells identified as suitable are indeed suitable and calculate the maximum heat and electricity production values, on the basis of which the annual heat and electricity production can be calculated. In the case of heat production, the heating period should be taken into account. In total, let us calculate a heating period of 1,500 hours. For electricity production, we take into account the hours where the price of the electricity produced exceeds EUR 90 per MWh. In 2024, according to the historic data downloaded from the Hungarian Power Exchange (HPEX) portal, this was 4,257 hours.

Pannonian Basin (Hungary)	DBHE	HE	EGS
Total number of wells	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

Table 39: The amount of heat and electricity that can be produced from an abandoned well deemed suitable.

However, since the ratios calculated in this way are derived from a database that has already been filtered, they probably significantly overestimate the actual possibilities. It is recommended to extrapolate 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,presence of two nearby wells, for example reinjection problems. This results (Table 40) in the following ratios for the 624 wells:

Pannonian Basin (Hungary)	DBHE	HE	EGS
Total number of wells	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 %

Table 40: Number of suitable and reasonable wells relative to the number of abandoned wells examined in a pre-study.

This solution provides sufficiently realistic results and the raw reasonable means a very conservative estimation: There are a total of 8,354 hydrocarbon exploration and production wells deeper than 400 m in Hungary. Assuming that at least 2,258 of these wells are abandoned, we believe that the remaining number of 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 TRANSGEO pilot project, we used a filtered database, which only included those wells from the 624 wells pre-qualified by BVH for which a portfolio had been created. From BVH's portfolio of 62 wells, 50 wells and 62 aquifers were analysed in detail, taking into account BVH's previous activities and assessments in this area, supplemented by the possibilities offered by IT tools, primarily in terms of the market. A total of 27 reservoirs were 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 four 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 project implementation, and 3 for EGS implementation. If we exclude from the projects those 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 (e.g., possibility of strong gas flow, proven well integrity problems), 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 Plain. There are two potential EGSs in the Hungarian Great Plain and 1 in Zala County. Based on this, one-third of HE-suitable projects could be implemented in carbonate reservoirs (4 wells out of 12). This means that HE projects can be expected to generate 100% heat, but only 33,3% electricity. If we take these numbers and ratios for the total well stock and use the assumptions above, we have the following estimate (Table 41):

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 TWth	0.560 TWth	**0.149 TWth**
Potential max. annual electric production	-	0.954 TWe	0.702 TWe
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

Table 41: The potential of currently operating hydrocarbon wells for heat and electricity generation.

This would give a total annual heat production of 3.469 PJ/y and electricity production of 5.963 PJ/y. If we take all possibilities into account (suitable), we can expect heat production of 5.922 PJ/y and electricity production of 11.796 PJ/y. However, it is worth noting that in the case of EGS projects, the heat produced is unlikely to be sold (marked bold in Table 41), and in the case of HE projects 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 as follows (Table 42):

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)

Table 42: Hungary's energy demand and its sources in 2023 and 2024

Annual heat consumption from district heating systems in 2022 is around 26 PJ.

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.

7.3 Slovenian part of Pannonian Basin

In Slovenia, geothermal systems most commonly occur in fault zones, primarily in carbonate rocks, where thermal springs represent characteristic surface expressions of heat flow. In these environments, thermal waters are usually only slightly more mineralized than ordinary groundwater, and their temperature and chemical composition are suitable for various energy and balneological applications. Due to good recharge, changes in aquifers are typically reflected not as a drop in water levels but rather as variations in thermal water temperature (Rman et al., 2019).

Within the Pannonian Basin (PB), which covers the northeastern part of Slovenia (Figure 97), the most important aquifers are intergranular, developed within the sedimentary fill of Neogene basins and largely of transboundary character. Approximately 87% of all wells access these aquifers, together providing around 70% of all extracted thermal water. A prominent example of such a system is the transboundary aquifer in the poorly consolidated Pontian and Upper Pannonian sandstones of the Mura Formation in the Mura-Zala Basin, which Slovenia shares with Croatia and Hungary.

Between 2001 and 2011, an extensive campaign was carried out in Slovenia to decommission abandoned oil and gas wells, during which more than 200 wells were closed, and several dozen were repurposed for alternative uses, including potential geothermal research (Nafta Geoterm, 2012). Most of these wells are located in the northeastern part of the country, particularly in the Petišovci, Lendava, Čentiba, and Murska Sobota areas. They reach depths of approximately 3,000–3,800 m and were originally drilled for hydrocarbon exploration.

These wells provide an important source of geological and thermal data on the composition and thermal characteristics of the Neogene aquifers and enable the assessment of their technical potential for reuse in geothermal applications. Incorporating these data into the analysis of the geothermal potential of the PB allows a direct connection between the regional geological framework and existing infrastructure, significantly contributing to the evaluation of feasibility and sustainable development of geothermal projects in Slovenia.

In the southeastern region along the coast and in other parts of Slovenia, geothermal waters are extracted from fractured bedrock aquifers beneath overlying sedimentary basins. Due to the complex fracture systems, temperature and chemical composition vary significantly with depth. Recharge of these aquifers is very limited, meaning that excessive extraction may lead to drops in groundwater levels and, in some cases, intrusion of gases or waters with different chemical compositions and temperatures (Rman et al., 2019).

The highest temperatures measured in wells occur in the area of the PB in eastern Slovenia. There, a several-hundred-meter-thick layer of poorly permeable strata prevents rapid infiltration of cold precipitation, while elevated geothermal heat flow - due to the relatively thin crust, only about 30 km thick - effectively heats the slowly moving groundwater (Rman et al., 2019).

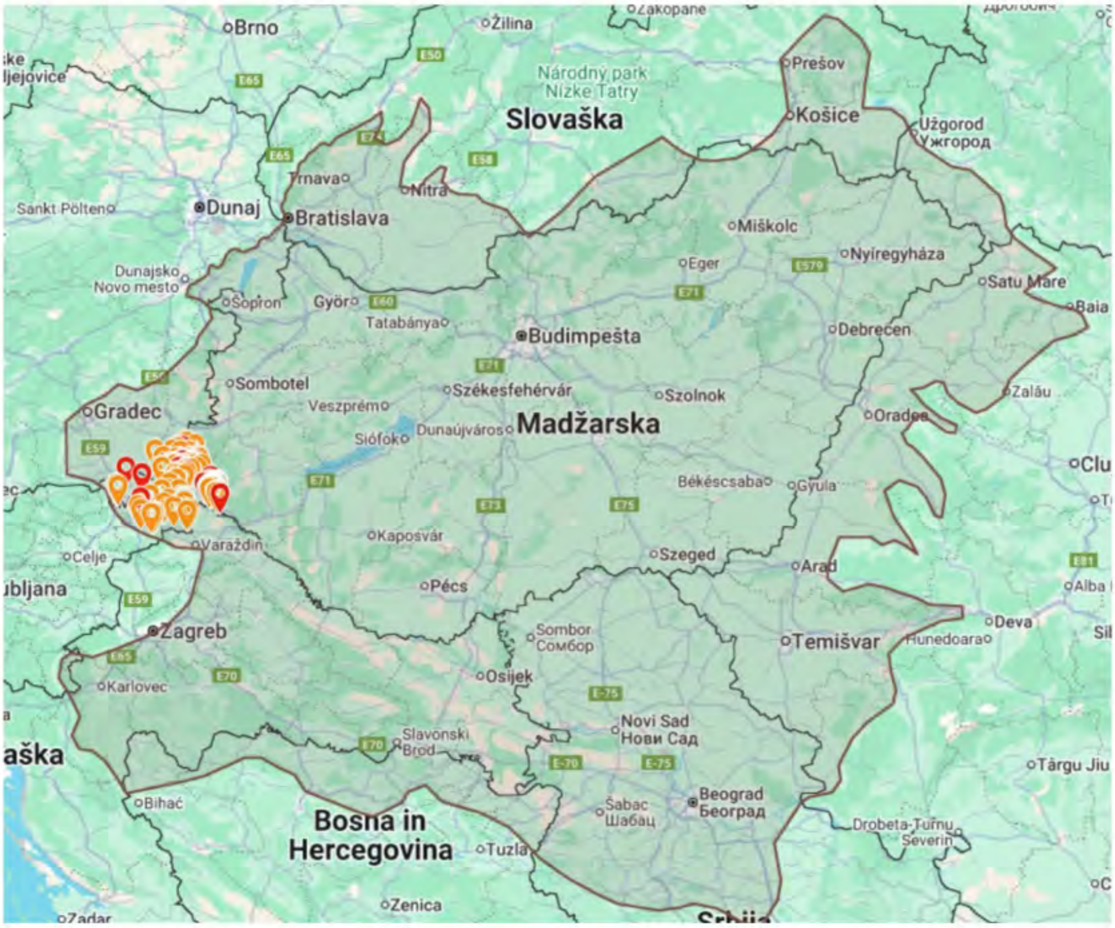


Figure 97: Map of the outline of the Pannonian basin (grey) with the Slovenian wells.

7.3.1 ATES

From the input dataset of 244 wells the results from the IT tool assessing the repurposing potential of existing wells in the Slovenian part of the Pannonian Basin for Aquifer Temperature Energy Storage (ATES) filtered out following results:

- **Green flags** indicate wells that are suitable for repurposing without restrictions.
- **Orange flags** represent wells with uncertain status, requiring further investigation or data.
- **Red flags** are wells deemed not suitable for repurposing.

Table 43 provides a quantitative overview: Out of **244** total wells assessed, **2** (0.8%) are classified as suitable for repurposing. **78 wells** (32%) fall into the uncertain category, which need to be analysed more to understand their potential. The majority, **164 wells** (67.2%), are not suitable for ATES repurposing under current criteria.

Pannonian Basin (Slovenia)	ATES (absolute)	ATES (percentage)
Totals of wells	244	100
Suitable	2	0.8
Uncertain	78	32
Not suitable	164	67.2

Table 43: Absolute numbers and percentages of reusable wells for ATES in the Slovenian part of the Pannonian Basin.

Figure 98 shows the spatial distribution of the wells that are categorised based on their suitability for ATES repurposing and Figure 99 highlights only the suitable wells, clearly showing clusters of potential ATES infrastructure, particularly in areas with favorable subsurface conditions and Figure 100 displays wells that could be conditionally suitable, where some limitations or missing data must be addressed before confirming their reuse potential.

