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Application of the Play Type Approach for the Federal Exploration Initiative in Germany – Criteria Catalogue and Case Studies

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ABSTRACT

The modernization of the heating supply received recently primary attention in German politics to reach climate protection goals. Geothermal energy plays a primary role towards the decarbonization of the heating market and the German government has started the geothermal initiative to accelerate a nationwide geothermal rollout by funding geothermal exploration of prospective sites. Such an approach raises the question of how to define prospective to streamline governmental funding of exploration into successful geothermal projects. As a solution, two distinguished research projects accompany this politically induced and societally required geothermal rollout: The projects WärmeGut to lead the geothermal data campaign, and the project Warm-Up to guide through the geothermal exploration campaign. This article focusses on the exploration campaign, classifying the potential of geothermal sites by a play-based criteria catalogue and describing exploration case studies, which are selected by this criteria catalogue. The case studies exemplify how a selective geothermal potential can be progressed to prosperous geothermal field development. The one case study is from the North German Basin, where a successful deep geothermal well has been drilled into a facies-controlled sandstone reservoir. The other case study is from the Upper Rhine Graben, where seismic exploration with following target selection in a fracture-controlled reservoir has been successfully conducted under tight time restrictions. While these case studies are side specific exploration examples, the approach of the German exploration campaign might be adoptable to other countries.

1 INTRODUCTION

In 2022, the former Federal Ministry of Economic Affairs and Climate Action (BMWK) has launched a so-called geothermal campaign in Germany, which included the federal exploration campaign and the federal data campaign. While the data campaign focuses on collecting, harmonizing and unifying heterogenous geothermal information data from the federal states of Germany to produce nation-wide consistent suitability and potential maps for shallow geothermal technologies, the exploration campaign aims to support deep geothermal development, particularly of hydrothermal resources towards 10 TWh heat production per year by 2030. Two dedicated research projects were initiated in 2023 to accompany these campaigns and accelerate geothermal development in Germany: (I) the project WärmeGut, which supports the national data campaign by expanding GeotIS, the Geothermal Information System of Germany (www.geotis.de), in consultation with the 16 individual State Geological Surveys and coordinated by the LIAG Institute for Applied Geophysics (Schintgen et al., this volume; Ravidà et al., 2024; 2025; this volume), and (II) the project Warm-Up, framed within the national exploration campaign and coordinated by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR). In 2025, the recent Federal Ministry of Economic Affairs and Energy (BMWE) extended the geothermal exploration program by the incorporation of a broader range of geothermal technologies (not only hydrothermal but also petrothermal technologies) naming it now exploration initiative. This contribution focusses on the exploration campaign and highlights selected projects therein, describing the process of its implementation and application.

The exploration campaign pursues the goal of selecting up to 100 projects eligible for federal funding to help achieving the above-mentioned ambitious development target of 10 TWh heat production per year by 2030. Within this framework, the research project Warm-Up has been initiated to develop a scientifically-grounded criteria catalogue that streamlines the selection process of favorable exploration sites. *"Favorability"*, in this funding context, refers to identifiable geothermal prospectivity combined with a significant exploration risk due to lack of data or understudied region. The identification of such favorable exploration sites can be managed by the application of the well-known geothermal play concept, that scrutinizes the geothermal-technical and the

societal-technical potential in three different resolution scales (Moeck et al., 2020). Before the play-based criteria catalog for favorable geothermal development settings and its application in two case studies is described in the following chapters, the next chapter addresses and clarifies the different terms of *"potential"*.

2 DEFINITION OF GEOTHERMAL POTENTIAL BY A PLAY-BASED APPROACH

In general, geothermal potential describes or quantifies the likelihood of recovering geothermal energy from the subsurface. However, when analyzing the potential for geothermal development, it should be clearly defined what kind of potential is addressed. Rybach (2015) subdivides the geothermal potential into the three hierarchical categories, which are in this study related to the geothermal play assessment pyramids (Moeck et al., 2020):

"Theoretical geothermal potential" describes the theoretically usable heat in the subsurface, namely the heat in place. It is defined by physical and spatial limits (i.e. heat a defined crustal volume). The theoretical geothermal potential is dependent from the heat flow and the dominating heat transport mechanism in the play type, as these processes determine the geothermal gradient which can be used for heat in place calculations in both scales, the geosystem scale (i.e. a defined crustal volume) (Fig. 1, level 1) and the play scale (i.e. a certain geological formation) (Fig. 1, level 2).

The heat in place is however not the same as recoverable geothermal heat. Therefore, the technical geothermal potential needs to be defined.

"Technical geothermal potential" considers the geothermal technology, that shall be used to recover the heat in place. This can be any kind of available geothermal technology for direct or indirect use, including collector systems, borehole heat exchangers and well doublets on various scales (small or large scale, shallow or deep, single well or borehole field). The technical geothermal potential considers also the geological conditions which are required for the respective technology (e.g. the existence of aquifer systems for hydrothermal direct use in a well doublet). Additionally, regulatory and legal restrictions influence the technical geothermal potential (Fig. 2, level 3).

Moreover, the consideration of the technical geothermal potential requires a societal demand, especially if heating and cooling supply is intended, which is often the case in conduction dominated plays (Moeck et al., 2019; Moeck et al. 2020). Therefore, the technical potential analysis requires the play level 2 of the geological-technical focus pyramid and play level 3 of the societal-technical focus pyramid.

