

Categorisation and Analysis of Flooded Mines with Regard to their Geothermal Potential

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Abstract

The use of heat from flooded mines via mine water represents low-emission geothermal energy with base-load capability. Despite favourable conditions, it is rarely applied in Saxony's former mining regions. A study by the Saxon State Office for the Environment, Agriculture and Geology analysed the potential of mine water for heating and cooling. Fourteen sites were selected and evaluated using underground geological and mining parameters and above-ground municipal heat demand. GIS-based potential layers combined supply and demand. Laboratory experiments at two test sites examined fouling on heat exchangers. Optimised materials reduced deposits by 30–40%, and mitigation measures were developed for future projects.

Keywords: Mine water geothermal systems, abandoned mines, heat demand analysis, heat exchanger fouling, geothermal potential mapping

Introduction

The European Green Deal aims to increase the share of renewable energy to 40% by 2030. While Germany already generates more than half of its electricity from renewable sources, the share of renewable heat remains comparatively low at around 19%, although heating accounts for more than half of total final energy consumption, AG Energiebilanzen (2024). Expanding renewable heat sources therefore represents a key element of the energy transition. One promising but still underutilised option is the use of mine water from flooded underground mines. Mining cavities provide large heat transfer surfaces and may contain considerable water volumes that can be used as geothermal energy sources. Existing shafts and galleries may reduce exploration costs compared to new drilling, Grab et al. (2018). However, challenges include pumping requirements, underground logistics and the chemical composition of mine water, which may affect technical components through corrosion or deposit formation, Oppelt et al. (2025). The study, conducted by the TU Bergakademie Freiberg, examines the geothermal potential of mine water in

Saxony, Ebel *et al.* (2025). Based on literature research and practical investigations, selected mining sites were evaluated using a structured assessment method. The results were visualised using GIS tools. In addition, laboratory experiments and operational analyses were conducted to expand practical knowledge and to support future mine water geothermal projects.

Mine Water Geothermal Systems

Mine water geothermal systems utilise flooded underground mining structures as heat sources. The water is in thermal contact with surrounding rock masses, enabling efficient heat exchange.

Three basic system types can be distinguished:

- open systems without reinjection, return of mine water to surface waters
- open systems with reinjection of mine water to the mine
- closed systems

In open systems, mine water is pumped directly to the heat exchanger and used as the heat carrier. In closed systems, heat is transferred through a secondary fluid circulating in a



closed loop. Open systems are widely used due to their comparatively high heat output and simple design. After heat extraction, the water can either be discharged into surface waters or reinjected into the mine.

Methodology for Site Assessment

Data Basis and Site Selection

Several mining regions in Saxony contain potentially suitable mine water resources. To identify suitable sites, different information sources were evaluated, including archives of the Technical University Bergakademie Freiberg, municipal archives, the Wismut company archive and the underground cavity map of the Saxon Mining Authority, SOBA (2023). Existing geothermal projects and studies in regions such as Ehrenfriedersdorf, Freiberg, Zwickau and Marienberg provided important references. Additional information was obtained from mining museums and local authorities. Based on the available data, 14 municipalities were selected for further

investigation. These locations represent a large share of the mining-related underground cavities in Saxony (Figure 1).

Underground Site Assessment

The geological and mining conditions vary significantly between the investigated sites. Therefore, a general assessment approach based on Grimm *et al.* (2001) was expanded and applied to enable a systematic comparison of all sites. Eight parameters were considered, (Tab. 1 left site). The assessment considers age, drainage system, flooded depth, and cavity volume. More recent mining periods generally provide better data availability, larger tunnel cross-sections, and improved structural conditions. Drainage systems are evaluated based on their degree of centralization and discharge rate, as higher flow rates enable greater thermal output. Smaller flooding depths reduce pumping effort. Larger cavity volumes increase the likelihood of usable water mobilization. Each parameter was evaluated using a scale from

