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Spatial and Regulatory Constraints on Shallow Geothermal Energy Utilisation in Germany

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1. INTRODUCTION

The heating and cooling sector (HCS) in Germany accounts for around 48% of final energy consumption and nearly 90% of household energy use - over 630 terawatt-hours (TWh) [1]. In 2024, approximately 81% of national demand was met by fossil fuels, while the remaining share was supplied by renewable sources, primarily biofuels [2]. To achieve 50% climate-neutral heat production by 2050, the German government is accelerating the expansion of shallow geothermal energy (SGE), tapping into the heat stored within the first 400 meters of depths. However, scaling up SGE nationwide is hindered by several technical, economic, and social challenges [3]. Key technical barriers include complex permitting procedures, inconsistent assessments of theoretical and technical geothermal potential across Germany's 16 federal states and high variability in regional policies governing ground source heat pump (GSHP) installation. Furthermore, existing data and resources are often fragmented across multiple authorities, difficult to access and not directly comparable or scalable.

This contribution takes a step toward a more consistent and comprehensive assessment of SGE potential in Germany by analysing and mapping the site-suitability for GSHP utilization. Specifically, we evaluate the variability of regional policies and guidelines governing the use of BHEs across the country, considering their compatibility with national and regional environmental regulations as well as the known subsurface geological conditions at each site.

2. WORKFLOW

The site-suitability assessment involves several phases, beginning with the identification and evaluation of relevant factors (e.g., subsurface geological conditions, environmental risk zones, land-use restrictions) that may hinder GSHP installation. This is followed by data compilation, processing, and mapping [4, 5]. All steps were carried out in consultation with the Staatliche Geologische Dienste (SGDs – State Geological Surveys of Germany) and other environmental authorities. A statistical analysis was then performed to identify the factors that most strongly affect the suitability of locations for BHE systems across the country.

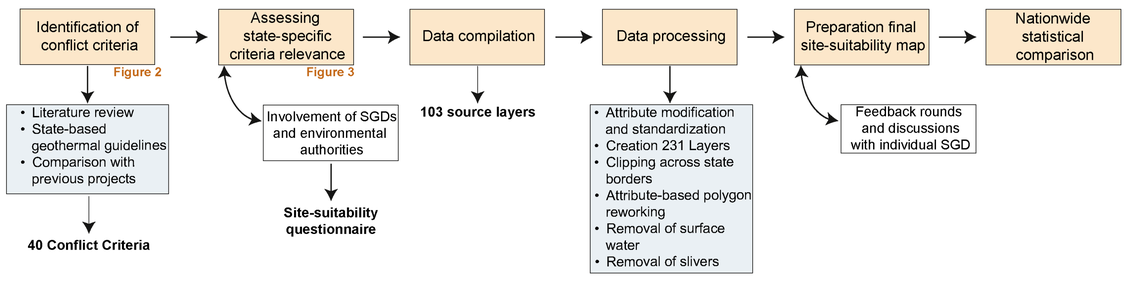


Figure 1. Workflow developed for mapping site-suitability, standardizing geospatial information, and investigating regional policies variations governing the use of SGE.

Conservation Areas and Environmental Risk Zones
Drinking water protection areas I and II
Qualitative curative spring water protection areas I and II
Drinking water protection III, III/A or III/1
Qualitative curative spring water protection areas III, III/A or III/1
Quantitative curative spring water protection areas A
Quantitative curative spring water protection areas B
Other drinking water protection areas
Other quantitative and qualitative curative spring water protection areas
Planned drinking water protection areas
Drinking water production areas
Other existing uses of groundwater
Coastal protection areas
Waterfront strips and floodplains
Flood risk areas
State-specific water laws
Landslide areas
Natural protection areas
National parks
Protected soils
Waterfront strips
Geological Features
Salt structures and salt-bearing rocks
Karst and sinkholes
Bedrock, fractured aquifers
Sulphate-bearing rocks
Highly permeable rocks
Fault zones
Swellable rocks (e.g. clay minerals)
Groundwater Systems
Glacial channels
Artesian
Aquifers in a pronounced storey structure
Deep aquifers
Salty groundwater, cement-corrosive groundwater
CO_2 and H_2S gas uprising
Ineffectiveness of protective covering layers
Depth-dependent, usable aquifers and limitations of drilling depth
Land Use Restrictions
Mining areas
Underground storages (e.g. radioactive waste, gas)
Oil and gas reservoirs and exploration areas
Contaminated sites: areas of soil contamination
Contaminated sites: areas of groundwater pollution

CRITERION	FEDERAL STATE			
	BE	HH	MW	NI
Drinking water protection areas I and II				
Qualitative curative spring water protection areas I and II	N/A	N/A		
Drinking water protection III, III/A or III/1				
Coastal protection areas	N/A	N/A		
Salt structures and salt-bearing rocks	N/A			
Glacial channels				
Contaminated sites: areas of groundwater pollution	S.D.	S.D.	S.D.	S.D.