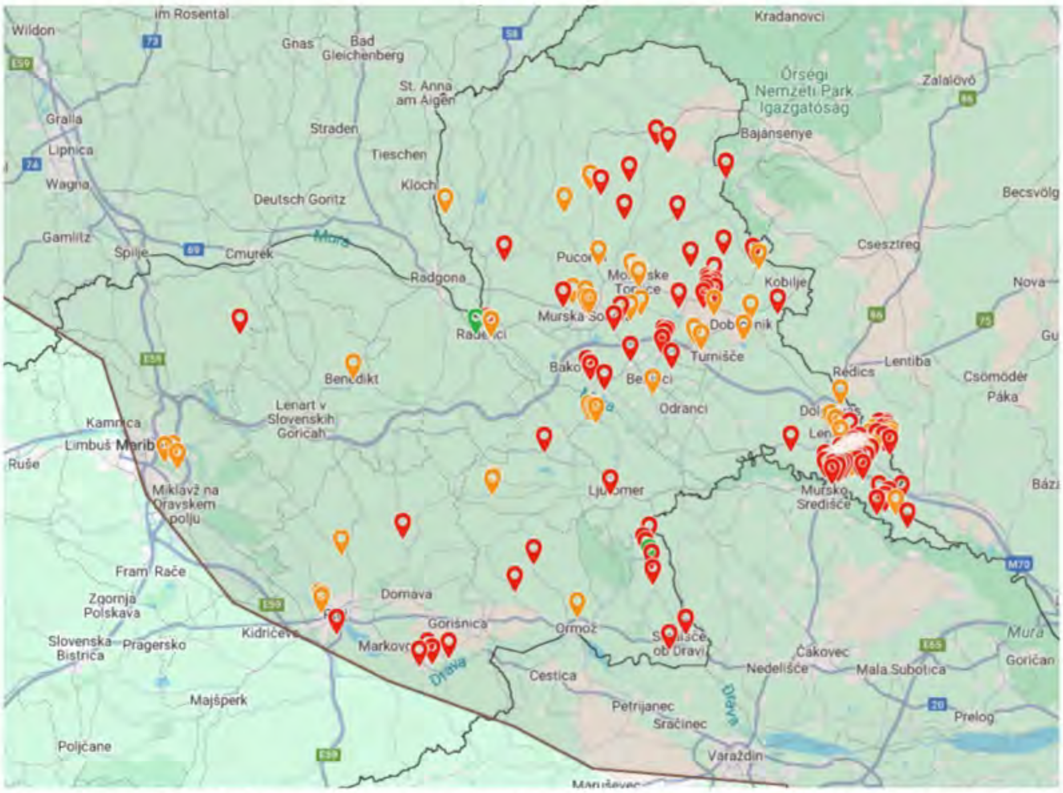


Figure 98: Map of the repurpose potential for ATES in the Slovenian part of the Pannonian Basin.

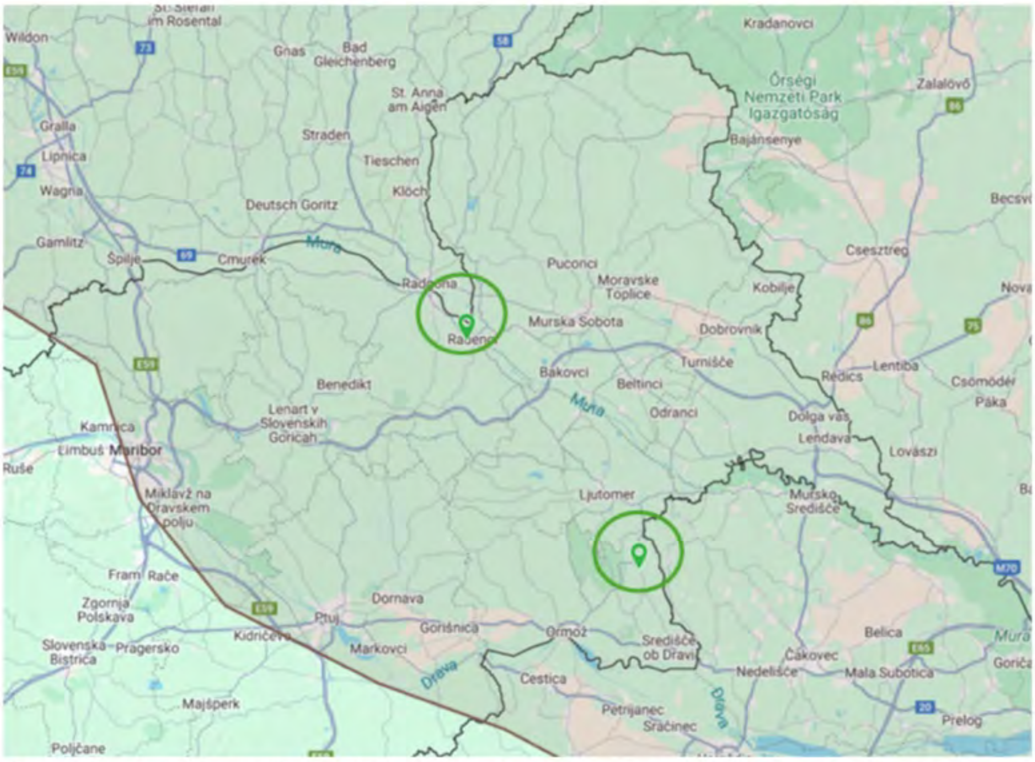


Figure 99: Suitable wells for ATES in the Slovenian part of the Pannonian Basin.

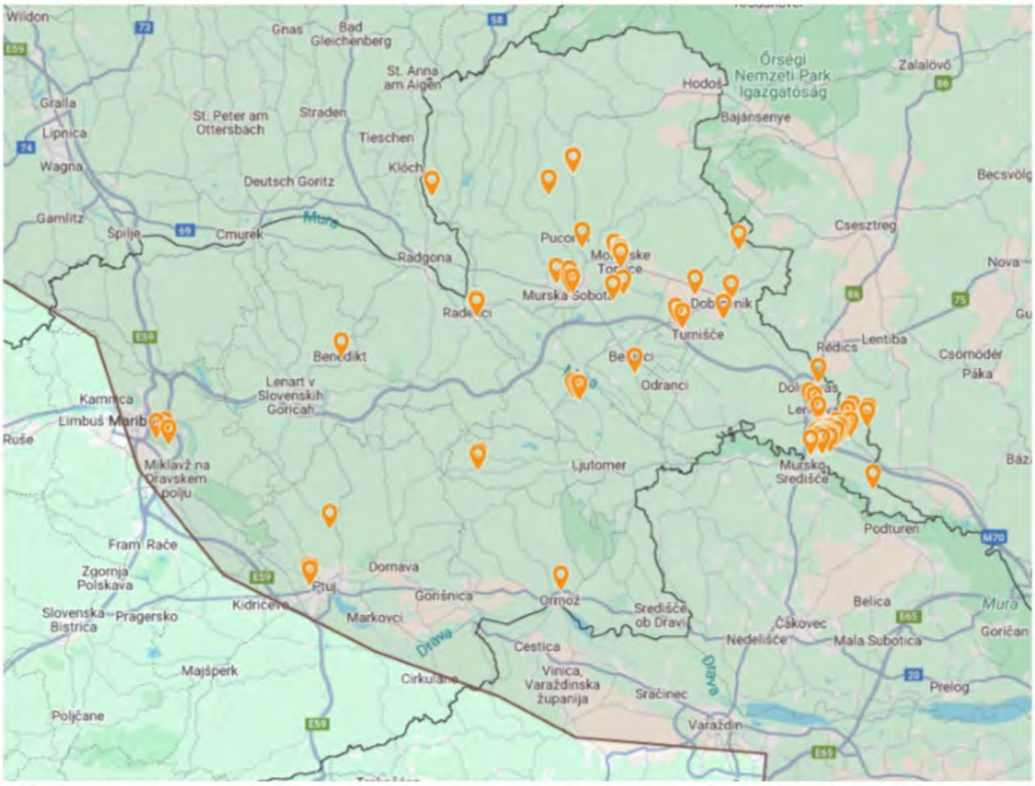


Figure 100: Wells suitable with certain restrictions for ATES in the Slovenian part of the Pannonian Basin.

7.3.2 DBHE

From the input dataset of 244 wells the results from the IT tool assessing the repurposing potential of existing wells in the Slovenian part of the Pannonian Basin for Deep Borehole Heat Exchanger (DBHE) filtered out following results:

- Green flags indicate wells that are suitable for repurposing without restrictions.
- Orange flags represent wells with uncertain status, requiring further investigation or data.
- Red flags are wells deemed not suitable for repurposing.

Table 44 provides a quantitative overview: Out of **244** total wells assessed, **2** (0.8%) are classified as suitable for repurposing. The majority of **164 wells** (67.2%) fall into the uncertain category, which need to be analysed more to understand their potential. **78 wells** (32%), are not suitable for DBHE repurposing under current criteria.

Pannonian Basin (Slovenia)	DBHE (absolute)	DBHE (percentage)
Totals of wells	244	100
Suitable	2	0.8
Uncertain	164	67.2
Not suitable	78	32

Table 44: Absolute numbers and percentages of reusable wells for DBHE in the Slovenian part of the Pannonian Basin.

Figure 101 shows the spatial distribution of the wells that are categorised based on their suitability for DBHE repurposing and Figure 102 highlights only the suitable wells, clearly showing clusters of potential DBHE infrastructure, particularly in areas with favorable subsurface conditions and Figure 103 displays wells that could be conditionally suitable, where some limitations or missing data must be addressed before confirming their reuse potential.

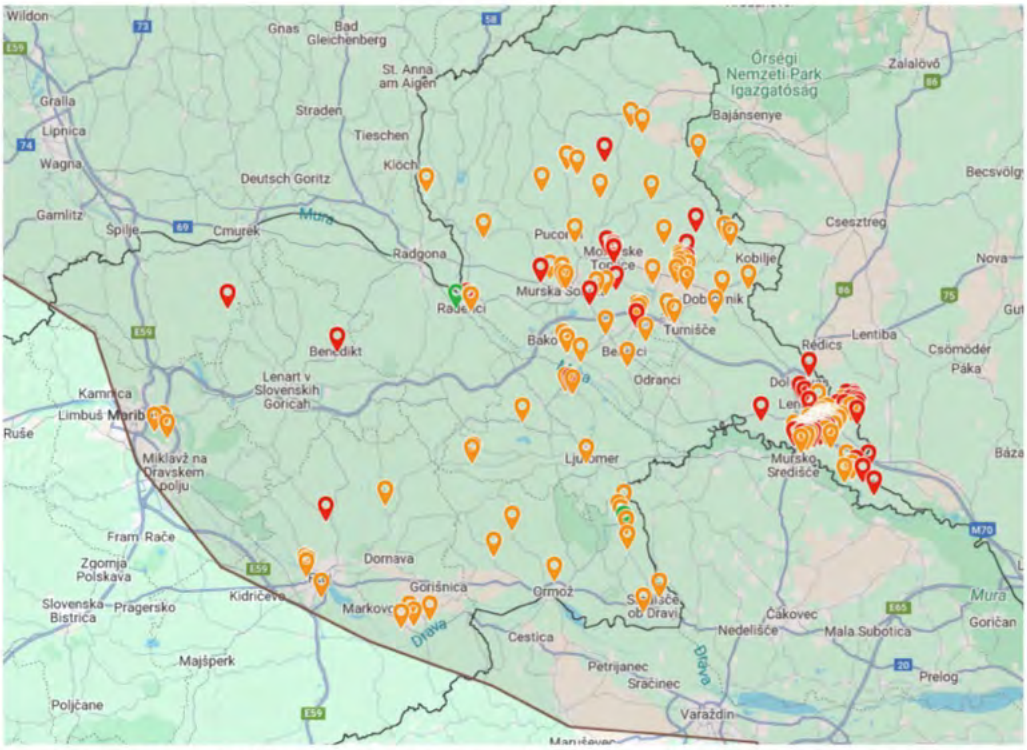


Figure 101: Map of the repurpose potential for DBHE in the Slovenian part of the Pannonian Basin.