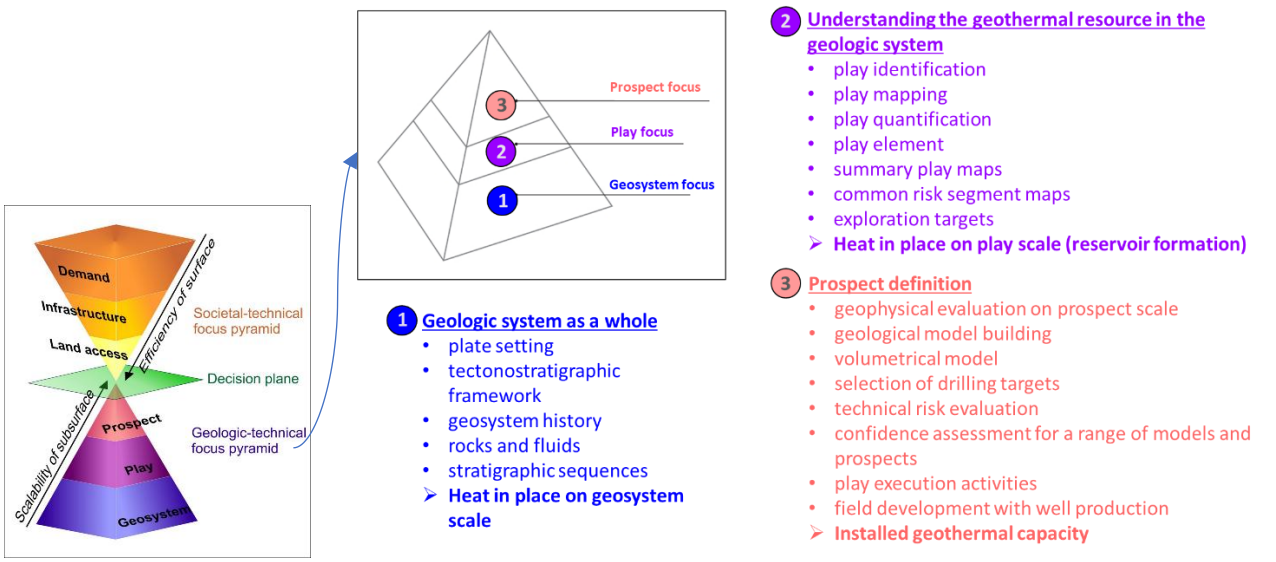


Figure 1. Play-based geothermal potential analysis: Subsurface conditions presented by the geological-technical focus pyramid as criteria for the assessment of the theoretical, technical and economic geothermal potential (extended after Moeck et al., 2020).

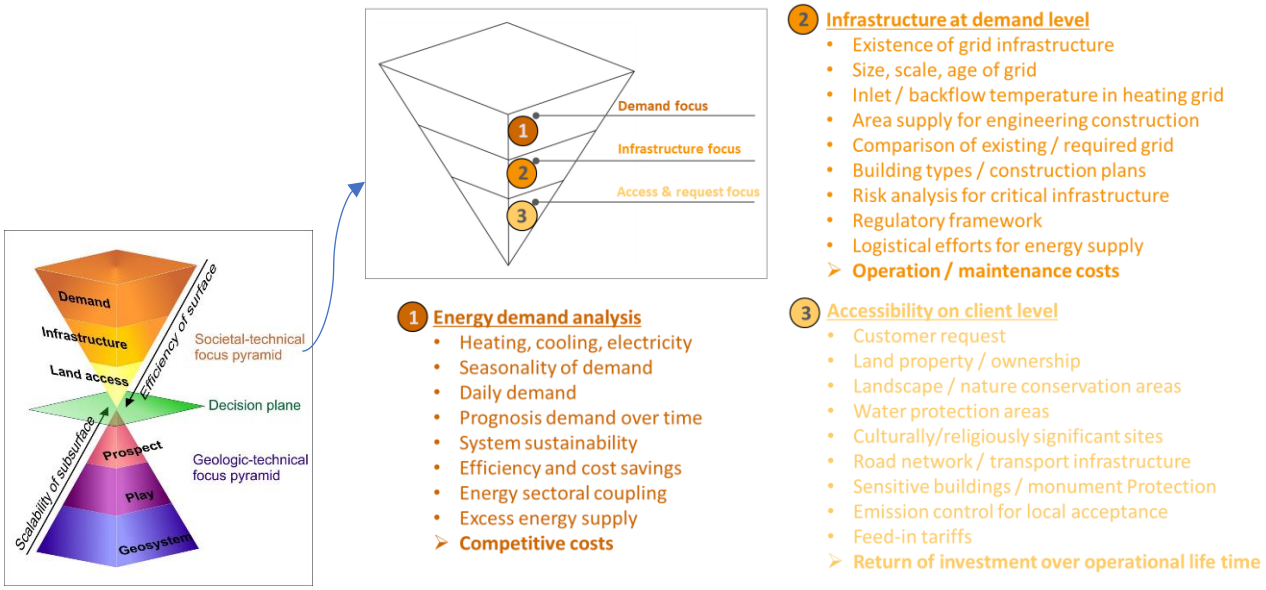


Figure 2. Play-based geothermal potential analysis: surface conditions represented by the societal-technical focus pyramid as criteria for the assessment of the theoretical, technical and economic geothermal potential (extended after Moeck et al., 2020).

