EGPD 2024

Conference Proceedings

EUROPEAN GEOTHERMAL PHD DAYS 2024

Sessions:

1. Above the Surface
2. Underground Thermal Energy Storage (UTES)
3. Shallow Geothermal
4. Deep Geothermal
5. Ultra Deep Geothermal (UDG)/ Enhanced Geothermal Systems (EGS)
6. Other

Presenter’s first name	Akhmad
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Selected Session *	6. Other
Title of Abstract	Strategic Scaling Solutions: A Comprehensive Approach to Addressing Challenges in Well 'X' through Broaching Methodology at the Vapour Dominated Geothermal Field
Abstract (up to 300 words)	A geothermal well can experience a decrease in the production of fluid (steam) due to the presence of scaling. The scale of the deposits that are formed can cause the diameter of the wellbore to be smaller so that it will reduce the production of a geothermal power plant. The purposes of this study were to investigate the problem caused by the scaling deposition in the well, observing and determining the location of the scaling formed and the type of the scaling, and to plan the scaling removal in the well X. In determining the scale location, sample collection and the well diameter reduction using well integrity, go-devil, sample catcher, and impression block method while in analyzing the scale sample mineral element by applying the XRD method. Besides that, the broaching method plan is utilized as the solution to eliminate the scale deposition in the well. The results showed that The X well has a scaling problem at a depth of 900.74 m in the 13 3/8 production casing with a scale column height of less than 1 meter and a scale thickness of 9.95 inches. The impact of formed scale on the reduction in production rate has been limited, primarily due to the relatively modest height of the scale column and the absence of scale formation points in the perforated liner and feed zone. This observation is substantiated by the recorded steam flow rates, with the last measurement on March 27, 2022, at 28.71 tons/hour compared to the initial flow of 29.03 tons/hour. However, it is noteworthy that Well X's Wellhead Pressure (WHP) has experienced a decline of 8.99936 bar over the past approximately 6 years. Based on the result from the XRD analysis, the scaling type can be determined as silika (Quartz) and this type of scale can be remove using the broaching method.

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Selected Session *	5. Ultra Deep Geothermal (UDG)/ Enhanced Geothermal Systems (EGS)
Title of Abstract	Influence of rock properties and geological conditions on the success of hydraulic shear stimulation treatments for geothermal purposes
Abstract (up to 300 words)	The utilization of injection-induced shear stimulation, generally referred to as 'hydro-shearing', is frequently employed in Enhanced Geothermal Systems (EGS) with the aim of augmenting the permeability of the reservoir. Hydro-shearing is a phenomenon that takes place when a pre-existing fracture or fault, which is under shear stress, experiences slip at an injection pressure that is lower than the minimum principal stress in the reservoir. This fracture slip causes the fracture to open up, primarily due to the self-propping effect caused by asperities present on the surface of the fracture. This study aims to investigate the conditions under which hydro shearing contributes to permeability enhancement and, conversely, the conditions leading to a reduction in permeability, and how these conditions influence the injection-induced shear slip/seismicity. The investigation focuses on a diverse range of rock types, seeking to comprehend the influence of intrinsic rock strength, mineralogy and mineral size distribution on permeability variations. In addition, laboratory experiments will explore the impact of extrinsic, engineering parameters, including cyclic injection schemes on the permeability evolution for the same rocks. The laboratory injection experiments on different reservoir rocks under various stress states aim to provide a systematic database to help judge if, where and how Enhanced Geothermal Systems can potentially be developed successfully (sufficient and sustainable permeability) and environmental-friendly, safely (manageable induced seismicity) by hydraulic shear stimulation treatments without proppants or chemical additives.

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Selected Session *	1. Above the Surface
Title of Abstract	Optimizing geothermal well control for a more sustainable production strategy
Abstract (up to 300 words)	The goal of this project is to use stock reservoir modelling and utilization optimization together to find a new methodology that improves the sustainable use of geothermal resources. The study focuses on defining the impacts of production for different wells in two geothermal fields in Iceland using stock reservoir modelling. Stock reservoir modelling proves to be a cost- and time-efficient method of recognizing the impact of production and recharge on geothermal wells. Then, by combining stock modelling with production optimization, the study proposes a method to maximize plant output and minimize environmental impacts such as greenhouse gas emissions. This model considers the different characteristics of the geothermal resource as well as the different requirements that the power station has.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Fluid-rock interaction in crystalline basement: implications for the understanding of the genesis of geothermal resources and ore deposits.
Abstract (up to 300 words)	Crystalline rocks are characterized by low primary porosity, but very often they form geothermal reservoirs, as is the case of the Italian Geothermal Fields: Larderello and Monte Amiata. Permeability in metamorphic rocks is associated with fracture systems in response to brittle deformation. Thus, the circulation of geothermal fluids is mainly controlled by the fractures and, in general, by their intersection, the setting of which depends on the orientation of the stress axes. In addition, the crystalline rocks react with the geothermal fluid, developing metasomatic processes that lead to the deposition of newly formed minerals in correspondence with the fractures, drastically reducing the permeability of the reservoir. My PhD project focuses on the study of exhumed geothermal systems developed in metamorphic rocks (phyllites and micaschists) exposed in southern Tuscany and Sardinia, which are the analogues of the deepest geothermal reservoir exploited in the Larderello and Monte Amiata geothermal fields, as well as in other geothermal systems active in the continental crust. The main objective is therefore to study the processes leading to fluid migration under different thermobaric conditions, through the analyses of the relationships between faulting/fracturing, metamorphism and fluid flow (also in the presence of magmatic sources), allowing the reconstruction of the (i) variations in fluid composition, (ii) characterization of dissolution-precipitation processes in areas affected by fluid circulation, (iii) development of high-permeability areas capable of storing geothermal fluids or hosting the formation of mineralized systems of economic interest.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Experimental Investigation of CO2 Heat Transfer and Circulation Properties for a Closed-Loop Geothermal System
Abstract (up to 300 words)	In the context of closed-cycle geothermal systems, the heat exchange surface area remains a major limitation. For this reason, the choice of vector fluid and its thermodynamic properties is a key parameter for the economic feasibility of these solutions. Among its objectives, The European HOrizontal Closed LOOP (HOCLOOP) project aims to investigate the performances of these systems by replacing water and using CO_2 as the carrier fluid in a DualPipe system. Indeed, from a thermodynamic point of view, CO2 has many advantages, including characteristics such as a greater thermosiphon effect or lower viscosity, which make it potentially very attractive for such applications. An experimental campaign was therefore planned to test and verify the behavior of CO2 to both the heat exchange with the rocks and the circulation effect generated by density gradient. The test section has been designed to operate in two separate modes using a couple of three-way valves, allowing detailed studies for both parameters of interest within a single test rig. One of the layouts provides heat exchange conditions that are representative of a medium/high-depth geothermal system to investigate the potential of CO2 in heat extraction. The second layout consists of a Natural Circulation Loop to properly investigate the thermosiphon effect. This work presents the preliminary design of the test bench that will be installed in the laboratory of the Department of Industrial Engineering at the University of Florence. Moreover, It will also discuss the methodology and type of tests foreseen for the experimental campaign.

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Selected Session *	2. Underground Thermal Energy storage (UTES)
Title of Abstract	Geological and hydrogeological conditions for ATES and BTES application in Slovenia
Abstract (up to 300 words)	The heating and cooling sector plays a pivotal role in the transition towards a low-carbon and sustainable energy system, accounting for half of all consumed final energy in Europe. However, 85% of this demand is currently met by fossil fuels, particularly natural gas. To address the seasonal mismatch between renewable thermal energy availability and demand, Underground Thermal Energy Storage (UTES) systems, such as Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES), offer promising solutions. Understanding the distinct geological and hydrogeological requirements of ATES and BTES systems is imperative for their effective deployment, contributing to the advancement of sustainable and efficient heating and cooling technologies in the broader context of a low-carbon energy transition. We are starting to investigate geological and hydrogeological conditions, defining the ATES and BTES potential in Slovenia.

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Selected Session *	5. Ultra Deep Geothermal (UDG)/ Enhanced Geothermal Systems (EGS)
Title of Abstract	Reuse of hydrocarbon wells for Enhanced Geothermal System development
Abstract (up to 300 words)	Petrothermal energy is a large indigenous resource capable of providing baseload electricity and heat that has yet to be tapped. This is because the exploration, drilling, and development costs of the technology to exploit this potential, referred to as Enhanced Geothermal Systems (EGS), are still high compared to conventional hydrothermal geothermal resources. After decades of research and development to prove its technical and economic feasibility, EGS technology has now reached a stage where commercial development is within reach. However, the upfront exploration risk and high drilling costs associated with the development of EGS remain high. Recent EGS demonstration projects show that reuse of existing data and infrastructure may significantly reduce both costs and risk. Therefore, this study aims to develop the engineering workflow of retrofitting hydrocarbon wells and evaluate the pre-existing conditions suitable for developing Enhanced Geothermal Systems. The study area focuses on the North German Basin considering its hydrocarbon potential with a certain amount of former hydrocarbon infrastructure. According to previous studies, the North German Basin, with a temperature gradient of 32 °C/km, has potential for EGS development. Literature reviews and reservoir simulations were performed based on the existing Enhanced Geothermal System (EGS) site Groß Schönebeck. Based on the results, we evaluate the best conditions and procedures for the development of EGS demonstrators by reusing existing hydrocarbon wells for production, injection or monitoring.

