Unlocking Hidden Geothermal Potential: Leveraging Artificial Intelligence for Subsurface Exploration

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Geothermal Energy

Geothermal energy is extracted from the Earth's subsurface layers and is derived from the heat generated during rock formation and the decay of radioactive materials. The main advantages of geothermal energy are its low operating costs, stable supply and the ability to operate at high-capacity factors all year round.

Recent Activities in Geothermal Energy

Many countries are investigating the feasibility of commercializing untapped geothermal resources. This requires information on the hydrological, geophysical, geological, geochemical, and thermal characteristics of the hydrothermal reservoirs to determine whether the geothermal resource has sufficient potential to recover exploration and development costs.
Geothermal Exploration Challenges

Geothermal exploration is challenging and costly due to the subsurface complexities involved in locating potential reservoirs.

Geothermal resource evaluation plans are often hindered by the significant investment and high financial risks associated with preliminary surveys, exploration and delineation drilling for data collection and interpretation. As a result, many geothermal reserves remain unexplored due to the ineffectiveness or high cost of existing detection methods.

Geothermal development project cost and risk profile throughout various project stages (The World Bank, 2019)
Role of Artificial Intelligence in Geothermal Exploration

Raw Data Analysis
Machine learning algorithms can analyze large, multidimensional datasets, including geophysical, geological, geochemical, thermal, and geospatial datasets, to identify complex patterns that guide the exploration of hidden geothermal resources.

Imagery Data Analysis
The analysis of raw geophysical imagery and seismic survey data to identify key subsurface features and stratification can be automated by deep neural networks.

Data Management
Unsupervised learning techniques, such as clustering analysis, can identify outliers and reveal distinct sets of characteristics associated with hidden geothermal potential.
## Summary of Different AI Approaches in Geothermal Exploration

<table>
<thead>
<tr>
<th>Research Area</th>
<th>AI Algorithm Used</th>
<th>References</th>
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<tbody>
<tr>
<td><strong>Play Fairway Analysis Application</strong></td>
<td>LR, ANN, PCA, K-means, Bayesian NN, NMF k, DT, XGB</td>
<td>Faulds et al. (2015); Faulds et al. (2020); Smith et al. (2021); Brown et al. (2020); Brown et al. (2022); Vesselinov et al. (2021); Holmes and Fournier (2022)</td>
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<tr>
<td><strong>Combined Geological, Geophysical, Geochemical, and Thermal Data Application</strong></td>
<td>NMF k, RF, ANN</td>
<td>Ahmmed et al. (2020); Ahmmed and Vesselinov (2021); Mudunuru, Ahmmed and Vesselinov (2022); Meshalkin et al. (2020); Shakirov et al. (2021)</td>
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<td><strong>Geochemical Data Application</strong></td>
<td>ANN, MLP, SVM, KNN, DNN, NMF k, K-means, Gaussian mixture model</td>
<td>Bayram (2001); Can (2002); Diaz-Gonzalez et al. (2008); Serpen et al. (2009); Bayram and Gultekin (2010); Perez-Zarate et al. (2019); Acevedo-Anicasio et al. (2021); Yang et al. (2022); Tut Haklidir and Mehmet Haklidir (2019, 2021); Ahmmed et al. (2021); Kazuya Ishitsuka et al. (2021)</td>
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<tr>
<td><strong>Geophysical Data Application</strong></td>
<td>ANN, NK, DT, Adaptive Booster Regression, RF, SVR, FNN, Bayesian NN, DBNN, CNN, K-means, ICA, DL, fuzzy logic</td>
<td>Spichak (2006); Ishitsuka et al. (2018); Namaswa et al. (2021); Akpan (2013); Maryadia and Mizunaga (2021); Trainor-Guitton et al. (2014); Sutarmin and Yunus Daud (2020); Yadav et al. (2021); Ishitsuka et al. (2021); Hokstad and Tanavsuu-Milkeviciene (2017); Zheng et al. (2021); Gao et al. (2021); Perozzi et al. (2021); Matzel et al. (2021); Abubakar et al. (2019); Moraga et al. (2022); Sadeghi and Khalajmasoumi (2014)</td>
</tr>
<tr>
<td><strong>Thermal Data Application</strong></td>
<td>NK, MNN, ANN, DL, ridge regression model, DT, XGB, RF, linear and polynomial regression</td>
<td>Koike et al. (2001); Spichak (2006); Shahdi et al. (2021); Bassam et al. (2010); Espinoza-Ojeda and Santoyo (2016)</td>
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<tr>
<td><strong>Other Data Application</strong></td>
<td>ANN, DL, (SVM), DT, KNN</td>
<td>Porkhial et al. (2015); Xiong et al. (2022)</td>
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</table>
Artificial Intelligence Limitations in Geothermal Exploration

Data Availability and Quality
The accuracy and reliability of AI models used in geothermal exploration heavily depend on the availability and quality of data. Limited datasets or data with inaccuracies can hinder their success.

Complexity of Subsurface Features
Geothermal exploration can be challenging for AI algorithms to accurately interpret due to the complexity of subsurface features.

Generalization to New Geological Environments
AI models trained on existing geological environments may struggle to apply their findings to new and unfamiliar geological settings. The limited availability of data from specific regions can restrict the applicability of AI in new regions.
Conclusions

▪ The use of AI in geothermal exploration is a recent development that has the potential to significantly enhance efficiency, effectiveness, and productivity compared to simple physics-based and statistical approaches.

▪ The growing use of AI in geothermal exploration indicates that its application will continue to expand. However, acquiring meaningful geothermal data remains a significant challenge that must be addressed for AI to have a transformative impact on geothermal exploration.

▪ To make multiple datasets and insights accessible to scientists, shared initiatives across the industry are necessary.

▪ Partnerships between academic and professional organizations can be particularly influential in accelerating the development and improvement of AI approaches on a larger scale.
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