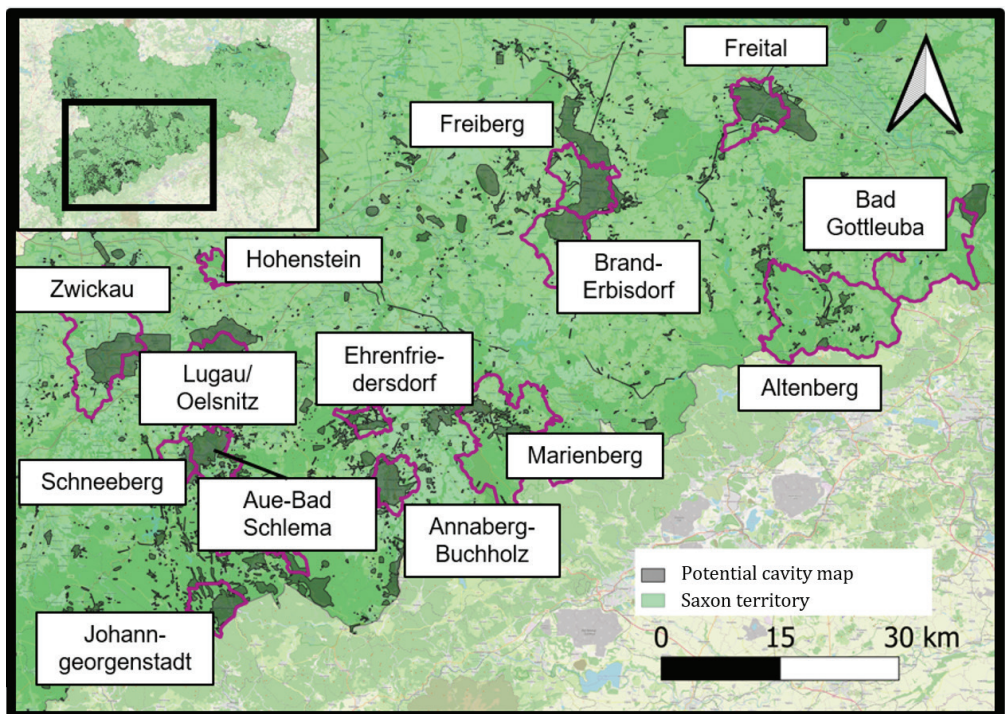


Figure 1 Overview of the areas and municipalities included in the federal state of Saxony in Germany (according to Ebel *et al.* (2025). and Oppelt *et al.* (2025)).

Table 1 Underground categories of evaluation criteria and their weighting.

Evaluation factors	Weighting
mining period and age of mine structures	3%
drainage systems and water discharge rates	17%
flooding depth and pumping requirements	11%
mine (residual) void volume	6%
availability of mining maps	22%
mine water temperature	8%
water chemistry	14%
accessibility of the mine structures	19%

1 (unfavourable) to 5 (very favourable). To account for different levels of importance, each of the eight parameters were weighted (Tab. 1 right site) using a pairwise comparison method, Wartzack (2020). The resulting weighted scores represent the underground geothermal potential of each site (Figure 2 A).

Above-Ground Site Assessment

The above-ground evaluation focuses on the heat demand structures of surrounding municipalities. Heat demand represents the most relevant indicator for the potential utilisation of mine water geothermal energy. Modelled heat demand data were spatially aggregated into demand polygons representing potential supply areas. These polygons were then classified into demand categories and evaluated using the same five-level scale applied in the underground assessment (Figure 2 B). The heat demand modelling was carried out using building-based data from the DBI building atlas, DBI GTI (2023). Georeferenced address data were combined with building parameters such as floor area, construction year, building type and specific energy demand. For residential buildings, literature values for specific energy demand were applied. Non-residential buildings were evaluated using sector-specific indicators such as energy demand per pupil, patient or sales area. Regional factors such as climate conditions and building renovation status were also considered. Climatic corrections were performed using heating degree days based on German reference values. The resulting dataset provides a house-level heat demand estimate for each building within the analysed municipalities.