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Selected Session *	5. Ultra Deep Geothermal (UDG)/ Enhanced Geothermal Systems (EGS)
Title of Abstract	Thermal Assessment of the Dikili-Bergama Region, Western Anatolia
Abstract (up to 300 words)	The evaluation of geothermal fields includes several techniques to assess the thermal properties and to utilize the energy potential. Geothermal mapping and numerical simulation techniques contribute to the understanding of the thermal structure and fluid composition in reservoirs. Among these methods, heat flow determination using thermal gradient/heat flow estimates from deep wells and geothermometer techniques is widely recognized as a reliable approach for geothermal exploration. This study focuses on the Dikili-Bergama geothermal region and presents the heat flow trends based on a thermal model. The gradient varies between 66.28 ^{0}C/km and 121.68 ^{0}C/km, with the western part of the study area showing particularly high values. Thermal conductivity properties and correlations, together with the assessment of heat flow, contribute to the understanding of the geothermal potential. The heat flow data obtained from the thermal conductivity coefficients of volcanic and plutonic rocks are supported by radioactive heat flow data. The integration of 3D geological modelling and numerical temperature models provides insights into geothermal reserves. The results provide valuable data for future detailed geothermal research and highlight the importance of heat flow in the characterization of geological formations. *<u>Keywords:</u>* Geothermal exploration, thermal conductivity, heat flow analysis, thermal modelling, Western Anatolia

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Selected Session *	4. Deep Geothermal
Title of Abstract	Structural controls of geothermal systems in the Northern Volcanic Zone, Iceland
Abstract (up to 300 words)	Structures such as fractures and faults play an important role as fluid flow pathways in geothermal reservoirs located in active tectonic regions. Fracture networks might act as either conduits or barriers and control the subsurface fluid flow processes. As such, understanding and characterization of this structural network is key for the long-term productivity and sustainable utilization of geothermal resources. High-temperature geothermal areas are located on active plate boundaries of the Northern Volcanic Zone (NVZ), which represents the surface extension of the Mid-Atlantic Ridge in the northern part of Iceland. This project focusses on the Þeistareykir and Krafla fissure swarms of the NVZ in NE Iceland. Although these fields are known to be fracture-controlled due to rift and transform zone tectonics, it is critical to investigate the extent and impact of structural constraints on fluids and heat flow in these volcanically-driven geothermal systems. The project will build upon an extensive array of geological and geophysical datasets, including, satellite images, fieldwork, core samples, well flow tests, geochemical analysis, microseismics, downhole petrophysical data and borehole images from across the two sites. It will integrate all surface and sub-surface structural analysis with 3D geological modelling techniques to develop initial fracture network models under current stress environments and assess the tendency of faults to slip or dilate, and how this impacts fluid flow in the system. This could then be extended to dynamic modelling of fluid flow through the discrete fracture network and examine the impact of changing stress environments, coupled to subsurface pressure and temperature changes. This study will lead to a better understanding of the geothermal reservoir boundaries, investigating how faults structures may compartmentalize geothermal reservoir and restrict lateral and vertical connectivity, or the impact of possible reactivation of favourably oriented structures, allowing the prediction and visualization of permeability distribution and fluid pathways. Keywords: Geothermal system, faults and fractures, stress state, fluid pathways, Iceland

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Selected Session	3. Shallow Geothermal
Title of Abstract	Enhancing Sustainable Urban Heating and Cooling with Groundwater Heat Pumps: A Case Study in Torino Urban City
Abstract	Groundwater Heat Pumps (GWHPs) are an efficient solution for reducing carbon emissions in heating and cooling systems in urban areas with favourable geological conditions. These systems draw water from shallow aquifers, undergo heat exchange processes, and return water at a modified temperature. It is important to preserve the groundwater quality of aquifers, which serve as renewable energy sources, for urban sustainability. In order to promote the adoption of GWHP, urban planning should be carried out while ensuring the long-term protection of groundwater. Torino Urban City has an alluvial shallow aquifer that is a valuable source of low-enthalpy geothermal energy. However, it is essential to conduct a comprehensive site assessment to evaluate the environmental impacts, taking into account well characteristics, locations, pumping rates, and thermal effects on local groundwater resources. A model and numerical simulations were developed to analyze two scenarios of over 150 geothermal wells in Torino City, accounting for maximum and average flow rates. The aim was to define changes in piezometric levels and the extent of thermally affected zones. The results at an average flow rate indicate that energy extraction is possible with minimal environmental impact due to the hydrogeological characteristics. The thermal plumes, which are shaped by water extraction and reinjection rates, have an impact only on downstream neighbouring plants. Accurate hydrogeological characterization is crucial for constructing new facilities, as positive aquifer responses to long-term disturbances demonstrate. The proposed urban-scale model is a valuable tool for experts and authorities, enabling the assessment of thermal disruptions at both localized and urban levels. Using this tool ensures the sustainable use of aquifer resources in complex systems, promoting informed decision-making for urban heating and cooling strategies.

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Selected Session *	2. Underground Thermal Energy Storage (UTES)
Title of Abstract	Modelling the design of a combined ATES and groundwater remediation system under the constraints of an urban environment
Abstract (up to 300 words)	In the KONATES project, a pilot-scale Aquifer Thermal Energy Storage (ATES) system is set up in the scientific park of Leipzig. The groundwater in the shallow quaternary aquifer is contaminated with chlorinated hydrocarbons up to several mg/L. As a proof of concept for the feasibility of combining remediation and thermal energy storage, a coupled surface-subsurface remediation system is being designed. Under the regulatory limitations on ATES operation in an urban area, it has to be ensured that the temperature increase at the boundary of the property does not exceed a few degrees Celsius. This poses a challenge as the planned injection temperature is around 80°C. Careful planning of injection and extraction cycles, as well as flow rates, is necessary to meet these requirements. The urban environment also presents additional complexities, such as dense surface and subsurface infrastructure, and the need for a dense grid of monitoring wells to observe the hydraulic, thermal, hydro-geochemical and microbiological changes during the ATES operation phases. To address these challenges, a 3D numerical model that simulates hydraulic and heat transport processes in the aquifer during ATES operation has been developed. The model is capable of predicting the propagation of the thermal plume based on different injection duration and flow rates. Following regulatory requirements as well as aquifer heterogeneities and high groundwater flow velocity, the modelling result suggests that an operational schedule of two 12-day cycles of injection each followed by a 12-day extraction periods, with a pumping rate of 600 l/h will result in a smaller than 4°C temperature change at the boundary of the property. This work demonstrates the potential of 3D coupled hydrothermal models in designing ATES systems that meet regulatory requirements and site-specific limitations.

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Selected Session *	6. Ultra Deep Geothermal (UDG)/Enhanced Geothermal Systems (EGS)
Title of Abstract	CO_2 and water as a working fluids – performance analysis of EGS technology – case study in Poland
Abstract (up to 300 words)	Research of this study is focused on performance analysis of geothermal working fluids in EGS technology. Water is the most common fluid among the whole geothermal industry, however, CO_2 is considered as a potential fluid to replace it, especially in the supercritical state. It is possible due to thermodynamic properties such as mobility, ability to geological sequestration or Joule-Thomson effect. EGS model is developed in IPSEpro software, where various direct and indirect topside systems are analyzed. REFPROP software is employed to check some thermodynamic properties of fluid in any elements of the system. Built model is based on reservoir model of volcanic and sedimentary rocks of Gorzów Block, the possible location of EGS in Poland. Research about various fluids in EGS were conducted by other researchers, such as Olasolo et al. (2016 and 2018), Kumari and Ranjith (2019) or Singh et al. (2023). Acknowledgements Research project supported by program „Excellence initiative – research university" for the AGH University of Krakow. The research leading to these results has received funding from the Norway Grants 2014-2021 via the National Centre for Research and Development. The results presented are part of the Polish–Norwegian project: CO2-Enhanced Geothermal Systems for Climate Neutral Energy Supply, acronym EnerGizerS, registration number NOR/POLNOR/EnerGizerS/0036/2019.