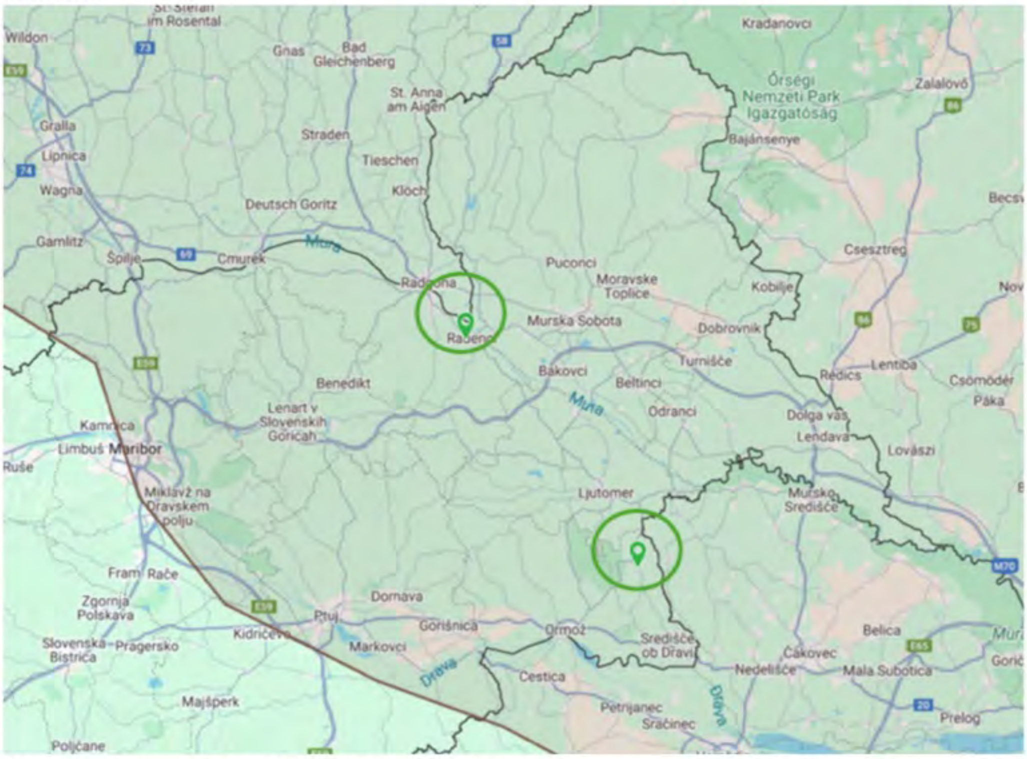


Figure 102: Suitable wells for DBHE in Slovenian part of the Pannonian Basin.

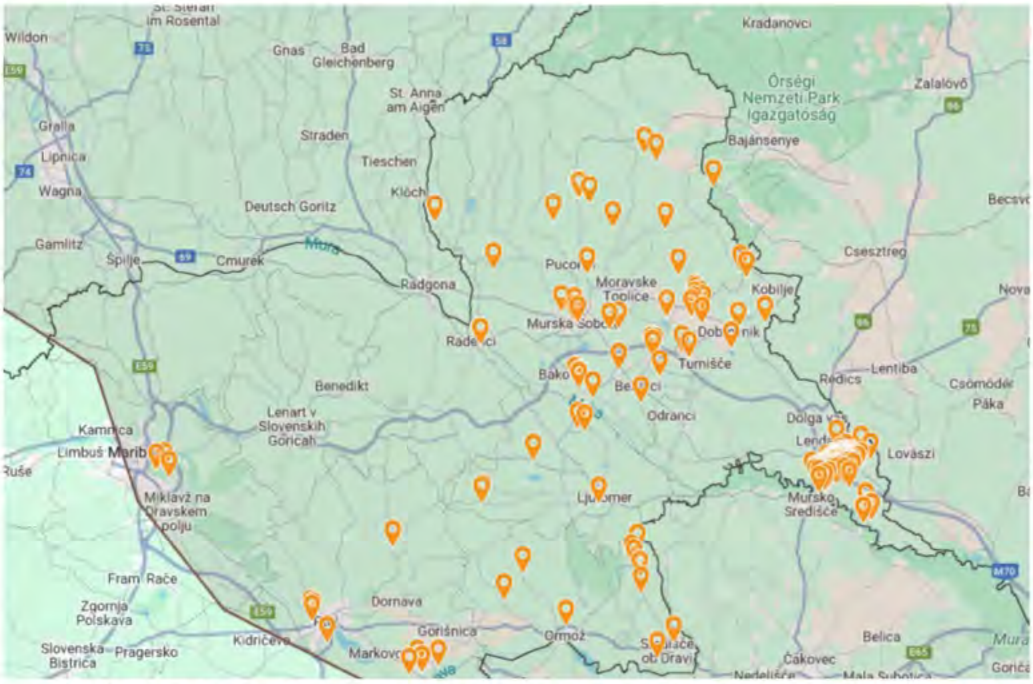


Figure 103: Suitable wells with certain restrictions for DBHE in Slovenian part of the Pannonian Basin.

7.3.3 BTES

From the input dataset of 244 wells the results from the IT tool assessing the repurposing potential of existing wells in the Slovenian part of the Pannonian Basin for Borehole Thermal Storage (BTES) filtered out following results:

- Green flags indicate wells that are suitable for repurposing without restrictions.
- Orange flags represent wells with uncertain status, requiring further investigation or data.
- Red flags are wells deemed not suitable for repurposing.

Table 45 provides a quantitative overview: Out of **244** total wells assessed, **2** (0.8%) are classified as suitable for repurposing. **34 wells** (14%) fall into the uncertain category, which need to be analysed more to understand their potential. The majority, **208 wells** (85.2%), are not suitable for BTES repurposing under current criteria.

Pannonian Basin (Slovenia)	BTES (absolute)	BTES (percentage)
Totals of wells	244	100
Suitable	2	0.8
Uncertain	34	14
Not suitable	208	85.2

Table 45: Absolute numbers and percentages of reusable wells for BTES in the Slovenian part of the Pannonian Basin.

Figure 104 shows the spatial distribution of the wells that are categorised based on their suitability for BTES repurposing and Figure 105 highlights only the suitable wells, clearly showing clusters of potential BTES infrastructure, particularly in areas with favorable subsurface conditions and Figure 106 displays wells that could be conditionally suitable, where some limitations or missing data must be addressed before confirming their reuse potential.

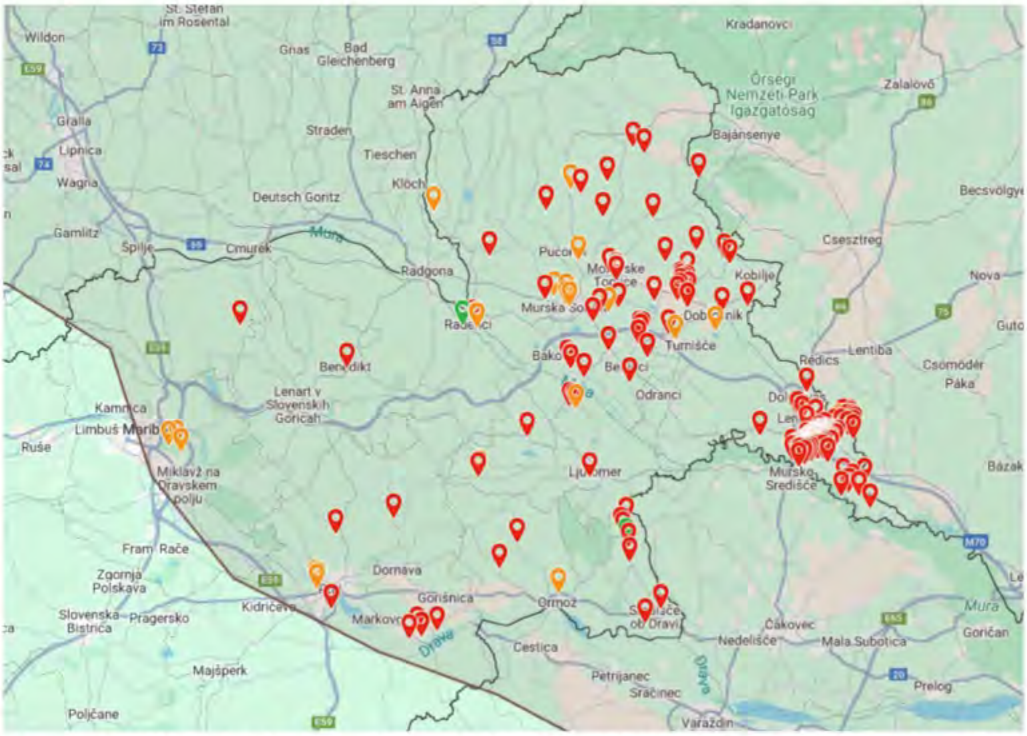


Figure 104: Map of the repurpose potential for BTES in the Slovenian part of the Pannonian Basin.

Figure 105: Suitable wells for BTES in Slovenian part of the Pannonian Basin.

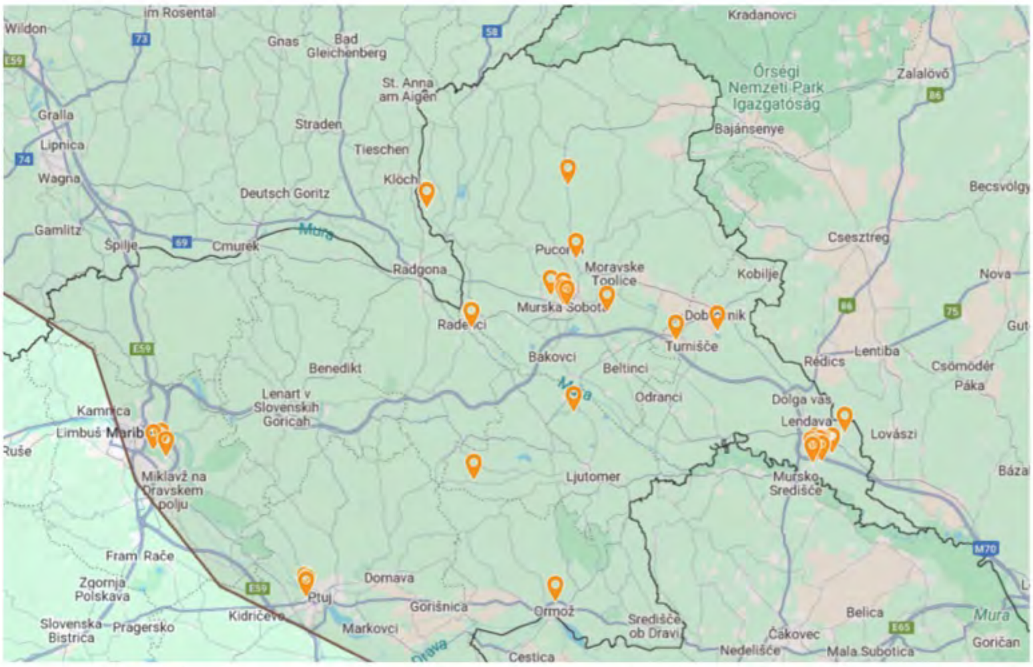


Figure 106: Suitable wells with certain restrictions for BTES in Slovenian part of the Pannonian Basin.