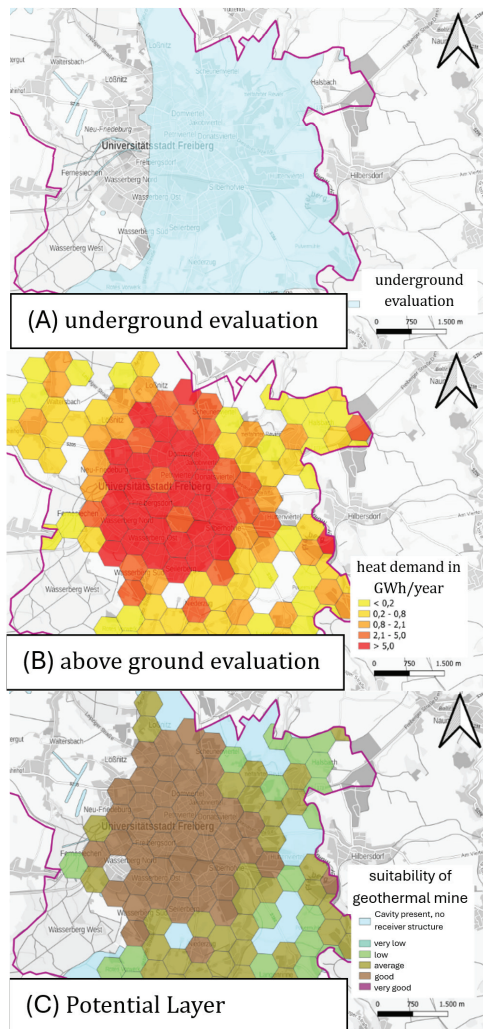


Figure 2 Illustration of the format used to present the results for each of the mining regions studied.



Potential Layer

To determine the overall geothermal potential, the underground and above-ground assessments were combined. For each polygon cell, the underground potential value of the corresponding mining district was merged with the heat demand score of the demand polygon (Figure 2 C). The overall potential was calculated as the arithmetic mean of both values. Only polygon cells located above underground cavities and belonging to the main supply area were included in the final analysis. This approach avoids overestimating small or isolated underground structures. The resulting GIS layer represents the spatial distribution of mine water geothermal potential across the analysed municipalities and will be made publicly available by the State Office for the Environment, Agriculture, and Geology of the Free State of Saxony.

Results of the Potential Analysis

All 14 analysed municipalities show at least one polygon with favourable conditions for mine water geothermal utilisation. The districts of Annaberg Buchholz (4.1 out of 5) and Freiberg, as well as Ehrenfriedersdorf, each with a score of 3.9 out of 5, receive particularly high ratings, (Table 2). High demand densities in urban areas lead to particularly favourable results, while in less populated regions favourable underground conditions can compensate for lower heat demand. The results primarily serve as a screening tool to identify promising areas. Detailed feasibility studies are required before implementing specific projects. Since not all Saxon municipalities were analysed,

additional suitable sites may exist beyond the investigated regions.

Experimental Investigations

Mobile Test Facility

A major challenge in mine water geothermal systems is the formation of deposits (fouling) on heat exchangers. Fouling can be caused by mineral precipitation, suspended particles or biological growth. To investigate these processes, the Institute of Technical Thermodynamics at TU Bergakademie Freiberg developed a mobile heat pump test facility, Oppelt et. al. (2022) Oppelt et. al. (2025EGC). The system includes a 4 kW heat pump connected to plate heat exchangers that simulate heating and cooling conditions under realistic operating parameters, see Fig. 3. Two mine water sites with different temperatures (approximately 26 °C and 12 °C) were investigated. The locations differ in their water chemistry but were anonymised for confidentiality reasons.

Experimental Results

The aim of the practical measurements of the mobile heat pump test rig was to investigate the fouling behaviour of substances dissolved in mine waters on heat exchangers. Two sites with three mine waters were examined to identify materials that reduce maintenance effort. A total of 7 plate materials and 11 surface types were tested. At both sites, fouling occurred independently of the material. Site 1 showed predominantly biological fouling, promoted by high temperatures, which was reduced by stainless steel NiCr23Mo16Cu, silver, or anti-biofouling coatings. At site 2, mine water 2 caused iron-containing deposits,

Table 2 Assessment of sites based on Saxony's flooded mine geothermal potential analysis.