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Selected Session *	3 Shallow Geothermal
Title of Abstract	Passive fiber-optic sensing for monitoring shallow geothermal systems
Abstract (up to 300 words)	Fiber-optic sensing has become an increasingly popular tool in both geoscientific research and industries over the last years, including for downhole applications. Unlike conventional borehole instruments, distributed strain sensing (DSS) offers high spatial and temporal resolution, while Fiber Bragg gratings (FBG) allow to take precise point measurements of temperature or strain at specific depths. Both technologies are relatively easy to deploy and do not interfere with operations, making this type of sensors highly attractive for the monitoring of geothermal operations across scales and in different geologic settings. Here we present a first analysis from both DSS and quasi-distributed FBG measurements in a future shallow low-enthalpy geothermal heating system in Brussels, Belgium. Throughout this project, we aim to estimate the potential of passive, noise-based seismic methods to monitor all stages of geothermal production in space and time. For this, fourteen 120m deep geothermal probes were equipped with different combinations of temperature and strain sensing FBG arrays and DSS cables. Preliminary results show the possibility of a purely noise-based borehole logging by calculating the seismic noise amplitude over depth. Regularly obtaining temperature profiles allows to estimate the local geothermal gradient and its variability after wellbore completion. Both is essential to better characterize and understand geothermal systems.

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Selected Session *	2. Underground Thermal Energy Storage (UTES)
Title of Abstract	Modeling the geomechanical effects of seasonal heat storage in an abandoned coal mine

Abstract (up to 300 words)	The Ruhr region is undergoing a profound transformation toward renewable energy solutions with the ending of traditional coal mining and steel industry. To meet the increasing demand for sustainable energy supply, the successful implementation of renewable energy and energy storage concepts is necessary, such as deep geothermal or solar energy. Particularly in the Ruhr region with its long mining history, disused coal mines possess a considerable geothermal potential when using as seasonal heat storage. The water and surrounding rocks of those so called mine thermal energy storage (MTES) systems are heated with a surplus of heat. The excess heat can be generated by solar collectors or waste heat during the summer and is then stored in the subsurface. During winter, this heat is extracted to heat the local buildings. However, thermal stress induced by the reinjection of hot water can cause local fault systems to reactivate causing induced seismicity as well as local uplift or subsidence phenomena. Therefore, a comprehensive condition monitoring of a MTES testing site is required to ensure a safe, long term operation. As a result, in the WINZER pilot study a condition monitoring was established for the operation of a small scale MTES pilot site at the locality Fraunhofer IEG in Bochum. For this study, a model of the mine layout was digitized and meshed to model the thermomechanical behaviour of the mine during injection with temperatures up to 60°C. The THM model will be implemented in the software MOOSE. The mechanical rock properties will be generated by triaxial experiments at the corresponding pressures and temperatures. Furthermore, the model will be validated with real-time data from the condition monitoring as in-situ pressure and temperature conditions, but also stress measurements at the old mining shafts.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Well logging data analysis using unsupervised machine learning for crystalline rock unit prediction in Krafla geothermal field in Iceland
Abstract (up to 300 words)	Keywords: Gaussian Mixture Model (GMM), Unsupervised Machine Learning,

	IDDP-1, Well Logging data, Rock Type **Objectives:** Understanding subsurface geology is pivotal for safe exploration and efficient exploitation of supercritical geothermal resources, especially in active volcanic areas like Iceland. The IDDP-1 well in the Krafla geothermal field aimed for 4-5 km depth to tap into supercritical conditions. However, drilling ceased at 2.1 km due to an unexpected magma encounter. Despite high productivity and bottom-hole temperature, the intended target depth was not reached. Missing cuttings hindered understanding of the encountered formations, rock-magma interface, and limited the completeness of the lithology log. **Procedure:** Unsupervised machine learning algorithms play a crucial role in clustering large data sets into groups of similar characteristics. Gamma Ray, Resistivity, Neutron and Calliper row data from IDDP-1 were used to form clusters based on similar data features using Gaussian Mixture Model (GMM). Subsequently statistical data analysis was performed using python scripts. Finally, the results were validated by comparing them with the available lithological descriptions. **Results and Conclusion:** Well log data was effectively clustered into broad classes of igneous rock types, including mafic, intermediate and felsic. The statistical analysis and correlation with lithological description proved instrumental in attributing intervals with missing cuttings to these generalized rock mass classifications, thereby enhancing the prediction of the lithological nature of these intervals. This process enabled the regeneration of composite logs, allowing the division of the entire borehole stratigraphy into intervals with similar properties. Moreover, the algorithm is believed to have accurately identified the transition zone from rock to magma, as it has been clustered independently. The results obtained will provide valuable support for the next drilling stage by offering insight into the depth and nature of encountered rock masses, lithological boundaries, and the rock-magma interface. This will be possible to achieve without waiting for the cuttings to emerge to the surface, utilizing real-time logging data.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Syn-rift fluvial deposits as geothermal reservoir: a case study from the West Netherlands Basin
Abstract (up to 300 words)	Being directly located underneath one of the most densely populated areas of the Netherlands, the West Netherlands Basin is an ideal spot for geothermal energy. Currently, the area has 14 realized projects and at least 3 in the development phase, with the syn-rift deposits of the Late Jurassic Nieuwerkerk Formation defining the main target. The West Netherlands Basin developed during Mesozoic multi-phase rifting, whereafter the area inverted during the Late Cretaceous. With publicly available seismic and well data, we identified two important rifting episodes during the Jurassic: the first one during the Early Jurassic and the second one, partly controlled by structures of the former, during the Late Jurassic, coinciding with the deposition of the fluvial-deltaic Nieuwerkerk Formation. Multi-phase rifting and its interplay of faults controlled the localized creation of sediment accommodation. This had a strong influence on the architecture of the fluvial system that deposited the Nieuwerkerk Formation. As a result, the distribution of its sandy facies is highly heterogeneous, causing lateral and vertical variations in porosity, permeability and net-to-gross. Our (re)interpretation, helps to understand the depositional environment of the Nieuwerkerk Formation and its structurally-controlled evolution, and thus, reduce the risk of geothermal well planning for fluvial sandstone reservoirs in inverted rift basins.

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Selected Session *	4. Deep Geothermal
Title of Abstract	SpiderTherm: Optimizing Geothermal Extraction for Sustainable Energy Transition
Abstract (up to 300 words)	Geothermal energy, characterized by its ubiquity and continuous availability, presents a promising solution for meeting thermal and electrical needs in residential, industrial, and renewable energy sectors. Geothermal fluids, categorized by temperature range, have diverse applications ranging from greenhouse heating to electricity production. Traditional geothermal methods face challenges in exploration, production, and environmental impact, with economic feasibility constraints. Retrofitting abandoned wells emerges as a cost-effective alternative, addressing economic limitations. A promising approach, the deep closed-loop geothermal system (DCHE), horizontally connects multiple wells to enhance efficiency. This study investigates the long-term performance of a novel DCHE configuration, exploring parameters such as number of reused wells, vertical and horizontal lengths, flow rate, injection temperature, heat exchange, and geothermal gradient. The objective is to identify conditions achieving the minimum recommended long-term production temperature of 100°C for binary geothermal power plants. Initially, numerical simulations using COMSOL 6.1 faced computational time limitations, leading to the exploration of deep learning, specifically Long-Short Term Memory (LSTM) neural networks, as a faster alternative. The LSTM system was trained using COMSOL results, and different learning strategies (curriculum and non-curriculum) were tested to compare the convergence speed and temperature forecasting accuracy over a ten-year production period. Applying these concepts to a case study in Cesano (Central Italy) and incorporating geological, geothermal and drilling information, numerical simulations predicted a production temperature of 139.57 °C in a 3-branch DCHE configuration. In comparison, the LSTM neural network, trained with curriculum and non-curriculum learning strategies, predicted temperatures of 136.8 °C and 95.7 °C, with absolute errors of 2.77 °C and 41.1°C, respectively. This highlights the potential of LSTM for accurate long-term production temperature predictions, offering an efficient alternative to time-consuming numerical simulations.

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Selected Session *	2. Underground Thermal Energy Storage (UTES)
Title of Abstract	High-Temperature Aquifer Thermal Energy Storage (HT-ATES) in the Upper Jurassic geothermal reservoir of the German Molasse Basin
Abstract (up to 300 words)	The successful development of High-Temperature Aquifer Thermal Energy Storage (HT-ATES) (> 50 °C) systems relies on the reservoir conditions and rock properties targeted for heat storage. Those parameters in conjunction with the assigned operational scheme will determine the HT-ATES system performance. Here, we assess numerically the storage of high-temperature fluids in the Upper Jurassic geothermal reservoir of the North Alpine Foreland Basin. The multiphysics numerical model derives from three operating geothermal sites of the German Molasse Basin at depths of ca. 2000-3000 m TVD, whereas a feasible reservoir-specific operation design is implemented. The 500 m thick reservoir, usually investigated as a single homogeneous entity, is subdivided into three homogeneous zones of distinct permeability based on borehole logging interpretation. This vertical heterogeneity in the permeability space enables to decipher conclusions on favorable fluid and heat migration, and thus on heat recovery efficiencies in such a multilayered reservoir. Previously performed field tests, borehole logs and rock core analyses are deployed to summarize encountered ranges of the reservoir rock properties. The reference numerical model, populated with average values of the collected property-ranges, reflects dominant thermal front propagation in the high-permeability zone. Stemming from the structural and geological reservoir heterogeneity, and thus variability in rock properties, we further evaluate additional heat storage scenarios. Those aim to examine, for instance, any thermal and hydraulic interference between injection and production, or the development of advective heat losses induced by high flow rates and conductive heat losses associated with increase of the contact-surface area between thermal front and adjacent reservoir layers as well as rock matrix. Additionally, through the consideration of density and viscosity variation (IAPWS thermodynamic property formulations), we investigate the occurrence of density-induced buoyancy as this is promoted by enhanced permeabilities. These are critical parameters affecting significantly the thermal efficiency of the developed HT-ATES system.