7.3.4 HE

From the input dataset of 244 wells the results from the IT tool assessing the repurposing potential of existing wells in the Slovenian part of the Pannonian Basin for Hydrothermal Energy (HE) filtered out following results:

- Green flags indicate wells that are suitable for repurposing without restrictions.
- Orange flags represent wells with uncertain status, requiring further investigation or data.
- Red flags are wells deemed not suitable for repurposing.

Table 46 provides a quantitative overview: Out of **244** total wells assessed, **0** (0%) are classified as suitable for repurposing. All **244 wells** (100%) fall into the uncertain category, which need to be analysed more to understand their potential. **0 wells** (0%), are not suitable for HE repurposing under current criteria.

Pannonian Basin (Slovenia)	HE (absolute)	HE (percentage)
Totals of wells	244	100
Suitable	0	0
Uncertain	244	100
Not suitable	0	0

Table 46: Absolute numbers and percentages of reusable wells for HE in the Slovenian part of the Pannonian Basin.

Figure 107 shows the spatial distribution of the wells that are categorised based on their suitability for HE repurposing. As for HE all wells result in the category uncertain, only one map is integrated into the report.

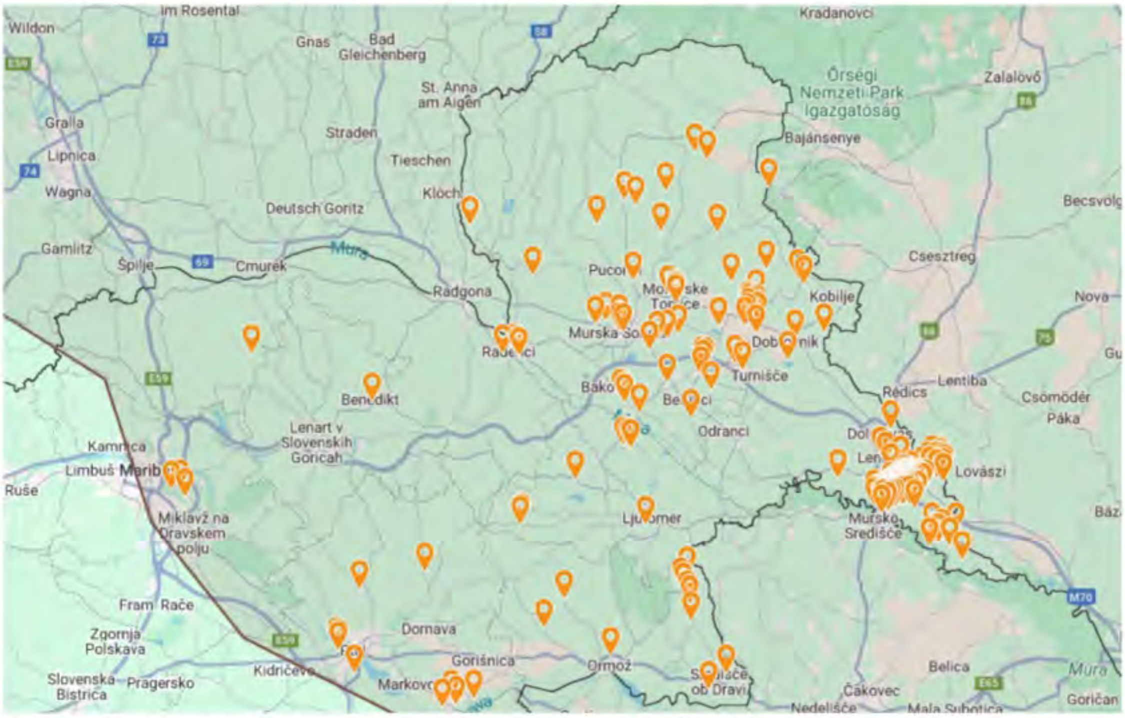


Figure 107: Map of the repurpose potential for HE in the Slovenian part of the Pannonian Basin.

7.3.5 EGS

From the input dataset of 244 wells the results from the IT tool assessing the repurposing potential of existing wells in the Slovenian part of the Pannonian Basin for Enhanced Geothermal Systems (EGS) filtered out following results:

- Green flags indicate wells that are suitable for repurposing without restrictions.
- Orange flags represent wells with uncertain status, requiring further investigation or data.
- Red flags are wells deemed not suitable for repurposing.

Table 47 provides a quantitative overview: Out of **244** total wells assessed, **0** (0%) are classified as suitable for repurposing. **73 wells** (30%) fall into the uncertain category, which need to be analysed more to understand their potential. The majority, **171 wells** (70%), are not suitable for EGS repurposing under current criteria.

Pannonian Basin (Slovenia)	EGS (absolute)	EGS (percentage)
Totals of wells	244	100
Suitable	0	0
Uncertain	73	30
Not suitable	171	70

Table 47: Absolute numbers and percentages of reusable wells for EGS in the Slovenian part of the Pannonian Basin.

Figure 108 shows the spatial distribution of the wells that are categorised based on their suitability for EGS repurposing and Figure 109 displays wells that could be conditionally suitable, where some limitations or missing data must be addressed before confirming their reuse potential.

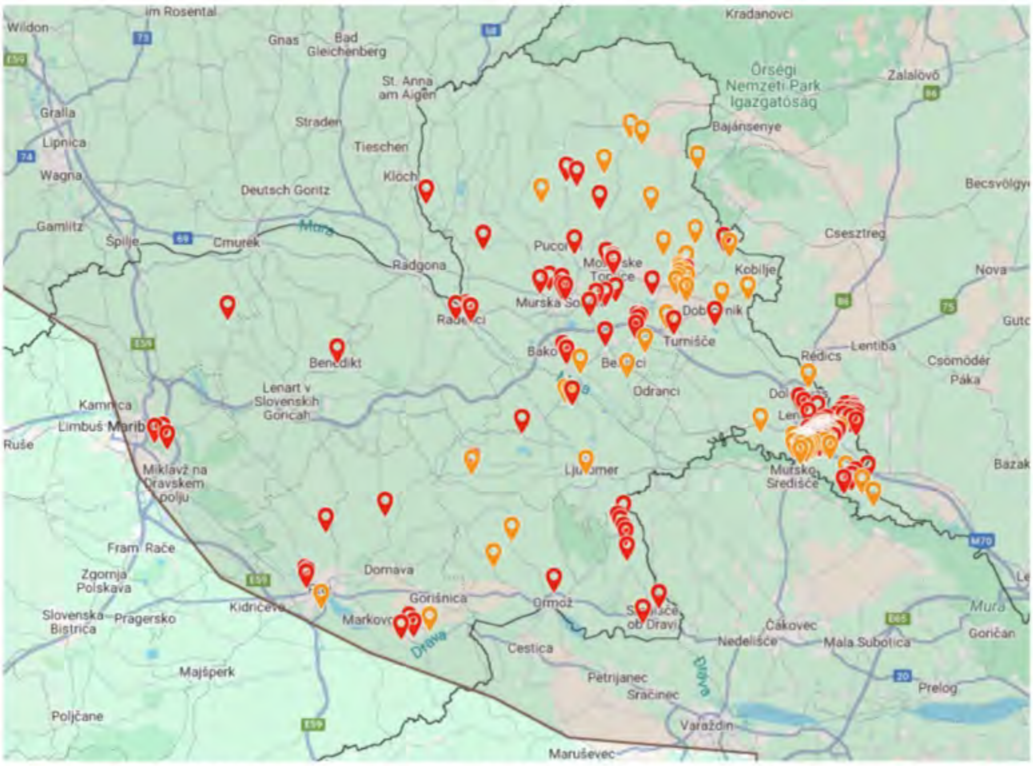


Figure 108: Map of the repurpose potential for EGS in the Slovenian part of the Pannonian Basin.

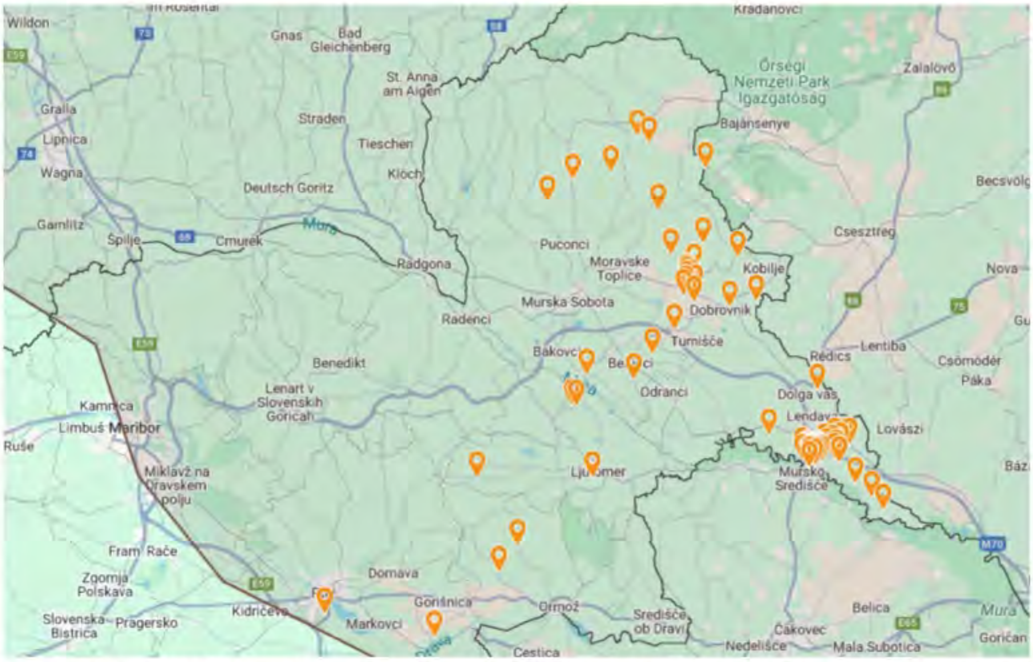


Figure 109: Suitable wells with certain restrictions for EGS in Slovenian part of the Pannonian Basin.