Strong restriction | Mild restriction | No restriction | N/A Not Applicable | S.D. Sensible data

Figure 3. Excerpt from the site-suitability questionnaire developed to determine the regional relevance of conflict criteria for the installation of BHEs. The questionnaire was completed based on state geothermal guidelines and in close consultation with SGDs and other environmental authorities. Criteria are classified into five categories: (i) *Strong restrictions* - BHE installation is generally prohibited; (ii) *Mild restrictions* - GSHP use is permitted with limitations; (ii) *No restrictions* - the criterion does not affect BHE installation; (iv) *Not applicable* - the criterion is not relevant in the region or the corresponding geospatial data are unavailable; (v) *Sensitive data* - the criterion may be relevant, but the data cannot be disclosed. BE – Berlin; HH – Hamburg; MW – Mecklenburg–Western Pomerania; NI – Lower Saxony [5].

Figure 2. List of criteria considered for assessing the suitability of BHEs. Criteria are grouped into four categories [4, 5].

3. NATIONWIDE-HARMONISED SITE-SUITABILITY MAP

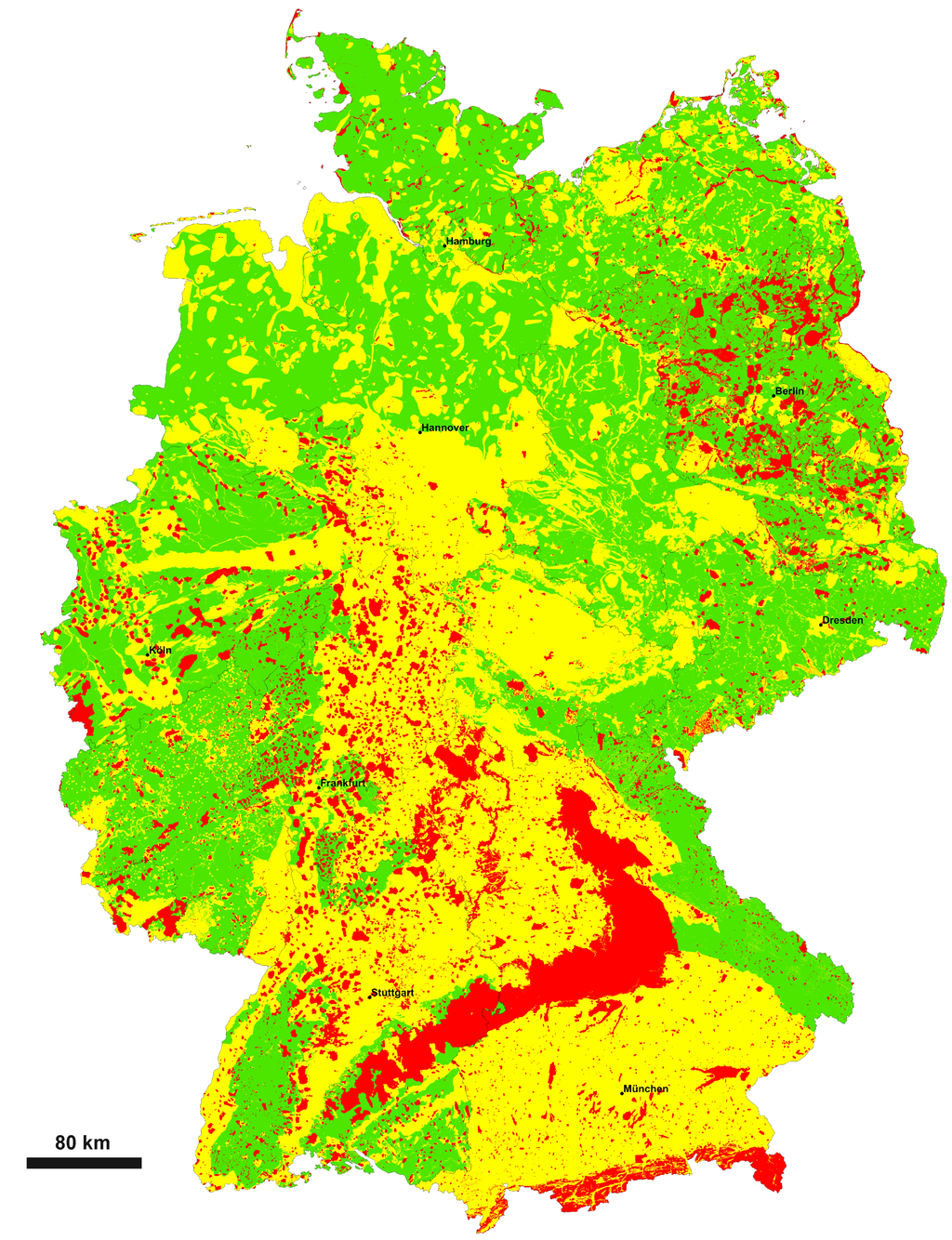


Figure 4. Map showing the effective site suitability for BHEs in Germany. A traffic-light color scheme was adopted to facilitate visual interpretation. Green areas cover about 154,739 km^2. Ravidà et al., *in prep.*

4. REGIONAL VARIABILITY

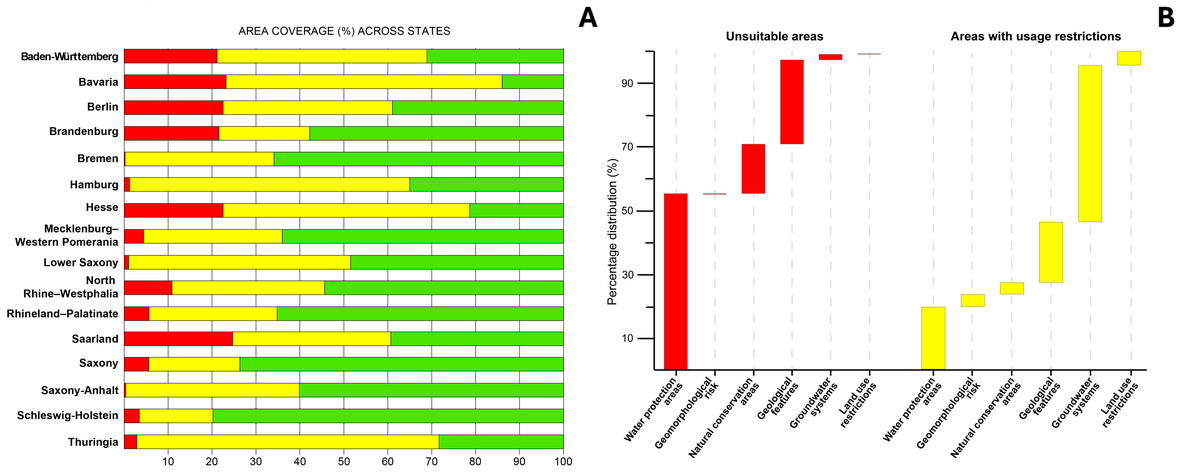


Figure 5. A) Average coverage (%) of suitability areas across the 16 federal states of Germany. B) Percentage contribution of the four risk categories (Figure 2) to the total areal coverage of unsuitable areas (43,942 km^2, red in Figure 4) and zones with usage restrictions (154,479 km^2, yellow in Figure 4).

5. FINAL CONSIDERATIONS

The presented site-suitability assessment represents the first analysis of its kind conducted at such a large spatial scale and level of detail in Europe, and likely worldwide. Although it does not represent the actual geothermal potential, it constitutes a fundamental building block for subsequent estimations of the technical and developable potential [6], thereby serving as an essential instrument to support the heat transition. The workflow developed here overcomes several challenges by providing a nationally standardised map while maintaining a representation that is both accessible and easy to understand. The approach is both versatile and broadly transferable. By integrating a structured process, widely available geospatial datasets, and a comprehensive catalogue of criteria tailored to regional or national regulatory frameworks and geological conditions, the methodology offers a practical template for developing comparable suitability assessments and supporting the deployment of shallow geothermal systems in other countries.

Acknowledgements

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For further information

www.waermegut.de

www.geotis.de

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