Due to the substantial heat energy demand in Germany, the heat-demand analysis is typically carried out first (Fig. 2, level 2) to determine the geothermal demand or request potential, and to select the most suitable geothermal technology under economic considerations to meet the energy demand at a defined locality.

"Economic geothermal potential" is the part of the technical geothermal potential, which considers all play levels of the societal-technical focus pyramid. Depending on the focus level, the energy demand analysis results into competitiveness of the selected geothermal technology on prospect level (Fig. 1, level 3 and Fig. 2, level 1), while the infrastructure analysis results into the operational and maintenance costs for energy supply (Fig. 2, level 2) and the accessibility analysis results into the likelihood of return of investment over the operational life time of a geothermal project (Fig. 2, level 3).

3 EXPLORATION PLAY-BASED CRITERIA CATALOGUE

The exploration criteria catalogue is subdivided into four levels and helps to identify hydrothermal project sites with significant heat demand and geothermal potential. As such, the criteria catalogue follows the play type approach, which analyses the societal-technical potential at surface and the geological-technical potential in the subsurface (Moeck et al., 2020). The workflow of the evaluation process based on this criteria catalog is structured into four steps (Fig. 3). The first step evaluates the in-principal eligibility: only under-explored regions or sites qualify for the funding of the federal exploration initiative. Otherwise, a different funding program applies (i.e. the federal support program for efficient heating grids). The second step assesses the societal-technical potential in line with the geothermal play concept (Fig. 2), with the result indicating whether heat demand is present and whether geothermal energy is desired by the community or industry. In a third step, the geological-technical evaluation – also based on the play concepts (Fig. 1) – determines, whether a reservoir exists and whether geothermal energy recovery is likely possible. In the fourth step, the appropriate exploration methods are decided.

To test this evaluation approach, the economic geothermal potential of medium-deep to deep hydrothermal well doublet technology is qualitatively scrutinized for Northern Germany using play-based criteria catalogue. Database, hosted in the publicly accessible German Geothermal Information System GeotIS, was utilized to identify and classify hydrothermal reservoirs in considerably high heat-demand areas in a depth interval of 400–5,000 m. Criteria as heat demand, infrastructure and land access were compiled for the societal-technical part, and reservoir quality based on several parameters such as porosity, permeability, temperature, reservoir thickness and extent were collated for the geological-technical part. A geothermal potential data sheet is developed and refined to classify medium- to large-scale cities using ArcGIS for data integration and optimal geothermal energy utilization based on the overlap of different favorable conditions (Fig. 4). As it turned out, 70% of the medium- (between 20.000 and 100.000 residents) and large- (larger than 100.000 residents) scale cities

are underlain by exploitable hydrothermal reservoirs. The geological-technical potential for Northern Germany is taken from Franz et al. (2018), who defines a high geothermal reservoir potential by more than 20 m reservoir thickness of reservoir quality parameters of at least 500 milli-Darcy permeability and 10 % effective porosity. A moderate geothermal reservoir potential is given by 10 to 20 m thickness of such reservoir quality, and a low geothermal reservoir quality corresponds to less than 10 m of such a reservoir quality.

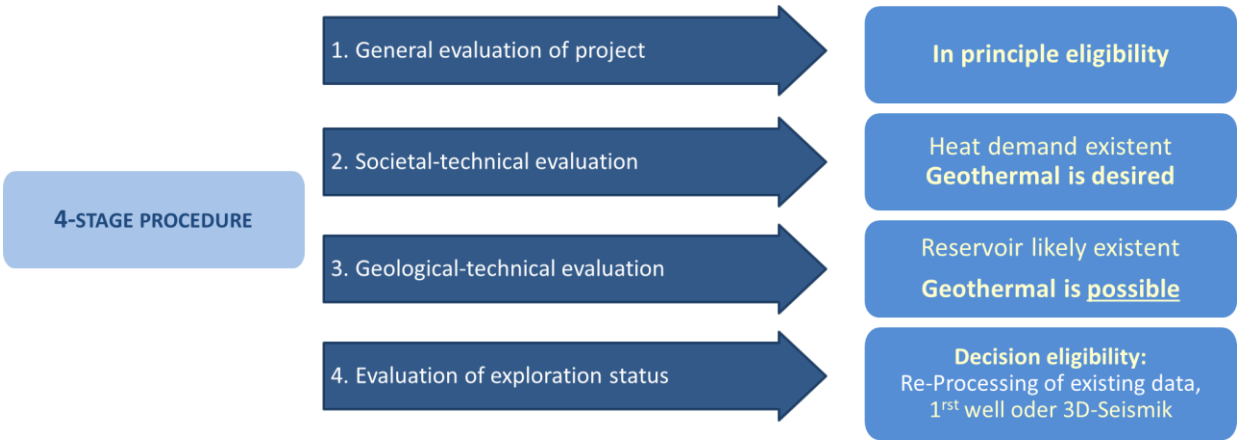


Figure 3. Workflow of play-based criteria catalogue to evaluate geothermal project sites for exploration.