7.3.6 Summary of the repurposing potential of the Pannonian Basin (Slovenian part)

The assessment of **244 wells** across five geothermal technology options (ATES, DBHE, BTES, HE, and EGS) shows in Table 48 a 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 favorable 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 characterised in this region.

-

Pannonian Basin (Slovenia)	ATES	DBHE	BTES	HE	EGS
Total of wells	244	244	244	244	244
Suitable	2	2	2	0	0
Uncertain	78	163	34	244	73
Not suitable	164	79	208	0	171

Table 48: Absolute numbers of reusable wells for 5 geothermal methods in the Slovenian part of the PB.

The percentage of wells located in the Slovenian part of the Pannonian Basin are shown in Table 49.

Pannonian Basin (Slovenia)	ATES	DBHE	BTES	HE	EGS
Suitable	0.8	0.8	0.8	0	0
Uncertain	32	66.8	14	100	30
Not suitable	67.2	32.4	85.2	0	70

Table 49: Percentages of reusable wells for 5 geothermal methods in the Slovenian part of the PB.

8 Summary of the repurpose potential in Central Europe

In the central Europe region of the TRANSGEO partner countries, Slovenia, Croatia, Hungary, Austria and Germany, approximately 8,900 existing wells have been analysed. The potential of geothermal reuse is distributed over the investigated basins and varies depending on the reuse method applied.

The following maps (Figure 110 to Figure 114) show the overall potential in Central Europe for ATES, DBHE, BTES, HE and EGS repurposing. The figures show well locations with green flags indicating wells that are suitable for repurposing without restrictions, orange flags representing wells with uncertain status, requiring further investigation or data collection, and wells with red flags, not suitable for the chosen application. It must be noted that the databases of Germany and Austria consist of large datasets with basic well data (location, name, depth, age) whereas the well inventory of the Pannonian Basin is pre-selected. Therefore, the total number of input wells is smaller (see Chapter 3.1.4 and Chapter 7), but individual wells have more detailed information attached than in Austria and Germany.

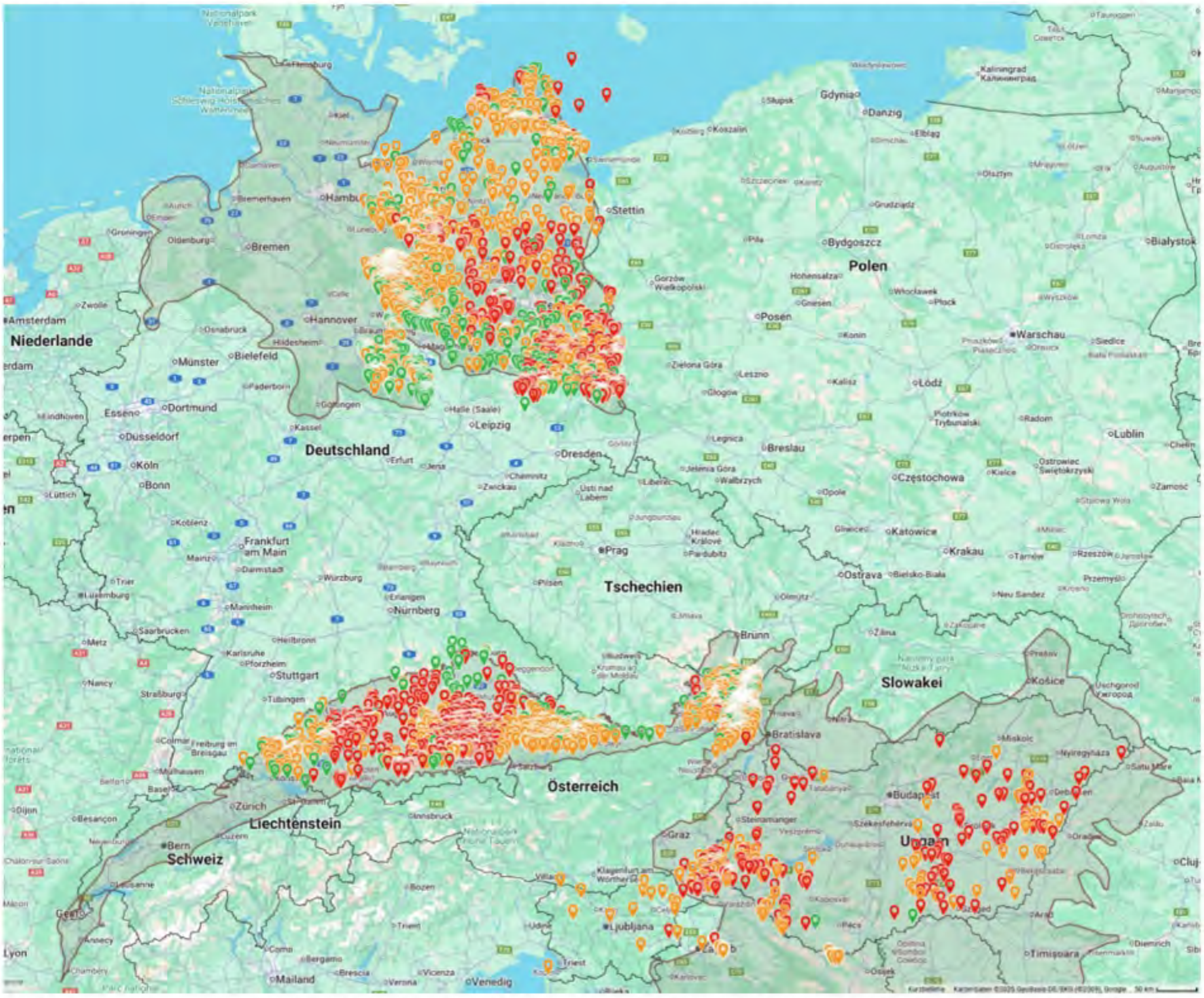


Figure 110: Repurpose potential in central Europe in the countries Germany, Austria, Hungary, Slovenia and Croatia for ATES. Green flags represent suitable wells, orange flags show suitable, but uncertain wells and red flags display non-suited wells. The grey areas represent the outlines of the sedimentary basins (North German Basin, Molasse, Vienna Basin and Pannonian Basin).

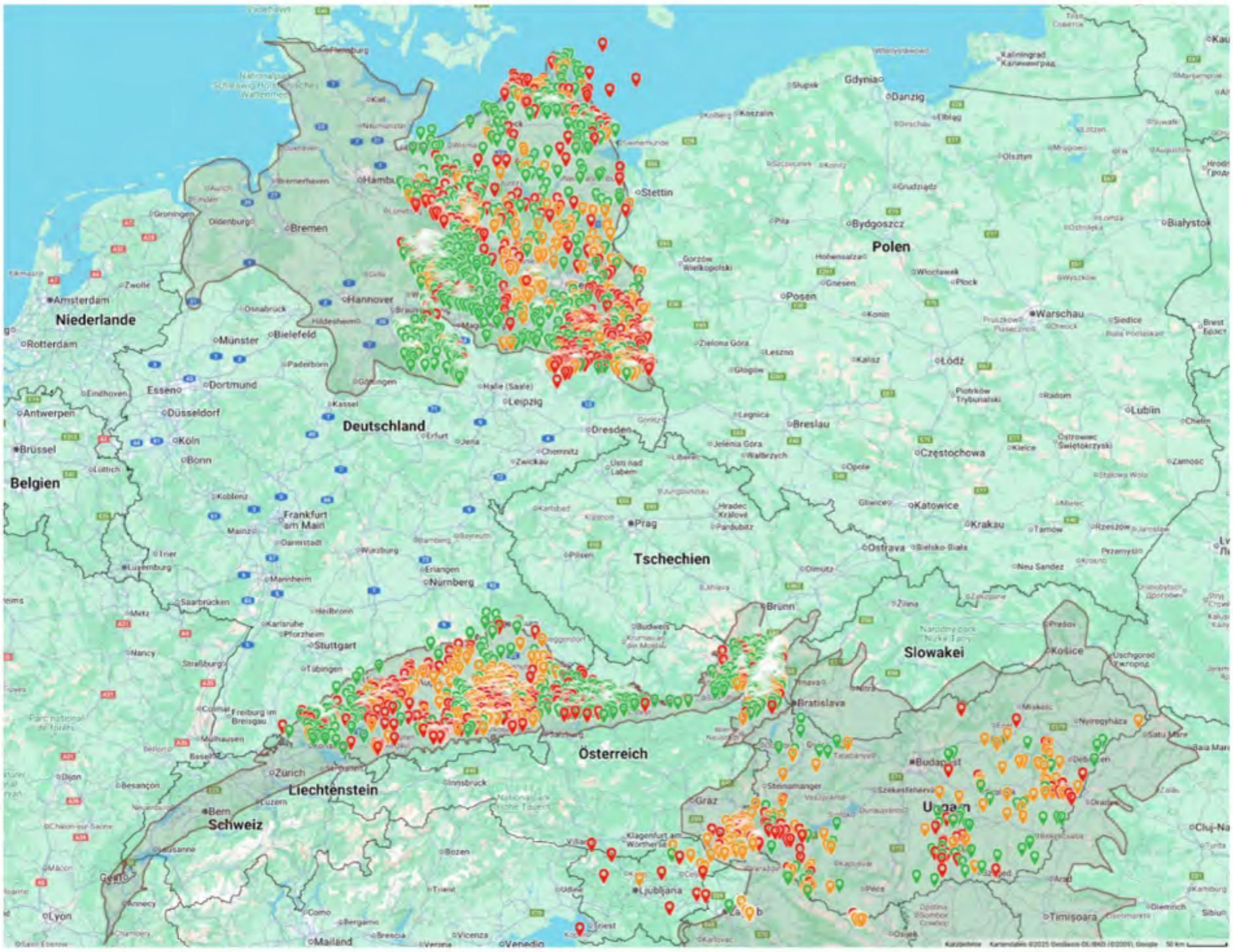


Figure 111: Repurpose potential in central Europe in the countries Germany, Austria, Hungary, Slovenia and Croatia for DBHE.Green flags represent suitable wells, orange flags show suitable, but uncertain wells and red flags display non-suited wells. The grey areas represent the outlines of the sedimentary basins (North German Basin, Molasse, Vienna Basin and Pannonian Basin).