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Selected Session *	4. Deep Geothermal
Title of Abstract	An experimental design study to assess the impact of geological heterogeneity on the performance of low-enthalpy geothermal reservoirs
Abstract (up to 300 words)	Geological uncertainty is inherent to all subsurface reservoirs but particularly prominent in geothermal systems due to limited data availability. To assess how geological uncertainty could impact the performance and longevity of low-enthalpy geothermal reservoirs for district heating, a robust and efficient procedure is needed to analyse the interplay of a range of geologically realistic multi-scale heterogeneities and heat flow in the reservoir. In this contribution we use a design-of-experiment approach to systematically assess how a range of range of multi-scale and hierarchical sedimentological heterogeneities that are typically encountered in shallow marine depositional environments impact heat flow in a low-enthalpy geothermal reservoir. The geological heterogeneities vary in scale from centimetres (e.g., bioturbation) to kilometres in length (e.g., geometry of the shoreline). The 3D geological models are based on an open-access model ensemble that was created in the Rapid Reservoir Modelling (RRM) software. Heat flow simulations are carried out with a commercial reservoir simulator, considering 1 km spaced geothermal doublets of different orientations Our results demonstrate which scales and types of heterogeneity have a more profound effect on the efficiency of producing heat from low-enthalpy geothermal systems situated in shallow marine environments. Conversely, we also highlight which scales and types of heterogeneity can likely be excluded in reservoir modelling studies, which allows operators to focus their efforts on characterising and quantifying the types of heterogeneities that matter most to reservoir performance. We further highlight the importance of using geologically realistic models to capture geological uncertainty in a comprehensive way and tightly integrate geologically realistic reservoir modelling with reservoir simulation. We also suggest that efficient screening techniques could not only accelerate but also enhance the reliably of geothermal reservoir modelling and simulation studies in the future.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Discontinuity Associations in Outcrops as a Predictive Tool for Fracture Network Geometry in Fractured Geothermal Reservoirs
Abstract (up to 300 words)	Natural discontinuity networks control fluid flow in fractured geothermal reservoirs, and therefore need to be modelled. To derive statistical parameters for these discontinuity network models, outcrops are studied as an analogue for the reservoir. However, in many outcrop studies, for each discontinuity set observed, a different deformation event is interpreted. This overcomplicates the deformation history, and with that, it hampers the useability of the outcrop as an analogue for the subsurface. In this study, we investigate outcrops of Lower Cretaceous pre-foredeep carbonates that potentially are an analogue of a naturally fractured geothermal reservoir in the Geneva Basin, Switzerland. In these outcrops, we introduce the concept of discontinuity associations where sets of fractures, veins and stylolites that formed coeval in a single stress field are grouped together. To make the link between outcrops and the subsurface, we compare orientations of $\sigma 1$ in different outcrops, and deduce the relative timing of the associations in respect with tilting of the strata. The outcrops studied are in ranges southeast and northwest of the Geneva Basin (Bornes Massif, Salève and Jura, maximum ~30 km away from the basin). These ranges are structurally separated from each other by regional Alpine NW-verging thrusts. All three areas have two associations in common; one with $\sigma 1$ oriented ~NW-SE, and a second with $\sigma 1$ oriented ~E-W. They formed prior to tilting of the strata, and therefore we qualify this network as background and thus predict its presence in the subsurface of the Geneva Basin. To validate this prediction, we compare the results with fracture orientation data obtained from borehole images logs from two wells that penetrate the Lower Cretaceous in the basin. By comparing five independent fracture interpretations of bore-hole images, we analyse the uncertainty of these interpretation and how this affects the validation of the outcrop study.

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Selected Session *	Other
Title of Abstract	The potential of mine water for energy purposes.
Abstract (up to 300 words)	There is a huge amount of water in hard coal mines both active and abandoned mines. Which are required to be drained every day. Mines water is characterized by relatively high temperatures and high pollution. Poland relies predominantly on fossil fuels, with a primary focus on coal within its energy sector. The mining of hard coal stands out as a crucial industry in the country, primarily concentrated in the Upper Silesian Coal Basin (GZW) and the Lublin Coal Basin (LZW), where active mining operations take place. The utilization of mine waters discharged from both active and decommissioned mines extends to various energy applications, including serving as a foundational source for heat pumps. An estimated 600,000 cubic meters of relatively high-temperature water are daily pumped from coal mines situated in the Upper Silesian Coal Basin (GZW). Effectively managing these waters holds the potential to notably enhance the mines' profitability and concurrently contribute to environmental quality improvement by repurposing waste waters for energy applications. **Acknowledgments** Research project supported by program „Excellence initiative – research university" for the AGH University of Krakow". This study was funded by grant IDUB-AGH UST ID4192.

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Selected Session *	6. Other
Title of Abstract	Lithium From source to sink in geothermal brines of European crystalline massifs and their derived detrital rocks. (LiFE)
Abstract (up to 300 words)	The growing demand of lithium for battery production is driving the research for sustainable extraction methods. Geothermal waters, which are already extracted for energy production, offer a promising alternative to conventional lithium mining. This PhD project aims to investigate the geochemical link between deep continental rocks and the lithium content of geothermal waters. The project will focus on two geographical areas: the Upper Rhine Graben in France and Germany, and the Rheno-Hercynian area in Belgium. Samples of rocks, brines and springwaters will be collected from these regions for geochemical analysis. The results will be combined with existing literature data to identify patterns and relationships between rocks, waters, and lithium content. Geochemical modeling will be used to simulate the exchange processes between rocks and geothermal waters. The project's main topic is a better understanding of the different sources and sinks of lithium in geothermal systems, identification of potential lithium exploration and extraction areas in Europe.

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Selected Session *	4. Deep Geothermal
Title of Abstract	An integrated geological evaluation of the Lower Triassic Main Buntsandstein sandstones for deep geothermal applications in the southern Netherlands – HotTrias project
Abstract (up to 300 words)	Sandstones from the Main Buntsandstein Subgroup represent a promising deep geothermal target in the subsurface of the Netherlands considering their widespread distribution and temperatures locally reaching 140-150 °C at depths of ~ 3 to 5 km. The Main Buntsandstein Subgroup is a sand-prone interval, but the reservoir quality of these sandstones is known to be heterogeneous as result of an interplay between depositional and diagenetic processes. This makes the Buntsandstein sediments an uncertain and risky geothermal play. In this project, we assess the syn- and post-depositional history of these sediments. The aim is to define structural, sedimentary, and diagenetic heterogeneities within the Main Buntsandstein sediments and assess their impact on reservoir quality. This will help reduce uncertainties for geothermal operations in the Triassic in the southern Netherlands and beyond. The structural analysis of the study area using seismic and well data reveals that the Main Buntsandstein sediments represent an early syn-rift sequence and that their present-day distribution is strongly controlled by faulting. In parallel, the study of the sedimentology and stratigraphy conducted on core and wireline data indicates that the depositional environment evolves through the Buntsandstein stratigraphy, resulting in the development of different reservoir architectures. Diagenesis has largely altered the primary relationship between sedimentary facies and porosity and permeability. Overall cementation seems to have a larger impact on reducing reservoir quality than compaction, with quartz, dolomite, and illite representing the most abundant types of cement. The analysis of fractures using core and image logs suggests that the fracture density is driven by the lithological variability within the Main Buntsandstein and that fracture joints and stylolites locally may contribute to enhancing the system permeability. The integrated assessment of the results allows the development of prospect play maps for the Buntsandstein in the southern Netherlands, addressing uncertainties and providing future recommendations for further exploration and optimizing geothermal operations in the Triassic.