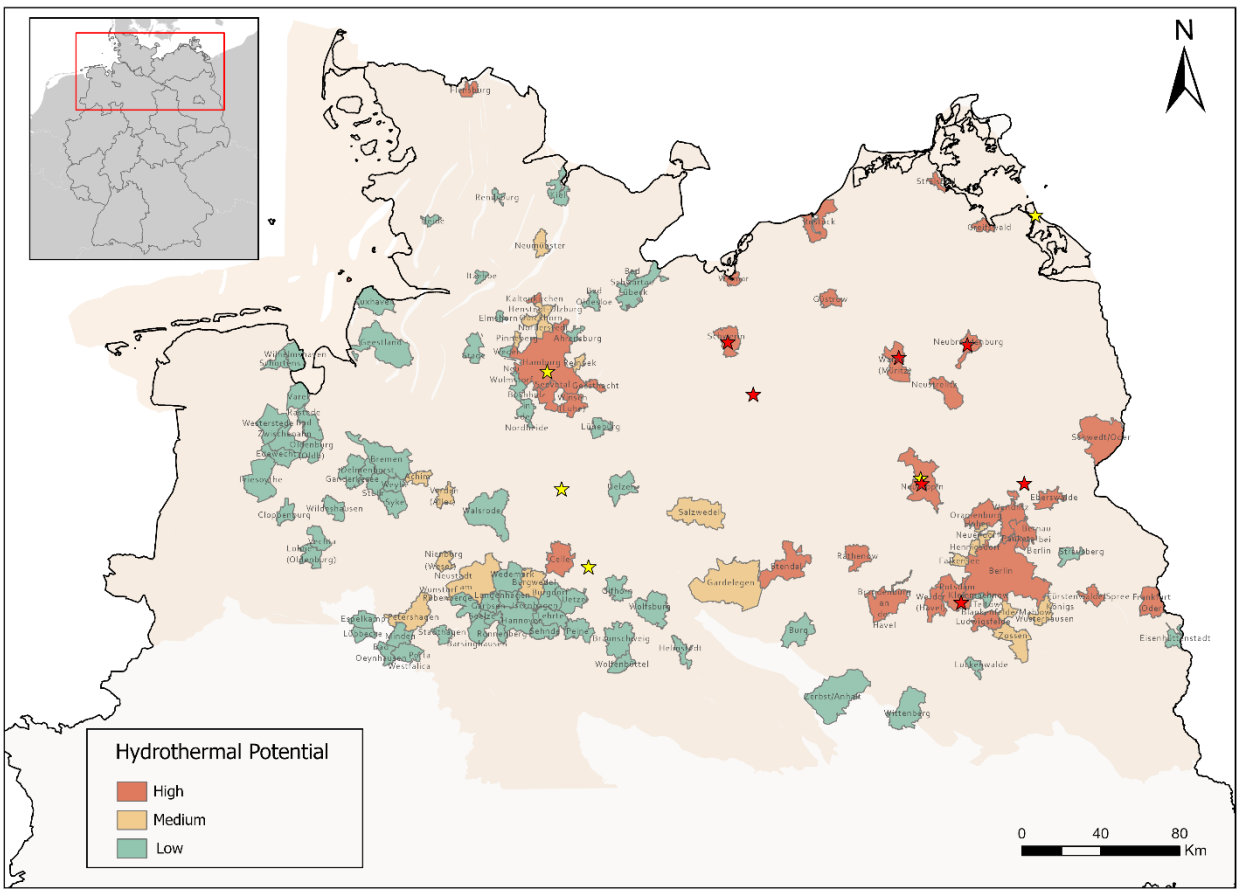


Figure 4. Map of Northern Germany, illustrating all medium scale (20k to 100k residents) cities and large scale (> 100k residents) cities that are underlain by potential geothermal reservoirs for hydrothermal well doublet use. Yellow star: geothermal system under construction, red star: geothermal system in operation.

The co-visualization with geothermal systems in operation indicates that some geothermal plants are located in areas of lower demand beyond medium-sized cities. At these locations, district heating grids already exist, reducing the CAPEX for a geothermal project. Even with a relatively small demand, a geothermal well-doublet system can be economically viable, provided the district heating grid is already installed and the settlement structure is rather clustered than widespread.

This play-based criteria catalogue has been applied for first operational exploration projects, which are now ongoing in different play types in Germany. Two exploration case studies are here presented: the project Dekapalatin in the Upper Rhine Graben in an extensional terrain play with convection dominated heat transport (CV3 type) (Moeck, 2014) and the project DemoCELL in the North German Basin, located in an intracratonal basin play with conduction dominated heat transport (CD1 type) (Moeck, 2014).

4 DEMOCELL - CASE STUDY EXPLORATION DRILLING IN THE NORTH GERMAN BASIN

DemoCELL is a joint project of Baker Hughes and the University Göttingen and aims to engineer a development concept for the technical and economic implementation of a demonstration project for deep geothermal energy (in particular medium-deep geothermal energy) in the area of the city Celle, north of Hannover (Fig. 5). For this purpose, a deep geothermal borehole is drilled down to 2.500 m to explore, test, sample and characterize the Upper Triassic Rhaetian sandstone. The drill site is Baker Hughes' Beta test field, which has so far only served Baker Hughes as the license field owner for the technical testing of drilling tools.