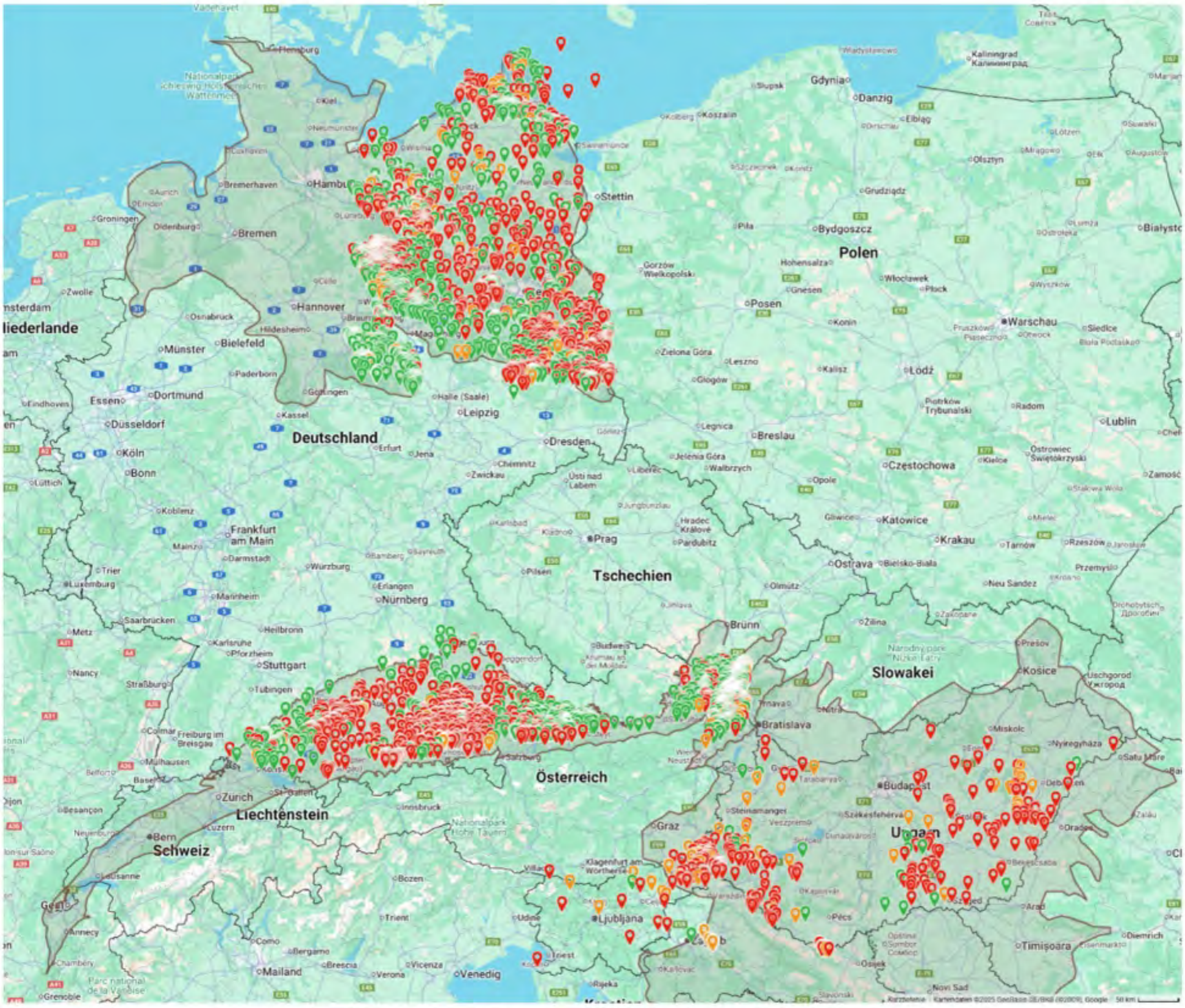


Figure 112: Repurpose potential in central Europe in the countries Germany, Austria, Hungary, Slovenia and Croatia for BTES. Green flags represent suitable wells, orange flags show suitable, but uncertain wells and red flags display non-suited wells. The grey areas represent the outlines of the sedimentary basins (North German Basin, Molasse, Vienna Basin and Pannonian Basin).

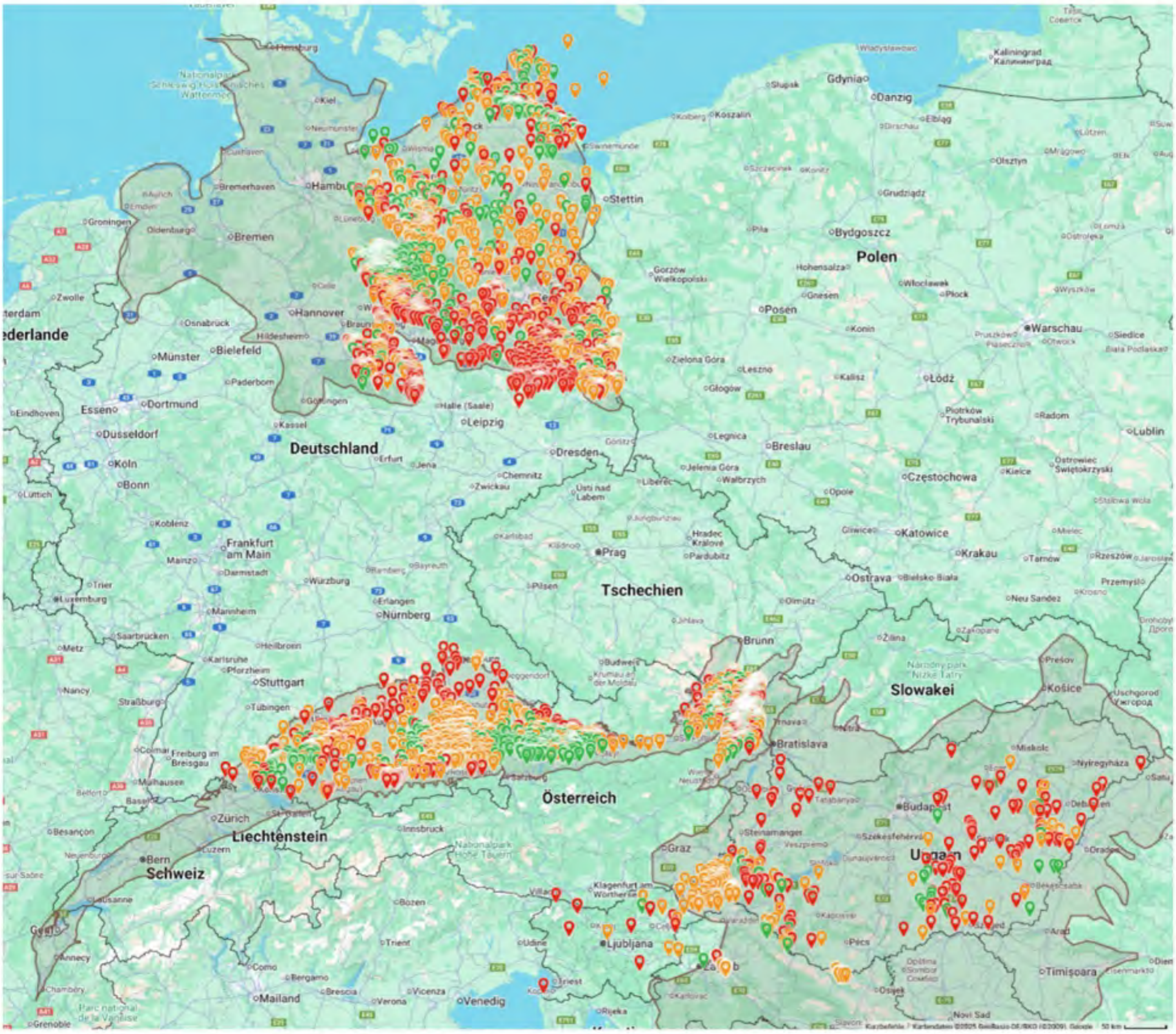


Figure 113: Repurpose potential in central Europe in the countries Germany, Austria, Hungary, Slovenia and Croatia for HE. Green flags represent suitable wells, orange flags show suitable, but uncertain wells and red flags display non-suited wells. The grey areas represent the outlines of the sedimentary basins (North German Basin, Molasse, Vienna Basin and Pannonian Basin).