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Selected Session *	3. Shallow Geothermal
Title of Abstract	DTS monitoring of thermal transport in three aquifers across England, UK
Abstract (up to 300 words)	The sustainable management of aquifers as thermal reservoirs requires long-term monitoring. We explore the variability of aquifer storage and thermal transport by conducting controlled thermal tests at three sites across England, including monitoring in shallow boreholes instrumented with fibre-optic cable to facilitate distributed temperature sensing (DTS). The first site is located at the University of Leeds, as part of a geothermal campus development, and features six boreholes which intersect the Elland Flags (a fractured sandstone aquifer). Four boreholes have installed u-tubes for thermal response testing (TRT), three of these are drilled to 150 m bgl, with the fourth to 250 m bgl to reach the deeper Rough Rock aquifer. Additionally, there are two 250 m cored pilot holes which will allow detailed characterisation of the subsurface using a suite of petrographical, geophysical, and petrophysical techniques. The monitoring boreholes surround a pair of reversible abstraction/injection wells, planned to connect to a heat pump for building heating and cooling. The second site features six boreholes at Trumpletts Farm, Berkshire, which penetrate a fractured chalk aquifer to a maximum depth of 100 m. The third site is the Cheshire Observatory, operated by the British Geological Survey (BGS), which features twenty-one boreholes that are permanently instrumented for a variety of experimental applications. These boreholes penetrate the Sherwood Sandstone aquifer to a depth of 100 m. DTS measurements during TRTs at these sites will give real-time updates on borehole temperature profiles. They will allow any developing heat plumes from injection, or zones of cooling from abstraction, to be mapped, alongside complementary datasets. For sites two and three, these include data from geophysical, hydrogeological and geomicrobiological experiments conducted by our partners on the NERC-funded SmartRes project: Imperial College London, University of Manchester, and BGS. We present preliminary observations from the early phases of these experiments.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Full Waveform Inversion of Vertical Seismic Profiling Data for Monitoring the Geothermal Reservoir in Munich Schaftlarnstrasse
Abstract (up to 300 words)	Geothermal energy, a vital eco-friendly resource, significantly reduces our dependence on traditional fossil fuels by harnessing heat from subsurface reservoirs. Monitoring the extraction processes of this energy is crucial for its sustainable utilization. Our study intricately examines the geothermal reservoir beneath Schaftlarnstrasse in Munich, Germany, extending from 2.25 to 2.55 km, primarily serving district heating with hot water. Geophysical techniques, notably seismic full waveform inversion (FWI), offer high-resolution subsurface imaging. FWI resolution relies on processing seismic data with high frequencies, often attained through the surface-to-borehole (vertical profiling) setup, like Vertical Seismic Profiling (VSP) used in the Schaftlarnstrasse reservoir. The 2020 VSP survey aimed to establish a foundational subsurface model. It deployed a vibrator source at two locations, lowering receivers with three degrees of freedom and 15m spacing into a borehole, reaching approximately 2.58 km depth. We present VSP data from Schaftlarnstrasse, detailing preprocessing for 1D FWI suitability. Acknowledging the crucial role of a robust initial model, we introduce a 1D travel time tomography code tailored for Schaftlarnstrasse. Leveraging the Gauss-Newton method, this code simultaneously inverts data from two shoot positions, providing a refined initial model. FWI success relies on factors such as full waveform modeling, where accounting for attenuation improves images. Implementing the spectral ratio method determines the attenuation factor in Schaftlarnstrasse seismic data. Preliminary FWI results mark a significant step in unraveling this geothermal reservoir's structure. Our research contributes to sustainable geothermal energy exploitation, emphasizing advancements in monitoring and understanding subsurface dynamics for sustainable geothermal energy production.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Numerical simulation of induced seismicity in geothermal applications
Abstract (up to 300 words)	Geothermal energy production from deep reservoirs is a promising and green technology which can provide reliable heating for households and greenhouses. However, challenges in a geothermal field development might occur. In this study we address the induced seismicity risk. The change of reservoir pressure and temperature due to colder fluid injection, impacts the stress field. The stress changes introduce risks of fault reactivation and induced seismicity. The open-source DARTS (Delft Advanced Research Terra Simulator) framework have been extended to account for the thermo-poroelastic response relevant to geothermal applications. The developed geomechanical simulator has been applied to a synthetic geothermal reservoir to evaluate the geomechanical state of the field and assessment of the induced seismicity risk. We investigated how the fault reactivation depends on model parameters, such as permeability distribution, geomechanical properties, fault dip angle, well locations and regimes.

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Selected Session *	3. Shallow Geothermal
Title of Abstract	Rare Earth Element Geochemistry of Geothermal waters from the High Salinity geothermal field in Tuzla, Türkiye.
Abstract (up to 300 words)	Rare Earth Elements (REE) have become pervasive in many technologies, especially those for improving energy efficiency and in digital technologies. Exploration activity for REE has increased greatly in recent years and geothermal waters have emerged as a new potential resource. Geothermal fluids often contain high concentrations of dissolved metals and a mixture of gasses, some of which are of commercial interest. Certain elements, such as Li, are already known to occur in economically-relevant concentrations in geothermal fluids and efforts are already underway to extract them. Although elevated concentrations of other critical raw elements are also found in geothermal fluids (brine and gas phase) or in precipitates (solid phase that forms in geothermal environments = scaling), no large-scale commercial extraction has yet been carried out. Recently, (hyper-)saline, metal-rich brines (containing e.g. Cu, Li, Zn, Au, Ag) have been found to exist in active and dormant volcanoes around the world and commercial exploitation has been considered. The geothermal fluids from the Tuzla geothermal reservoir have been shown to be enriched in Li and Sr with values of up to 23 ppm and 142 ppm, respectively, making the Tuzla geothermal field a potential future target for Li extraction in Türkiye. The geothermal waters also contain significant concentrations of other critical elements, such as Pb, Ba, Rb, Zn, Cr, Zr and Co, typically concentrated in

	scalings. Here we report the first REE data from the geothermal fluids from Tuzla. The total REE concentration is up to 0.173 ng/g with a mid REE enrichment compared to light and heavy REE. Interestingly, the geothermal waters are characterised by positive Eu anomalies, suggesting that the fluids have experienced higher temperatures than previously thought.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Integrated seismic reservoir characterisation for fluvial geothermal reservoirs: an outlook
Abstract (up to 300 words)	Geothermal exploration of channelised fluvial deposits in deep subsurface reservoirs is essential for the shift of the Netherlands towards sustainable energy sources. However, interpreting fluvial sandbodies from seismic data is uncertain due to the challenge of detecting geological heterogeneities that control reservoir heat and fluid flow on multiple length scales. This PhD thesis aims to combine novel seismic reservoir characterisation approaches with advanced geostatistical, process-based and conceptual reservoir modelling methods for enhancing our understanding of how geological complexities and flow dynamics in fluvial geothermal systems affect seismic image quality. One tool that we are employing is Rapid Reservoir Modelling, which facilitates intuitive and rapid visual as well as quantitative 3D evaluation of digitally sketched geological ideas, offering an opportunity to build geologically realistic reservoir architectures. To quantify geological uncertainty, synthetic seismic responses will be created for these 3D models using seismic forward modelling. Subsequent research may focus on refining seismic image quality through varying seismic acquisition designs, investigating the influence of fluid temperature on synthetic seismic images, and applying our findings to the Delft Aardwarmte Project well doublet.
Keywords	channelised fluvial deposits; seismic reservoir characterisation; reservoir modelling; geological uncertainty; seismic imaging

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Selected Session *	4. Deep geothermal
Title of Abstract	Is geothermal energy sustainable?
Abstract (up to 300 words)	Keywords: deepGeothermal, sustainability, basinDevelopment, uncertainty The production of geothermal heat and energy is reliable, low in emissions and renewable within human timescales. Whether or not it can be considered sustainable however, depends on two main factors: The rate at which the extracted heat is naturally replaced, and the degree of unwanted interferences with the environment and other subsurface applications. In conduction dominated settings, an individual geothermal doublet will always cool its reservoir and is limited in its lifetime by the point of thermal breakthrough. This makes it inherently unsustainable in the strict sense of the term. But at larger temporal and spatial scales (i. e. basin scale with several sites and > 100 years) it may be possible to extract heat only at a rate at which it recovers. Basinwide development requires an understanding of the behaviour of each site (expected lifetime, heat production and recovery time) and of interference effects, (does reservoir cooling add up linearly or intensify with parallel extraction from one reservoir). Both are sensitive to geological conditions and operational parameters, which are rarely known in sufficient detail before the start of drilling and may remain uncertain even after production has started. It has been shown, for example, that even shifting a geothermal doublet by 50m can change estimated lifetime by ten years (Wang et al, 2023). In this project I use the finite volume simulator Delft Advanced Research Terra Simulator (DARTS) to perform sensitivity analysis on factors expected to impact the recovery time of geothermal operations. These include i) subsurface characterization, ii) definition of thermal breakthrough as a proxy for intensity of exploitation and iii) definition of recovery efficiency and its impact on long-term basin development with several use cycles.