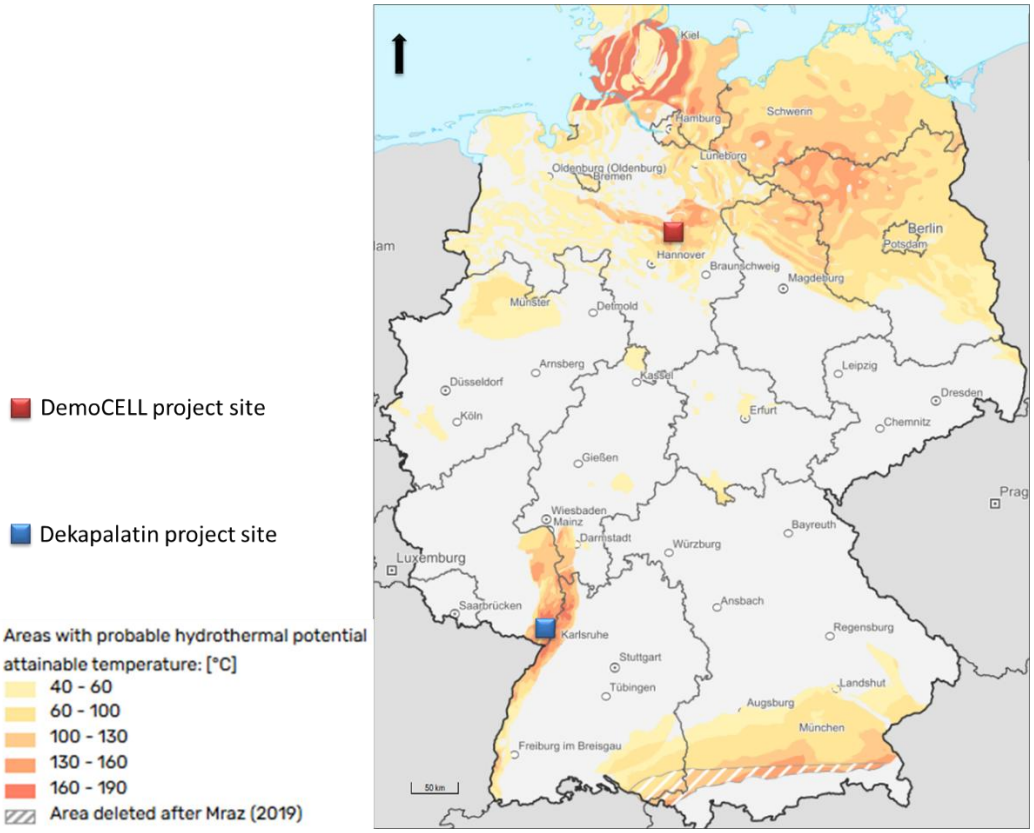


Figure 5. Map of Germany with geothermal plays North German Basin, Upper Rhine Graben and Molasse Basin and their technical geothermal potential for hydrothermal well doublets (modified from GeotIS, 2025).

The well Gt Beta 1j was drilled between March and April 2025, the pumping test was conducted in May 2025. Drilling operation included the recovery of a 100 m core section. The results of coring were extraordinary with core gain of 107 m, more than expected in the challenging geology of interbedded strata consisting of sandstone, heterolith and claystone formations. The reason for this drilling success might have been the application of the Baker Hughes JamBuster™ jam mitigation coring system, that incorporates telescoping inner core barrel sleeves into heavy-duty core barrels to eliminate the effects of core jamming. Concentric inner core barrel sleeves

automatically telescope if a core becomes jammed in the core barrel, allowing coring to continue without interruption. Consequently, round trips were minimized, and rig time was used efficiently for coring instead of tripping. Effectively, in six days 107 m drill core was recovered from a depth between 2.400 to 2.500 m in a vertical well. The coring system eliminated sample milling and accommodated multiple jams, although the well path transected a highly fractured zone in the claystone formation above the sandstone reservoir. Slanted formation faults and interbedded shales had no negative effects on the core drilling operation. The recovered 107 m core allows a complete sedimentological and biostratigraphic analysis.

The Rhaetian sandstone (44 m net sand) contains a pay zone of around 38 m thickness with a reservoir temperature of about 113°C. Porosity and permeability, determined from core analysis, average approximately 20% and 600 milli-Darcy, respectively. During the pumping test, more than 1,000 m^3 brine was produced at different flow rates. The results confirmed the hydraulic reservoir properties from the core analysis. With this result, the well Gt Beta 1j is the first successful deep geothermal well in the western North German Basin and in Lower Saxony.

The new well data (drill cores and geophysical logs) will be used to perform facial and diagenetic analysis in order to characterize, evaluate and classify the reservoir regionally.

5 DEKAPALATIN - CASE STUDY EXPLORATION SEISMIC IN THE UPPER RHINE GRABEN

The Dekapalatin-Bertha project is a joint project of the municipal partner City of Wörth (Rhine), the industry partners Daimler Truck and EnBW, as well as the scientific partners University of Göttingen, TU Darmstadt, IGEM, and LIAG. The aim of the project is to develop a geothermal site for heat generation through all project phases as a holistic demonstration project in one of the largest geothermal anomalies in Germany. The project is to be implemented as a real-world laboratory at the Wörth am Rhein site (Fig. 5), which forms the center of this thermal anomaly on the Middle Upper Rhine (MOR). For the first time for geothermal development in Germany, a large-scale industrial company with Daimler Truck, an experienced energy provider as EnbW and a municipality with the city of Wörth a. R. are joining forces in the project network to implement market-oriented, systemic but novel working approaches in a real environment, with the aim of providing both comparatively high-calorific process heat of more than 150°C and medium-calorific district heating of 70°- 90°C. As a result, a reservoir of at least 160°C must be explored and developed.