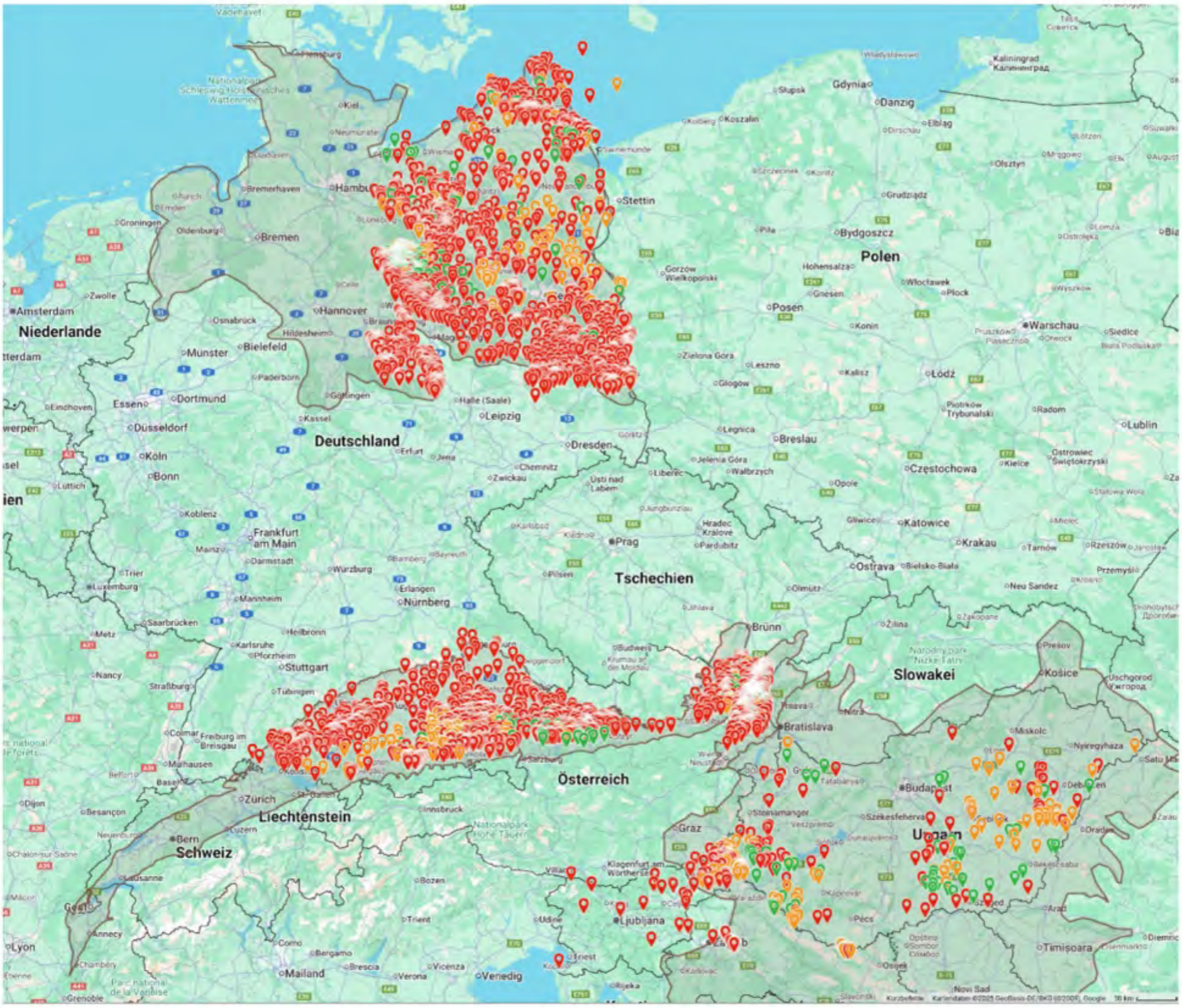
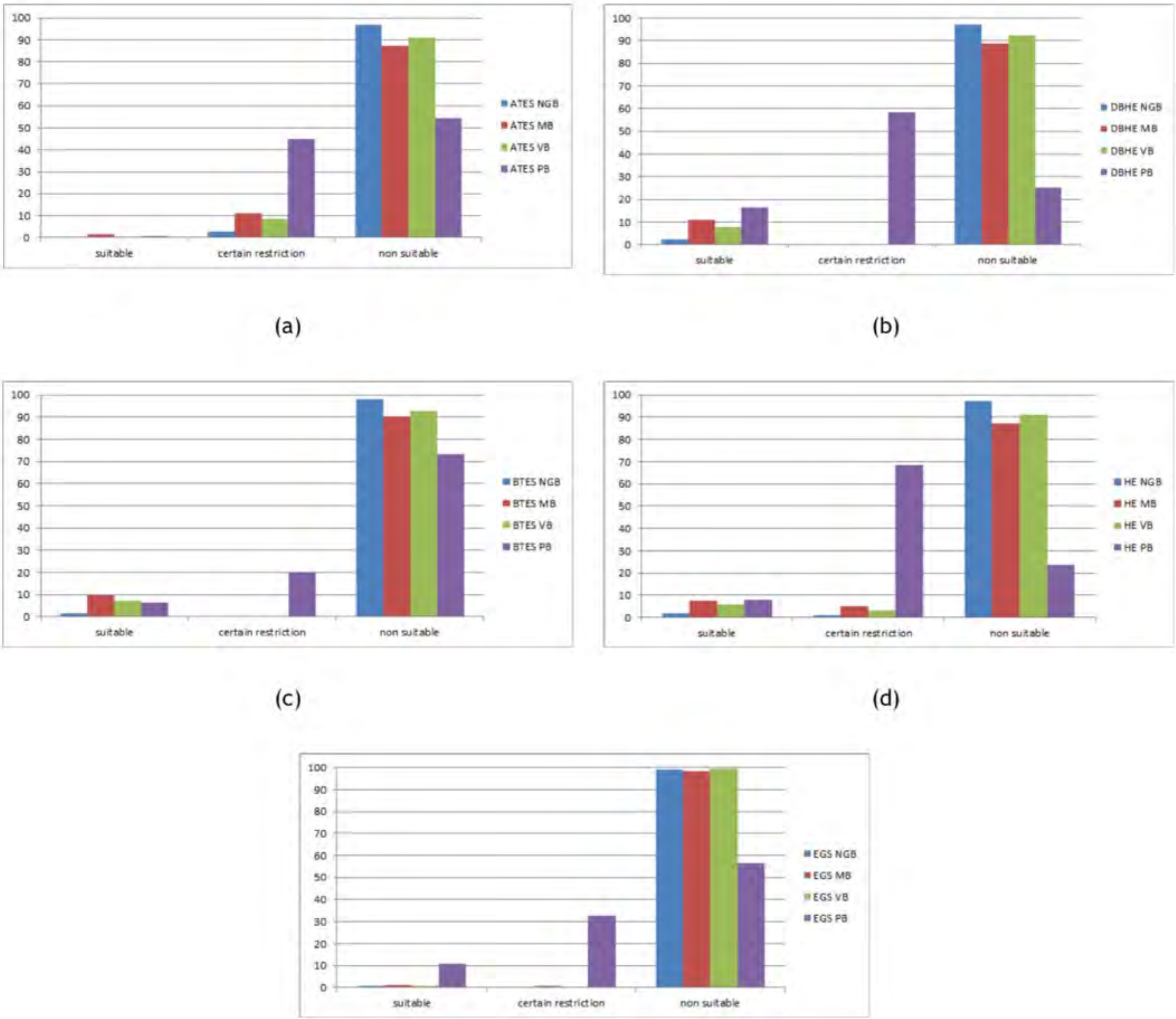


Figure 114: Repurpose potential in central Europe in the countries Germany, Austria, Hungary, Slovenia and Croatia for EGS. Green flags represent suitable wells, orange flags show suitable, but uncertain wells and red flags display non-suited wells. The grey areas represent the outlines of the sedimentary basins (North German Basin, Molasse, Vienna Basin and Pannonian Basin).

In Table 50 the percentages of wells suitable for certain geothermal reuse applications are listed, and in Figure 115 the percentages of wells are plotted per geothermal method and basin as bar charts. The diversity of input datasets between the countries has to be taken into account when comparing the potential. Many differences are based on different approaches of the database content and the query. That is based on regulations concerning data availability and publication rights (e.g., pre-selection of wells due to economic interests or no well status due to company interests). The Croatian and Hungarian well datasets were pre-selected for the TRANSGEO database due to pre-studies. Therefore the total number of available wells for the study is smaller than the German and Austrian well datasets, which include a larger number of wells, but only with basic information as location, depth or age. As the recent wells status record is not available to the public in Austria and the North German Basin datasets are missing important information, the authors chose to filter out wells drilled before 1990 for the Austrian and the North German Basin dataset, based on the consideration that the average lifespan of an oil and gas well is approximately 30 to 40 years (Planète Énergies, 2015; IOGP, 2018; OGA, 2018).

Wells percentage	North German Basin					Molasse Basin				
	ATES	DBHE	BTES	HE	EGS	ATES	DBHE	BTES	HE	EGS
suitable	0.5	2.4	1.7	1.7	0.7	1.5	11.0	9.6	7.5	1.1
uncertain	2.9	0.4	0.1	1.1	0.3	11.3	0.3	0.0	5.3	0.8
not suitable	96.6	97.2	98.2	97.2	99.0	87.2	88.7	90.4	87.2	98.2
	Vienna Basin					Pannonian Basin				
	ATES	DBHE	BTES	HE	EGS	ATES	DBHE	BTES	HE	EGS
suitable	0.4	7.6	7.0	5.7	0.6	0.7	16.6	6.3	8.0	10.8
uncertain	8.6	0.2	0.2	3.1	0.1	45.0	58.2	20.3	68.5	32.6
not suitable	91.1	92.2	92.8	91.2	99.3	54.3	25.2	73.3	23.5	56.5

Table 50: Percentages of wells suitable, uncertain and unsuitable for reuse per basin for the five different geothermal technologies. The most suitable technology of every basin has been highlighted in green, which is DBHE.



(e)

Figure 115: Percentages of suitable wells, wells with certain restrictions and non suitable wells for the geothermal application ATES (a), DBHE (b), BTES (c), HE (d) and EGS (e) in the North German Basin (NGB), Molasse Basin (MB), Vienna Basin (VB) and the Pannonian Basin (PB).

The most promising application for well reuse throughout the investigated area of Central Europe is the closed loop system of Deep Borehole Heat Exchangers (DBHE). For theMolasse and for the Pannonian Basin, DBHE well selection results show percentage values from 11- 17% of wells suitable for reuse, the Vienna and the North German Basin show lower values between 2.4 - 7.6% of the total well inventory.

Hydrothermal Energy (HE) and Borehole Thermal Energy Storage (BTES) result in similar numbers for all basins with suitable wells, in the range of 6-10% except the North German Basin (1.7%). In contrast, HE classifies many wells for further investigation, especially in the Pannonian Basin (69%), whereas BTES does not, except in the Pannonian Basin (20%).

Aquifer Thermal Energy Storage (ATES) shows fewer suitable wells with a range of 0.4 and 0.7% in the Vienna and Pannonian and North German Basin and up to 1.5% in the Molasse Basin, and higher percentages for reuse with uncertainties (yellow category) with 8.6% in the Vienna Basin and up to 45% in the Pannonian Basin.

EGS has the largest number of unsuitable wells with a range of 57% in the Pannonian Basin to 99.3% in the Vienna Basin, but the distinct well selection allows for faster screening of individual projects. However, existing wells could be reused as microseismic monitoring wells for this technology.

9 References

Árgyelán, G. B., Zadravecz, C., Nyiri, D. and Magyar, I. 2026. Seismic stratigraphic units, palaeogeography and their effect on hydrocarbon distribution in the upper Neogene of the Pannonian Basin. Geological Society, London, Special Publications, 554 (1), SP554-2024-2052. DOI: doi:10.1144/SP554-2024-52.

Bagoly-Árgyelán, G., Zadravecz, C., Nyíri, D. and Magyar, I. 2024. Seismic stratigraphic units, palaeogeography, and their effect on hydrocarbon distribution in the upper Neogene of the Pannonian Basin', Geological Society, London, Special Publications, 554, pp. 52. https://doi.org/10.1144/SP554-2024-52.

Bérczi, I. 1988. Preliminary sedimentological investigation of a Neogene depression in the Great Hungarian Plain. In: Royden, L.H. and Horváth, F. (eds) The Pannonian Basin: A Study in Basin Evolution. AAPG, Memoirs, 45, 107–116, https://doi.org/10.1306/M45474C10.

Bérczi, I. and Phillips, R.L. 1985. Process and depositional environments within Neogene deltaic-lacustrine sediments, Pannonian Basin, Southeast Hungary. Geophysical Transactions, 31, 55-74.

Bundesamt für Vermessung, Geoinformation und Kartographie (BVEG) 2024. BVEG Jahresbericht 2024. Retrieved from https://jahresbericht.bveg.de/ (accessed 02.07.2025).

Bundesministerium für Finanzen. 2025. Österreichisches Montan-Handbuch 2024. Wien (in German).

Cvetković, M., Matoš, B., Rukavina, D., Kolenković Močilac, I., Saftić, B., Baketarić, T., Baketarić, M., Vuić, I., Stopar, A., Jarić, A. and Paškov, T. 2019. Geoenergy potential of the Croatian part of the Pannonian Basin: insights from the reconstruction of the pre-Neogene basement unconformity', Journal of Maps, 15(2), pp. 651-661. doi: 10.1080/17445647.2019.164505.

Decker, K., Peresson, H. and Hinsch, R. 2005. Active tectonics and Quaternary basin formation along the Vienna Basin Transform Fault. Quaternary Science Reviews 24, 305-320.

Feldrappe, H., Obst, K. and Wolfgramm, M. 2008. Mesozoic sandstone aquifers of the North German Basin and their potential for geothermal utilization. Zeitschrift für geologische Wissenschaften, 36, 199-222.