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Selected Session *	6. Other – Ground Source Infrastructure De-Icing and Snow Melting Systems
Title of Abstract	Overview on the modeling approaches for Infrastructure De-Icing and Snow Melting using Geothermal Systems
Abstract (up to 300 words)	For several decades, hydronic and electric sub-surface heating systems have been employed to manage snow and ice on various paved surfaces, including viaducts, roads, walkways, airport aprons, and helicopter pads. Prioritizing winter transportation safety and preventing snow buildup and ice formation on such critical areas is crucial. Recently, automated hydronic snow melting systems have emerged as an alternative solution to salt application for preventing ice formation and melting snow on transportation infrastructure surfaces. In this context, shallow geothermal energy holds significant promise for replacing conventional energy sources. While these systems have been in use for several decades, their designs have traditionally relied on simplistic steady-state calculation methods. Modeling the process of snow melting on a heated surface is complicated by several factors, such as the complex heat and mass transfer mechanisms involved in the snow melting process, as well as the temporal and spatial variability of the surface and weather conditions. Moreover, during the geothermal de-icing system design phase, it is essential to assess the overall system performance by integrating various model types to account for climate interactions and energy storage considerations. To improve the creation of more efficient designs, various models for snow melting on hydronically-heated pavements using geothermal energy have been proposed to date. Such models vary in their capacity to address transient conditions and the level of complexity in representing surface conditions. This study aims to provide an overview of such methods by utilizing 30 illustrative examples, sourced from existing literature and arranged in a comprehensive database. This database functions as a valuable resource for extracting information related to both the components of the analyzed systems and the most prevalent and effective modeling approaches. The overarching objective is to create a practical tool that facilitates the efficient design of these systems, considering their extensive potential.

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Selected Session *	1. Above the Surface / 4. Deep geothermal
Title of Abstract	Comprehensive Analysis and Interdisciplinary Framework in geothermal Exploration – a case study of the Aachen Geothermal System (Germany)
Abstract (up to 300 words)	the comprehension of geothermal systems involves the efficient integration of geological, geophysical and geochemical tools that are crucial in unraveling the distinct features inherent in geothermal reservoirs. we seek to provide a first approach to comprehending the geologically complex geothermal system in the aachen area, which is known for its natural thermal spring occurrences since roman times. through a comprehensive analysis involving geochemical interpretation of water samples, a review of 2d seismic profiles, stress analysis, and surface geology, a dynamic model has been built, which serves as a conceptual framework providing a clearer understanding of the system. the model characterizes a non-magmatic, detachment fault-controlled convective thermal system, wherein the reservoir exhibits mixed properties of the mainly devonian carbonate rocks.. nw-se directed fault lines play a pivotal role in fluid transport, enabling the ascent of thermal waters without the need for additional energy. we additionally conducted magnetotelluric surveys and analysed apparent resistivity and impedance values obtained through forward modeling, along with an assessment of noise levels. these findings contribute to evaluating the potential use of mt methods in further exploring the geothermal prospects in the area.

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Selected Session *	3. Shallow Geothermal
Title of Abstract	PERFORMANCE ESTIMATION OF NEW BOREHOLE THERMAL ENERGY STORAGE SYSTEMS BY MEANS OF FEM AND CFD MODELING
Abstract (up to 300 words)	The rising demand for energy driven by factors such as population growth, industrial development, urbanization, and improved standards of living has raised significant challenges in the realm of energy production and distribution. To bridge this gap, enhancing thermal storage in the BTES system (Borehole Thermal Energy Storage) involves integrating the latent heat capability with the thermal conductivity. This work is finalized to evaluate the working conditions of Underground Thermal Energy Storage, by means of finite element numerical modelling, voted to reproduce the short and long time thermal storage behavior of borehole heat exchangers, by incorporating phase change material (PCM) into the well sealing grout, and considering high temperatures and depths. The utilization of PCM is voted to optimize thermal storage efficiency, addressing the challenges associated with energy storage and consumption in a more efficient and sustainable manner. The numerical simulation, coupled with a CFD method, applied in the research study, have provided interesting output useful to predict the best layout for the BTES system including PCM into the sealing grout. A comprehensive three-dimensional computational fluid dynamics simulation has been conducted obtaining exhaustive numerical analyses of heat transfer processes involved in BTES. The first results of the analyses show the dynamic behavior of the system during both PCM charging and discharging processes, providing an in-depth assessment of its thermal performance. Furthermore, to optimize the overall performance of the system, a sensitivity analyses has benne performed putting in evidence the marginal decrease in the thermal energy storage due to the increasing of BTES carrier fluid flow rate over a threshold value. The obtained results provide crucial insights for optimizing BTES systems, underscoring the advantages of integrating latent and sensible heat storage with innovative fluid flow strategies for improved the efficiency of this energy storage solution in renewable energy applications.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Optimizing Micro-CT Resolution for Geothermal Reservoir Characterization in the Pannonian Basin
Abstract (up to 300 words)	In the context of global efforts to transition towards renewable energy and reduce greenhouse gas emissions, geothermal energy is increasingly recognized as a viable and sustainable option. This paper presents a comprehensive assessment derived from a subset of a larger sample collection within the Dunántúli Group of the Pannonian Basin, Hungary. It focuses on optimizing micro-Computed Tomography (µ-CT) resolution for analyzing pore structures in sandstone formations. By categorizing samples based on geological properties and selecting representatives from each group, the study integrates helium porosity and gas permeability measurements with µ-CT imaging at various resolutions (5 µm, 2 µm, and 1 µm). The findings reveal that µ-CT resolution significantly affects the discernibility and characterization of pore structures. Finer resolutions (2 µm and 1 µm) effectively uncovered interconnected pore networks in medium to coarse-grained sandstones, indicating favorable properties for geothermal applications. Conversely, fine-grained samples showed limitations in geothermal applicability at higher resolutions due to compact nature and minimal pore connectivity, which could not be confidently imaged at 1 µm. The study also acknowledges the challenges in delineating boundaries within the Dunántúli Group Formations, adding complexity to the characterization process. The research underscores the importance of aligning µ-CT findings with geological backgrounds and laboratory measurements for accurate pore structure interpretation in heterogeneous formations. By providing vital petrophysical data for the Dunántúli Group and the Pannonian Basin, this study offers key insights for selecting appropriate µ-CT imaging resolutions, advancing sustainable geothermal energy strategies in the region. The outcomes of this research are fundamental for future studies aimed at developing experimental setups to investigate physical clogging and enhance geothermal exploitation methods, crucial for sustainable development of geothermal resources in the Pannonian Basin. Additionally, this study serves as a foundational guide for students and novice researchers in micro-CT and digital rock analysis. It offers a clear methodology and insights into selecting appropriate µ-CT resolutions, demystifying complexities in digital rock characterization and providing a practical starting point for newcomers in this field.

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Selected Session *	2. Underground Thermal Energy Storage
Title of Abstract	Assessment of the impact of heat losses from HT-ATES wells on the temperature of surrounding subsurface layers
Abstract (up to 300 words)	High Temperature Aquifer Thermal Energy Storage (HT-ATES) systems utilize tube wells to inject, store and recover heated groundwater (at e.g. 60 to 90 °C) from the subsurface. The thermal recovery efficiency of HT-ATES systems depend strongly on subsurface and operational conditions. The unrecovered heat is lost to the surrounding groundwater and subsurface layers that initially have lower ambient temperatures (e.g. 12 °C). As the resulting temperature increase could lead to undesired groundwater quality changes in surrounding subsurface layers, e.g. with respect to drinking water production purposes, it is important to know how heat losses from HT-ATES systems are being distributed through a groundwater system, both spatially and in time. Since multiple processes (e.g. conduction and buoyancy flow) may affect the transport of the lost heat, both the storage conditions (e.g. storage temperature and volume) and hydrogeological setting are likely to impact the rate and extent of the heat transport. Therefore, in this study, we investigated heat and temperature distribution development from an HT-ATES storage aquifer in all directions, for varying subsurface and storage conditions by a combination of numerical simulations and analytical approaches. Results show that the vertical temperature increase is generally strongest in the upward direction due to buoyancy-driven flow, which is influenced by subsurface hydrogeological conditions of the layers above and below the storage aquifer. Horizontally, the temperature increase beyond the thermal radius (the minimal radial distance from the well that will be heated) is mainly influenced by the degree of buoyancy-driven flow in the aquifer, which is influenced by the storage geometry of the system, and the hydraulic conductivity of the aquifer. The insights from this study allow the anticipation of thermal impact based on storage and hydrogeological conditions. This can be used as a consideration in HT-ATES design to minimize undesired long-term subsurface temperature effects of these systems.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Numerical modelling of the Asal Goubbhet rift (Djibouti) geothermal field.
Abstract (up to words)	The Asal-Goubbet rift is one of the youngest and most active segments of rift within the Afar Depression, boasting tectonic and magmatic processes dating back to less than a million years. Its notable features include steep thermal gradients, ranging from 14°C to 20°C per 100 meters, attributed primarily to shallow magma intrusion. However, despite these promising thermal conditions, the exploitation of geothermal resources in the Asal area encounters significant challenges, with several initially promising sites yielding disappointing results. These challenges are largely rooted in an incomplete understanding of the complex geothermal system at play. To address this knowledge gap, this thesis undertook the construction of a preliminary 3D structural geological model of the Asal rift zone using advanced software tools such as SKUA-GOCAD®. Given the scarcity of available data, a multidisciplinary approach combining drilling data, surface geology observations, and structural analyses was adopted to generate four representative geological cross-sections. These cross-sections serve as the foundation for the development of the 3D model, which delineates four distinct geological units, each composed of different facies, and identifies 17 parallel normal fault planes aligned with the rift axis. These fault planes exhibit predominant NW to SE orientations and dips ranging between 60 and 80 degrees. This 3D geological model represents an essential initial phase in the broader endeavor of simulating heat and fluid dynamics within the Asal rift zone. By using numerical simulations, this thesis aims to find the intricate interplay between geological structures, and fluid flow pathways, getting a deeper insight into the geothermal system's behavior. Such knowledge is indispensable to support the geothermal resource exploration and exploitation at the Asal Goubbhet rift.