For this purpose, in February 2025 a 3D reflection seismic survey covering about 100 km^2 was carried out in and around the city of Wörth (Rhein) (Fig. 6). The challenge for the survey was the muddy plains of the Rhine River, which reduced the transmission of seismic energy and reflection. In early 2027, and a deep geothermal borehole named Bertha 1 is to be drilled to a maximum depth of about 5,000 m to the base of Buntsandstein. An extensive scientific measurement program including well logging and VSP shall be carried out in the borehole, accompanied by core drilling. With the project, various technologies will be tested and evaluated in real operation as part of an experimental development, for example core drilling and borehole measurement technology for reservoir temperatures >160°C or safe development through integrated thermal-hydraulic-geomechanical-microseismical analyses by the scientific partners.

In addition to the above-mentioned operational work, the project encompasses several research tasks and objectives, carried out by the scientific partners to better understand the causes and variability of the geothermal potential of the sedimentary cover of the MOR. Among these the University Göttingen addresses: (i) The regional-scale sedimentological desktop studies for the identification of potential reservoir formations in the Tertiary and Mesozoic, relevant to the heat transition at MOR, complemented by high-resolution reservoir characterization at the drilling site through scientific logging and drill-core analysis; (ii) Thermal-hydraulic-chemical (THC) modelling on a regional, local and pore scale for play type analysis, clarification of the thermal anomaly at the MOR and reservoir engineering for sustainable duplicate operation (Meneses Rioseco et al., this volume); (III) Geothermal potential analysis and reservoir characterization by drill cores and well logs with subsequent provision of results through GeotIS; (iv) Development of a thermal-hydraulic operator's model comparable to that of the greater Munich area."

The project is being implemented very efficiently despite extensive approval processes. The 3D seismic campaign in the urban environment of Wörth (Rhein) in February 2025 took less than a month without any significant opposition from the public. After a short time of seismic data processing and interpretation, already in August 2025 the targeting and drill site selection was put into practice. Three potential drill sites with preliminary well path geometries are specified and allocated to feasibility-risk hierarchy. The challenges in this play type are (I) the fault and fracture pattern with disadvantageous effects in the seismic imaging, and (II) the urban environment with limited area for drill site construction and requirements on operational infrastructure.

However, well path planning can be executed for the favorable drill site and drilling operation is planned for winter season 2026 to spring 2027.

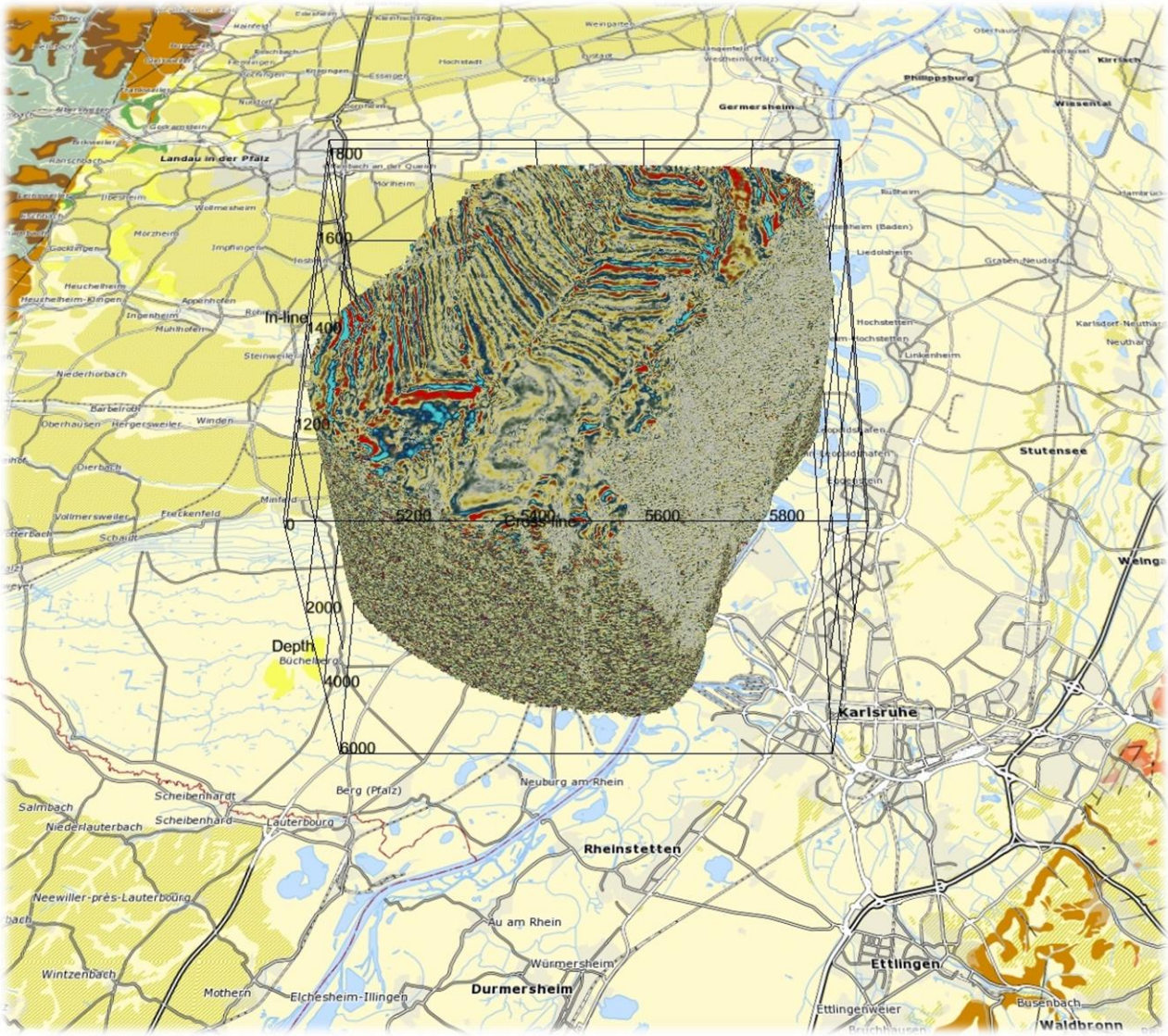


Figure 6. Projection of the stacked 3D seismic data onto the geological map from the GeORG model (GeORG, 2025).