Fejes, Z. 2021. Examination of the geothermal and hydrogeological conditions of the Tokaj Hills, PhD dissertation, Miskolc (in Hungarian).

Horváth, F., Musitz, B., Balázs, A., Végh, A., Uhrin, A., Nádor, A., Koroknai, B., Pap, N., Tóth, T. and Wórum, G. 2015. Evolution of the Pannonian Basin and its geothermal resources, Geothermics, 53, pp. 328-352. doi: 10.1016/j.geothermics.2014.07.009.

International Association of Oil & Gas Producers (IOGP). 2018. *Europe E&P Trends Report 2018*. Retrieved from https://www.iogp.org/wp-content/uploads/2019/01/EP-Trends-Report.pdf#:~:text=the%20Emlichheim%20oil%20field%20on,for%20domestic%20production%20can%20be (accessed 24.09.2025).

Juhász, G., Pogácsás, G., Magyar, I. and Vakarcs, G. 2006. Integrated stratigraphy and sedimentary evolution of the Late Neogene sediments of the Hungarian Plain, Pannonian Basin', Földtani Közlöny, 136, pp. 51-86 (in Hungarian with English abstract).

Kalmár, D., Hetényi, G., Balázs, A., Bondár, I. and AlpArray Working Group. 2021. Crustal thinning from orogen to back-arc basin: the structure of the Pannonian Basin region revealed by P-to-S converted seismic waves. Journal of Geophysical Research: Solid Earth, 126, e2020JB021309, https://doi.org/10.1029/2020JB021309.

Kalmár, D., Petrescu, L., Stipčević, J., Balázs, A. and Kovács, J.I. 2023. Lithospheric structure of the circum-pannonian region imaged by S-to-P receiver functions. Geochemistry, Geophysics, Geosystems, 24, e2023GC010937, https://doi.org/10.1029/2023GC010937.

Kreutzer, N. 1993. Die ÖMV-Gas- und Öllagerstätten der Nieder- und Oberösterreichischen Molassezone. In Erdöl und Erdgas in Österreich, eds. F. Brix and O. Schultz. Wien: NHM Wien - Fa. Berger Horn, 455-68. (in German).

Lenkey, L., Dövényi, P., Horváth, F. and Cloetingh, S.A.P.L. 2002. Geothermics of the Pannonian Basin and its bearing on neotectonic. In: Cloetingh, S., Horváth, F., Bada, G. and Lankreijer, A. (eds) Neotectonics and Surface Processes: the Pannonian Basin and Alpine/Carpathians System. European Geosciences Union, Stephan Mueller Special Publications, 3, 29-40.

Mádlné, Dr. and Szőnyi, J. (ed) 2008. The international and domestic situation of geothermal energy utilization, its future prospects in Hungary - Recommendations for government measures to promote utilization and background study, Budapest, (in Hungarian).

Magyar, I., Geary, D.H. and Müller, P. 1999. Paleogeographic evolution of the Late Miocene Lake Pannon in Central Europe. Palaeogeography, Palaeoclimatology, Palaeoecology, 147, 151-167, https://doi.org/10.1016/S0031-0182(98)00155-2.

Malvić, T. and Velić, J. 2011. Neogene tectonics in the Croatian part of the Pannonian Basin and reflectance in hydrocarbon accumulationsNew Frontiers in Tectonic Research: At the Midst of Plate Convergence. Rijeka: IntechOpen, 215-238. https://doi.org/10.5772/21270.

Mattick, R.E., Rumpler, J., Ujfalusy, A., Szanyi, B. and Nagy, I. 1994. Sequence Stratigraphy of the Békés Basin', in Teleki, P.G., Mattick, R.E. & Kókai, J. (eds.) Basin Analysis in Petroleum Exploration. Dordrecht: Springer. pp. 39-65. https://doi.org/10.1007/978-94-011-0954-3_2.

Mielke, P., Bauer, D., Homuth, S., Götz, A. E. and Sass I. 2014. Thermal effect of a borehole thermal energy store on the subsurface Geothermal Energy 2 (1) (2014) 5.

Nafta Geoterm d.o.o. 2012. Report on the ecological remediation of mining facilities and equipment in the period 1999-2011. Nafta Geoterm d.o.o.,Ljubljana, eko_san_vrtin_1999_2011.pdf

Oil & Gas Authority (OGA). 2018. Wells Insight Report 2018. Retrieved from https://www.nstauthority.co.uk/media/5107/oga_wells_insight_report_2018.pdf (accessed 24.09.2025).

Phillips, R.L., Révész, I. and Bérczi, I. 1994. Lower Pannonian deltaic-lacustrine processes and sedimentation, Békés Basin. In: Teleki, P.G., Mattick, R. and Kókay, J. (eds) Basin Analysis in Petroleum

Exploration. A Case Study from the Békés Basin, Hungary. Kluwer, Dordrecht, 67-82, https://doi.org/10.1007/978-94-011-0954-3_3.

Planète Énergies. 2015. The life cycle of oil and gas fields. Retrieved July 10, 2025, from Planète Énergies website: https://www.planete-energies.com/en/media/article/life-cycle-oil-and-gas-fields (accessed 24.10.2025).

Prelogović, E., Saftić, B., Kuk, V., Velić, J., Dragaš, M. and Lučić, D. 1998. Tectonic activity in the Croatian part of the Pannonian Basin, Tectonophysics, 297, pp. 283-293, https://doi.org/10.1016/S0040-1951(98)00173-5.

Révész, I. 1980. Az Algyö-2 telep földtani felépítése, üledékföldtani heterogenitása és ősföldrajzi viszonyai [The geological structure, sedimentological heterogeneity and palaeogeographic conditions of the Algyő-2 reservoir (Algyő Field)]', Földtani Közlöny, 110 (3-4), pp. 512-539.

Royden, L.H. and Horváth, F. (eds.) 1988. The Pannonian Basin: A Study in Basin Evolution. AAPG Memoir 45. Tulsa, OK: American Association of Petroleum Geologists. DOI: 10.1306/M45474.

Rman, N., Lapanje, A., Rajver, D., Vengust, A., Meglič, P. and Prestor, J. 2019. *Geothermal energy in eastern Slovenia*. Ljubljana: Geološki zavod Slovenije, https://dtp.interreg-danube.eu, e4f438e9de0b90408d4d163b0af82e7402458885.pdf.

Sachsenhofer, R. F., Misch, D., Rainer, T., Rupprecht, B. J. and Siedl, W. 2024. The Vienna Basin: Petroleum systems, storage and geothermal potential. In G. C. Tari et al. (Eds.), *The Miocene Extensional Pannonian Superbasin, Volume 2: Geoenergy Exploration*. Geological Society, London, Special Publications, Vol. 555, https://doi.org/10.1144/SP555-2023-205.

Salcher, B. C., Meurers, B., Decker, K., Hölzel, M. and Wagreich, M. 2012. Strike-slip tectonics and Quaternary basin formation along the Vienna Basin fault system inferred from Bouguer gravity derivatives. Tectonics 31(3).

Šujan, M., Rybár, S., Kováč, M., Bielik, M., Minár, J., Plašienka, D., Nováková, P. and Kotulová, J. 2021. The polyphase rifting and inversion of the Danube Basin revised, Global and Planetary Change, 196, 103375. https://doi.org/10.1016/j.gloplacha.2020.103375.

Subová, V., Rybár, S., Šarinová, K., Hudáčková, N., Jamrich, M., Sliva, Ľ. and Hlavatý, I. 2022. Evolution of the lower Badenian depositional system in the East Slovakian Basin: implications for reservoir rock potential. Geologica Carpathica, 73, 319-352, https://doi.org/10.31577/GeolCarp.73.4.3.

Stadtwerke München. 2025. Current ambitious new geothermal projects in Munich that include newly drilled ATES wells. Retrieved from Stadtwerke München website: https://www.swm.de/(accessed 1.09. 2025).

Sztanó, O., Szafián, P., Magyar, I., Horányi, A., Bada, G., Hughes, D.W. and Wallis, R.J. 2013. Aggradation and progradation controlled clinothems and deep-water sand delivery model in the Neogene Lake Pannon, Makó Trough, Pannonian Basin, SE Hungary. Global and Planetary Change, 103, 149-167, https://doi.org/10.1016/j.gloplacha.2012.05.026.

Sztanó, O., Balázs, A., Bartha, I. R., Ben Mahrez, H., Horányi, A., Kovács, Á., Šujan, M., Tőkés, L., Törő, B., Vallner, F., Varga, G. and Magyar, I. 2025. Sedimentology, lithostratigraphy, palaeogeography and water-level changes in a lacustrine basin: the depositional model of Lake Pannon, Geological Society, London, Special Publications, 554. https://doi.org/10.1144/SP554-2024-72.

Tari, G., Bada, G., Boote, D.R.D., Krézsek, C.S., Koroknai, B., Kovács, G. and Tóth, T. 2023. The Pannonian Super Basin: a brief overview. AAPG Bulletin, 107, 1391-1417, https://doi.org/10.1306/02172322098.

TRANSGEO Deliverable, D.1.1.6 Engineering workflows for retrofitting abandoned wells.Retrieved from https://www.interreg-central.eu/wp-content/uploads/2025/02/TRANSGEO-D1.1.6-Engineering-Workflows-FINAL-December-2024.pdf. (accessed 30.10.2025)

TRANSGEO Deliverable, D.1.3.1 Criteria catalogue for well repurposing (in preparation).

TRANSGEO Deliverable, D.1.4.1 Beta version of web-based IT tool for well repurposing, 11.2024.

TRANSGEO Deliverable, D.1.4.3 IT Tool, https://transgeo.eu/, 10.2025.

TRANSGEO Deliverables, D.2.1.1-D.2.1.4 Regional databases of the Pannonian Basin, Vienna Basin, Molasse Basin, and North German Basin, 11.2024.

TRANSGEO Deliverable, D.3.2.1 Transnational strategy for a sustainable development of Central European regions 10.2025 (in preparation).

Velić, J., Malvić, T., Cvetković, M. and Vrbanac, B. 2012. Reservoir geology, hydrocarbon reserves and production in the Croatian part of the Pannonian Basin System', Geologia Croatica, 65(1), pp. 91–101. https://doi.org/10.4154/GC.2012.07.

Vlček, T., Šarinová, K., Kováčová, M., Sztanó, O. and Šujan, M. 2024. Sources and composition of organic matter as a tool for understanding the complex variation in paleoenvironments and the connectivity of an epicontinental basin: The Miocene in the northern Pannonian Basin. Sedimentary Geology, 470, 106721, https://doi.org/10.1016/j.sedgeo.2024.106721.

Welsch, B., Göllner-Völker, L., Schulte D. O., Bär, K., Sass, I. and Schebek, L. 2018. Environmental and economic assessment of borehole thermal energy storage in district heating systems. Applied Energy, 216, 73-90.

Wessely, G. 2006. Geologie der österreichischen Bundesländer: Niederösterreich (Vol. 4). Wien: Geologische Bundesanstalt (in German).