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Country	France - Belgium
Selected Session *	5. Enhanced Geothermal Systems (EGS)
Title of Abstract	Geochemical characterization and temperature quantification of a clay rich shear zone and associated fluid circulation in the Black Forest (Germany)
Abstract (up to 300 words)	In the Upper Rhine Graben (Eastern France and Western Germany), enhanced geothermal systems collect hot brines within natural fracture networks crosscutting the crystalline basement at kilometre depths. The permeability of fracture zones is dependent on their deformation and hydrothermal alteration history, inducing permeability uncertainties for drilled targets during geothermal operations. To better characterize fracture networks, a clay rich shear zone within a gneiss body is studied in the Schauinsland mine (Black Forest, Germany) as a sub-surface 3D analogue for crystalline geothermal reservoirs. In this analogue, a perpendicular ore vein disappears close to the fault core of the shear zone and is considered to result from the circulation of a hot brine. The gneiss through the shear zone was geochemically characterized to highlight the influence of hydrothermal alteration on the structure permeability. Major element concentrations were quantified using micro X-ray fluorescence while the trace element concentrations, including those of the REE were determined by using ICP-MS to constrain the geochemical signature of the damage and core zones of the shear zone. This will provide novel insights on dissolution and precipitation phenomena within the fractures and their wall-rocks by identifying elements transported from the gneiss. Clumped isotopes on carbonate veins sampled in the gneiss and within the damage and core zone were measured to obtain the origin of the brine fluid (T, $d^{18}O_f$). This might reveal the presence of a single or multiple fluids that have circulated in various parts of the shear zone. Compared to previous results on the petrophysical and mineralogical properties of the shear zone, the study will yield insights on which parts of a fault zone remain permeable after various episodes of shearing and fluid circulation.

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Selected Session *	1. Above the Surface
Title of Abstract	Application of UAV thermal imaging for geothermal prospecting in low-temperature hydrothermal systems: case studies in Croatia.
Abstract (up to 300 words)	Thermal imaging was employed in three hydrothermal systems in Croatia (Daruvar, Hrvatsko zagorje and Topusko) to detect low-temperature surface hydrothermal manifestations, especially subthermal springs (13 – 20 °C). Additionally, the effectiveness of such remote sensing method for the initial phase of geothermal surveys and monitoring of surface geothermal anomalies was assessed. Presented methodology utilises GIS tools to identify potential zones of subthermal water outflow in the hinterlands of thermal springs based on the analysis of thermal orthomosaics derived from photogrammetric reconstruction of thermal infrared images. The fixed-wing eBee Plus RTK, equipped with a senseFly thermoMap camera, was used to acquire thermal images, which were processed using the Pix4Dmapper software. Direct temperatures of various water bodies and ground surfaces were recorded to evaluate the accuracy of captured temperature values. The thermal image acquisition took place in the cold part of 2022. A total of 33,1 km^2 was imaged with an average ground sampling distance of around 20 cm. Thermal maps were obtained as infrared reflection maps and indexed temperature maps. Contrary to the manufacturer's specification, the temperature maps (a TIFF image) show inaccurate values that differ from measured temperatures on the ground. Therefore, radiometric calibration of thermal images was done based on the linear relationship between radiometric values and direct ground surface temperature measurements. The methodology was tested in Daruvar hydrothermal system, where subthermal spring Isić (15 °C) was previously verified. A thermal anomaly was visually detected in a temperature map at the subthermal spring location, indicating the applicability of the method in surface investigation of low-temperature geothermal systems. This methodology faces some limitations due to a narrow favourable period for thermal data acquisition, demanding flying permitting legislation, or the need for sampling ground temperature control points for image calibration, which slows down the process. **Key words:** thermal imaging, UAV, subthermal spring, hydrothermal system, Croatia

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Selected Session *	5. Enhanced Geothermal Systems
Title of Abstract	Balancing fracture permeability and induced seismicity with feedback-controlled injection
Abstract (up to 300 words)	The application of hydraulic simulation to improve permeability in geothermal systems is a frequently used approach to optimize heat extraction efficiency. However, an undesired consequence can be potentially damaging induced seismicity, which is currently a challenge to mitigate. The aim of this study is to investigate the relationship between injection parameters, fracture aperture, slip and slip velocity in order to develop safe and efficient injection protocols, giving guidance on how to enhance the permeability in geothermal systems while mitigating seismic hazards. In a first step, we use finite element models of laboratory experiments to validate our simulation approach and explore injection criteria. Next, we will apply the knowledge from laboratory scale models to field scale simulations of the Balmat geothermal site in Belgium to investigate the influence of feedback-controlled injection schemes on induced seismicity and permeability.

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Selected Session *	3. Shallow Geothermal
Title of Abstract	Machine learning approach to improve shallow geothermal efficiency by accurate groundwater temperature prediction: A Case Study in Austria
Abstract (up to 300 words)	Accurate groundwater temperature (GWT) prediction is vital in assessing the potential and efficiency of shallow geothermal systems, especially for the heating and cooling of buildings. Weather is a factor that significantly affects GWT; therefore, leveraging weather data to predict GWT offers a cost-effective solution compared to on-site measurement. Implementing machine learning (ML) models promotes the accuracy of such predictions. This paper proposes a comprehensive investigation of predicting accurate GWT from weather data using ML models. We employed comprehensive historical datasets of weather as input data, Linear Regression (LR), Support Vector Machine (SVM), and Random Forest (RF) as ML models, and the corresponding GWT for a location in Vienna, Austria, as the target variable. We examined several feature sets using PCA and SBS techniques to increase the accuracy of GWT predictions. Evaluation metrics containing R^2, mean squared error (MSE), and root mean squared error (RMSE) analyzed the performance of our ML models. The outcomes emphasize that the proposed ML models successfully predict GWT based on weather data with considerable precision. The proposed models generalize beyond the investigated location in Vienna and have the capability to predict GWT with available weather forecasts in other locations. We applied our models to other locations with considerably different geographical situations compared to Vienna. Some of these locations are in mountainous regions with weather conditions different from Vienna, which lies in a relatively flat and riverine landscape. The GWT predictions were satisfying, with 0.892, 0.008, and 0.091 for R^2 for MSE, and RMSE respectively indicating the models' applicability in various locations. This practical prediction method not only gets around the restrictions of local measurement but enhances our understanding of climate-geothermal interactions.

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Selected Session *	2. Underground Thermal Energy Storage (UTES)
Title of Abstract	Stability Analysis of Expanded Diameter Boreholes in Unconsolidated Formations
Abstract (up to 300 words)	High-Temperature Aquifer Thermal Energy Storage (HT-ATES) systems offer a promising solution for cost-effectively storing large volumes of thermal energy, thereby bridging the supply-demand gap for various demand profiles and renewable heat sources. These systems utilise tube wells to inject and extract heated and cooled groundwater into aquifers. At TU Delft, an HT-ATES system is being developed, which involves the use of Expanded Diameter Gravel Wells (EDGW) to increase well capacity and reduce mechanical clogging compared to conventional wells. This has the potential to reduce costs by expanding life time and/or reduce the number of wells needed for HT-ATES systems. However, challenges in the drilling process concerning the stability of expanded boreholes have previously been encountered. Preceding attempts at borehole expansion in unconsolidated formations using a jetting technique sometimes resulted in collapse during drilling, highlighting the need for a thorough investigation into well stability to optimise drilling procedures. This study aims to fill this need by analysing the effects of borehole enlargement on stability through theoretical analysis. Initial two-dimensional analysis in the axial plane indicates minimal influence of borehole radius on effective stresses, suggesting no additional risk of instability in enlarged boreholes compared with conventionally sized boreholes. Conversely, the presence of a filter cake, which reduces permeability near the wellbore, significantly impacts wellbore strengthening. Further assessment through quasi 3D (axisymmetric) numerical analysis explores the stability of expanded boreholes in the longitudinal plane. In addition to the role of the filter cake, this evaluation also considers factors, including the influence of thin clay/silt layers and the stability of the borehole roof.