6 DISCUSSION AND CONCLUSION

The geothermal play concept captures a fundamental role in the design of the criteria catalogue that helps to identify potential geothermal sites for federally funded exploration initiative in Germany. The advantage of the play concept is the streamlined consideration of geological-technical and societal-technical criteria on different scales to ultimately describe the theoretical, technical and economic geothermal potential. However, quantify the potential is challenging. More likely, Monte Carlo simulations are needed to quantify probabilities to meet certain geological or economic conditions, which are required for viable geothermal projects.

As for economics, drilling costs exhibit a major portion of the investment costs and boost the CAPEX over the OPEX (Schlagermann & Reinicke, 2023), which mirrors a disadvantageous distribution of overall project costs. To overcome this economic obstacle, three tracks can be taken into account:

1. Reducing the geological uncertainties and limiting economic risks for the stakeholder by smaller stakes and sharing risk instead of fully financing an individual project by one stakeholder (BVEG, 2024)

2. Reducing the investment costs by reducing drilling depth to save drilling costs and exploring medium-deep to shallow reservoirs (Schlagermann & Reinicke, 2023). Low reservoir temperature can be thermally enhanced by ATES (aquifer thermal energy storage) or BTES (borehole thermal energy storage) using excess heat from wind power, solar thermal or industrial waste heat.

3. Reducing the exploration risk by a coherent geological reservoir characterization strategy based on existing but former exploration data (Franz et al., 2018). This exploration strategy encompasses detailed litho- and biofacies analyses, integrated with macro- and micropalaeontology, palynology, reconstruction of depositional environments to delineate reservoir complexes, which are verified by well logging, petrography, geochemistry and petrophysics from drill cores to evaluate reservoir quality and to summarize these results in reservoir maps (Franz et al., 2018).

DemoCELL as case study project of the exploration initiative in Germany demonstrates the relevance of the coherent geological reservoir characterization. The drill site is located in an area of fluvial-dominated Upper Triassic sandstone channels of a deltaic system (Franz et al., 2018) (Fig. 7). Since reservoir maps resulting from this coherent geological reservoir characterization are publicly accessible in the GeotIS, project developers can use this information for their potential analysis and decision making (Fig. 7a).

Such geological information from reservoir maps can be co-visualized with the heat demand structure to identify the co-existence of geothermal reservoir with anchor client for heat, which is also provided by the GeotIS (Fig. 7b).

Another possibility to lower the exploration risk, to increase the economic potential of geothermal license fields and to accelerate the geothermal rollout in general is to utilize the geological subsurface by a multi-layer approach. Franz et al. (2018) identified several hydrothermal reservoirs in the Mesozoic of the North German Basin, representing an intracratonic sedimentary basin play. At least six siliciclastic reservoir units are characterized by good reservoir properties (Fig. 8). The depth and consequently the temperature of these units depend on salt tectonics and development of the North German Basin. If the reservoir temperature is not sufficient enough for direct district heating, a heat pump can uplift the temperature as in the project of Potsdam. At lower temperatures, hydrothermal reservoirs can be utilized as aquifer thermal energy storage (ATES) (Fig. 8), e.g. combined with solar thermal energy or waste heat or any other excess heat, which can be stored efficiently in the geothermal subsurface until the period of demand.