Municipalitie	Site assessment (max 5)	Municipalitie	Site assessment (max 5)
Altenberg	3.1	Freital/Gittersee	3.1
Annaberg-Buchholz	4.1	Hohenstein-Ernstahl	3.5
Aue – Bad Schlema	3.8	Johanngeorgenstadt	3.3
Berggießhübel	3.3	Marienberg	3.9
Brand – Erbsdorf	3.0	Oelsnitz/Erzgeb.	3.3
Ehrenfriedersdorf	3.9	Schneeberg	3.7
Freiberg	3.9	Zwickau	3.1

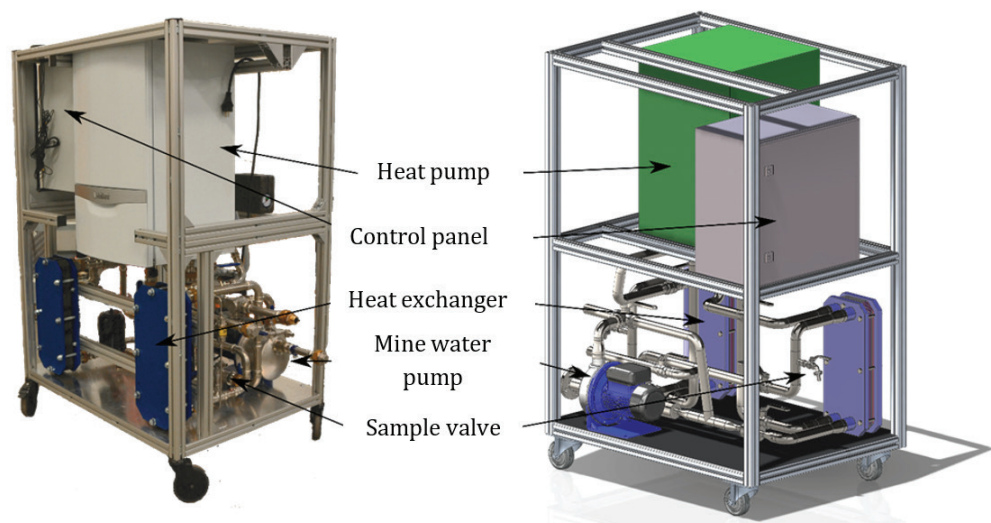


Figure 3 Mobile heat pump test rig of the Institute of Technical Thermodynamics at the TU Bergakademie Freiberg.

number of materials should be reduced and installed multiple times to increase accuracy. Thermal conductivity must be considered, as low fouling does not automatically imply high efficiency. Cleaning is relevant, as deposits adhere with varying strength; tests with chemical cleaning in place are planned.

The position of the plates in parallel-flow heat exchangers did not influence deposit formation. Analyses of the deposits showed high proportions of organic compounds and dominant iron, mainly as particulate fouling. This correlation was also demonstrated in earlier experiments by Oppelt *et al.*, (2020) and Abewywickrama *et al.*, (2021). The investigations provide practical insights, enable the preselection of suitable materials, and form the basis for further cleaning and efficiency studies.

Analysis of Existing Mine Water Plants

Existing mine water geothermal installations in Saxony were analysed to derive practical recommendations. The evaluation of permits, technical reports and operator interviews identified 14 factors that may influence project success. Key challenges include incorrect drilling, insufficient water temperatures, low flow rates, fouling of heat exchangers and technical failures of heat pumps. Mitigation

measures include improved geological data, exploratory drilling, suitable material selection, filtration systems, monitoring and regular maintenance. Early coordination with authorities and potential heat consumers is also essential.

Conclusion and Outlook

Mine water geothermal energy represents a promising renewable heat source with low emissions and base-load capability. However, its application in Saxony remains limited. This study analysed 14 mining sites using a combined assessment of underground conditions and above-ground heat demand. The results were integrated into a GIS-based potential map that identifies promising areas for future projects. Additional investigations improved the understanding of mine water chemistry and heat exchanger fouling. Experimental tests demonstrated that appropriate material selection can significantly reduce deposit formation. The findings were compiled into a practical guideline supporting planning, approval procedures and funding options. Future developments should focus on the digitalisation of mining maps, improved potential calculation methods and expanded data availability. With these advancements,



mine water geothermal systems could play an important role in the sustainable redevelopment of former mining regions and contribute to the renewable heat transition.

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