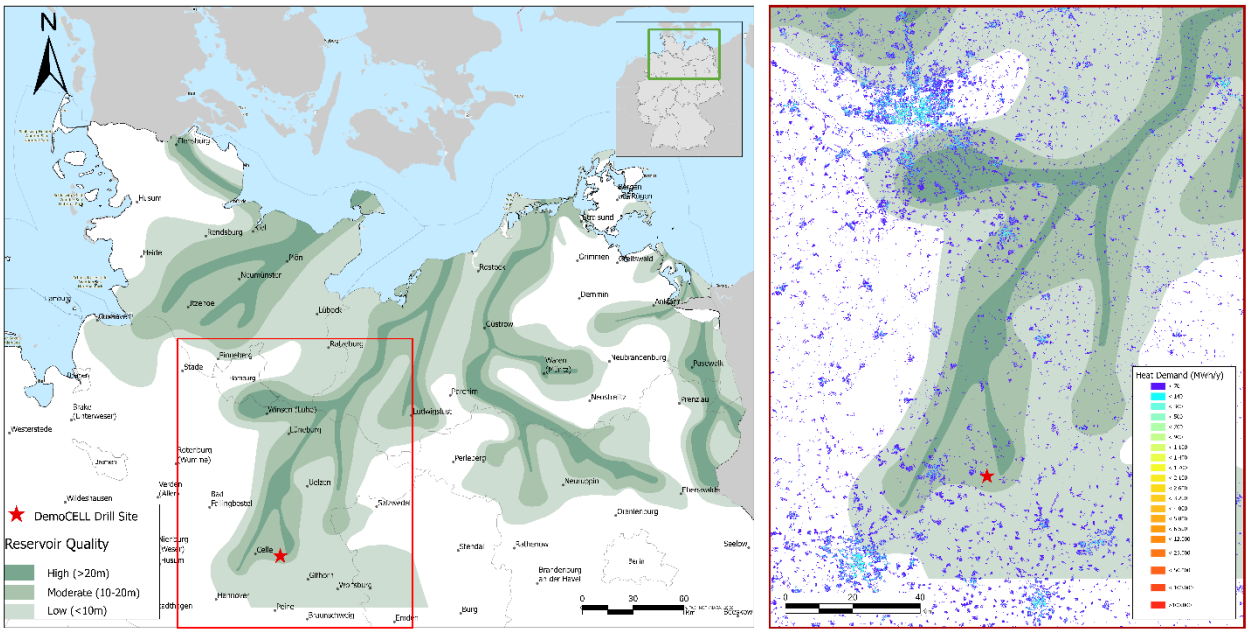


Figure 7. Left map – Fig. 7a: Reservoir map of the Upper Triassic Rhaetian fluvial-deltaic system. Dark green: good reservoir quality with more than 20 m thickness, medium green: moderate reservoir quality with 10-20 m thickness, light green: low reservoir quality with less than 10 m thickness. Red star: location of DemoCELL drill site. (modified from GeotIS, 2025, based on Franz et al., 2018). Right map – Fig. 7b: Reservoir map co-visualized with heat demand map. Violet colors: 70-140 MWh per year and hectare, light blue: 300-500 MWh, light blue to green: 700-900 MWh per year and hectare. For more details see GeotIS (www.geotis.de)

Whether Germany will reach its goal of rolling out with 10 TWh/a of geothermal capacity by 2030 is still uncertain. However, information about surface and subsurface conditions are provided by GeotIS, and several extensive funding programs for geothermal exploration and district heating grid modernization are available. Such an approach may serve as a blueprint for other countries. However, society and local public will ultimately decide whether they are willing to support the renewal of the energy infrastructure and the exploitation of domestic energy sources despite higher energy costs, prolonged construction phases, and general change of accustomed behavior. Eventually, the degree of public acceptance will determine the success of energy transformation, not only in Germany but elsewhere.

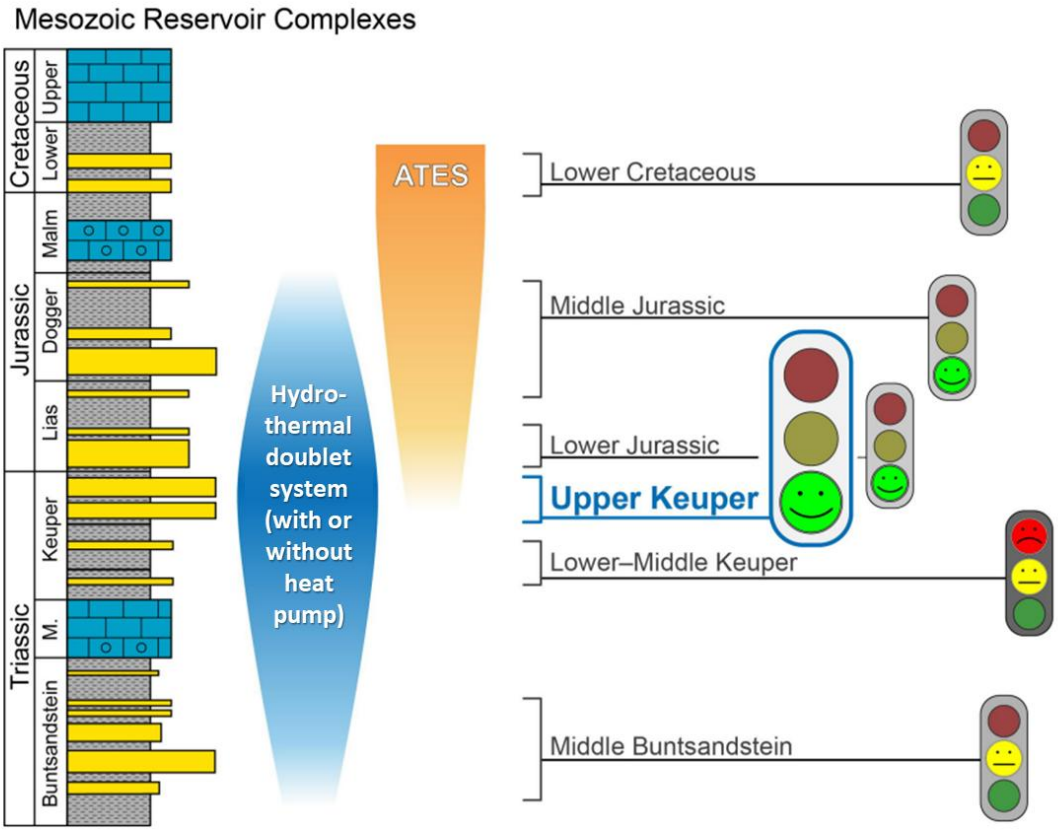


Figure 8. Major hydrothermal reservoir units of the North German Basin and its possible utilization types (modified after Franz et al. 2018).

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