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Selected Session *	4. Deep geothermal
Title of Abstract	Surface Wave Anisotropy in Geothermal Fields/Prospects: Insights from Wavefield Modelling
Abstract (up to 300 words)	Characterization of faults and fractures is crucial for the development of geothermal fields as they provide secondary permeability, making them essential parameters in geothermal exploration. Using ambient seismic noise for mapping and monitoring geothermal fields provides a cheaper and widely available alternative to active seismic methods. In this study, we used three-component (3C) beamforming of ambient seismic noise (B3AM) to analyse fault-related surface wave anisotropy and anisotropy in the form of the point of contact with surrounding rock and hot radiogenic granite. 3C beamforming is an array-based method that extracts the polarizations (wave type), azimuths (direction), and phase velocities of coherent waves as a function of frequency, providing a detailed comprehension of the surface wave velocities at different azimuths and depths. Wavefield modelling was used to gain further insight into the Rayleigh wave behaviour in fractured and granite pluton media and the implications for applying B3AM in these situations. Anisotropic velocities can be caused by the presence of faults and boundaries between rocks, indicating the maximum depth of permeability and location of prospects. Several simulations were tested, some with faults of varying parameters in a homogeneous medium and others with a media with a dominant fabric and a granite pluton at depth; this was done to imitate several geothermal fields/prospects with known geological parameters. We show that anisotropic behaviour can be reproduced in the numerical models, however, the analysis of synthetic data suggests that surface wave anisotropy is much more sensitive to the overall geological setting and the parameters of the fault (and not just to the presence of a fault). Furthermore, the ratio between recorded wavelengths and dominant features plays a vital role in the analysis and must be considered in the ambient noise analysis.

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Selected Session *	2. Underground Thermal Energy Storage (UTES)
Title of Abstract	HT-ATES reservoir characterization using borehole and core data
Abstract (up to 300 words)	Enabling a climate-neutral transformation of the heating sector is key challenge for the transition to sustainable energy usage, and geothermal energy stands out as a promising local solution to meet climate protection objectives. The recent boom of deep geothermal energy production in the URG (Upper Rhine Graben) can produce a base load with excess heat in summer and deficit in winter. Heat storage increase the efficient use of deep geothermal heat production. Utilizing existing and forthcoming borehole measurements and core data allows the establishment of a geological model based on correlations, describing the potential sandstone horizon layers in the reservoirs and finally provides the basis of a tool to delimit the regional heat storage potential. An extensive borehole data analysis, based on 1200 logs north of Karlsruhe, Germany, reveals insights. Self-potential logs aid in precisely locating sandstone layers, correlating with core data analyses. The correlation of sandstone layers varies based on their depositional origin, with marine Oligocene Meletta sandstones exhibiting widespread deposition, while sandstones from the brackish to lacustrine Niederrödern Formation show thickness variations. These findings underscore the importance of investigating deeper layers beneath Karlsruhe to understand their heat storage potential. The planned research infrastructure, DeepStor, at KIT-Campus North, aims to explore high-temperature aquifer thermal energy storage (HT-ATES). It will contribute data to comprehend small-scale depositional and petrophysical changes in reservoir rocks. Currently, two boreholes are scheduled for drilling on the KIT-campus North site. The objective is to investigate thermal, hydraulic, mechanical, and chemical processes within the potential storage aquifer, specifically targeting calcareous sandstone horizons between 800 and 1300 meters at the periphery of the former Leopoldshafen oil field. This research is crucial for advancing our understanding of geothermal energy storage and its role in achieving climate protection objectives.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Modelling & Optimization of Geothermal Energy in the Gulf of Suez
Abstract (up to 300 words)	Geothermal energy in Egypt represents a huge untapped renewable resource that can reduce reliance on conventional sources for power generation. Exploitation of these geothermal resources is depth-, temperature range-, and geological characteristics-dependent. The intracontinental rift setting of the Gulf of Suez-Red Sea rift is a favourable tectonic setting for convection-dominated geothermal plays. These fault and/or fault leakage-controlled systems are associated with high enthalpy and high geothermal gradients, which are enhanced by the natural occurrence of fluid flow and favourable fluid dynamics. The Geothermal gradient across the Gulf of Suez ranges from 24.9 to 86.66 °C Km^{-1} and heat flow range of 31 – 127.2 m W K^{-1}. These heat anomalies can be classified as low to medium enthalpy systems whereas the depocenters of the rift characterize high enthalpy settings. Surface expressions of convective heat loss emerge along the gulf flanks as hot springs (including Hammam Faraun, Hamam Musa, Ayun Musa, Sudr and Ain Sokhna) accompanying deeper geothermal resources. The thermal anomalies are mainly driven by the local tectonic configuration. Characterising the structural framework of the major faults and their control on reservoir properties and subsurface circulation of hydrothermal fluids is vital for geothermal application in the gulf. The geothermal play systems of the Gulf of Suez are dependent on structural and stratal properties contributing to heat storage and vertical transportation. Potential geothermal reservoirs include the Nubia sandstones, which consists of porous fluvial, deltaic to shallow marine sandstones. Their thickness, continuity and contact with hot basement rocks at a mean depth of 3km creates an extensive reservoir for geothermal fluids. To develop these geothermal resources for energy production, defining the permeability anisotropy of the reservoir due to faults and facies variation is a crucial step in our study, particularly evaluation of influence on thermal breakthrough and production rates.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Environmental Impacts of deep geothermal heat projects in the Southern German Molasse Basin
Abstract (up to 300 words)	To meet the challenges of the climate crisis, it is essential to increase the share of renewable energy sources, especially in the heating sector, which is currently dominated by fossil fuels. Deep geothermal energy, in particular in regions with favourable geological conditions, such as the Southern German Molasse Basin, is emerging as a viable alternative. To assess the environmental impact of these energy systems, a Life-Cycle Assessment is applied. In this study, currently operating heat plants in the greater Munich area are investigated. Particular emphasis is placed on aligning with the EU taxonomy CO_2equivalent (CO2e) threshold to meet the objectives of the Paris Climate Agreement goals. A key aspect of this alignment involves striving to achieve net-zero emissions by 2050. Therefore, mitigation strategies need to be identified. The findings show that peak load and redundancy coverage have a significant impact on greenhouse gas emissions with up to 62 %, attributed to the use of fossil-fueled boilers. To identify mitigation strategies, in this study sensitivity analyses are conducted to investigate the influence of peak load shares and redundancy coverage. Additionally, as a renewable fuel for the boilers biomethane is considered. In summary, transitioning to more renewable energy, like deep geothermal in regions like the Southern German Molasse Basin, is crucial for addressing the climate crisis. This study underscores the need to meet EU taxonomy CO_2e thresholds and reveals the massive impacts of peak load and redundancy coverage. The findings emphasize the necessity for strategic mitigation through optimizing peak load and redundancy coverage.

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Selected Session *	6. Other
Title of Abstract	Using Machine Learning to Characterize Fluid Flow Behaviour in Fractured Geothermal Reservoirs
Abstract (up to 300 words)	Geothermal reservoirs are recognized as a promising sustainable energy resource with a potential to play a crucial role in the shift to net-zero emissions. To maximize their potential, it is essential to understand the dynamics of heat and fluid flow within these reservoirs. Many geothermal reservoirs contain fractures, which enhance permeability and often comprise the primary reservoir permeability. Predicting heat and fluid flow behaviour in fractured (geothermal) reservoirs is notoriously challenging because fracture properties are difficult to constrain. Well testing and pressure transient analysis are key methods for reservoir characterisation and can help to quantify flow geometries in fractured reservoirs. However, existing methodologies for fractured reservoirs often provide limited insights, restricting a more in-depth characterization of fracture properties. In this study, we address this limitation by applying machine learning to classify pressure responses, aiming to offer a more comprehensive characterization of fracture properties and enhance the overall understanding of reservoir behaviour. We use an in-house Discrete Fracture Network generator to create diverse fracture network realizations representative of real-world scenarios. Advanced fluid flow simulations, facilitated by DARTS (Delft Advanced Research Terra Simulator), produced a dataset of synthetic pressure response data. These pressure responses were grouped using machine learning and clustering to extract key fracture characteristics that are representative of more complex fracture geometries and associated flow behaviours. First results indicate that this approach is effective in identifying and classifying pressure responses and hence provide deeper insights into the links between fracture properties and fluid flow. Future work aims towards maturing this methodology and aspired to develop a comprehensive framework for understanding the nuances of fracture network properties and their impact on pressure transient dynamics and heat flow in fractured geothermal reservoirs.

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Selected Session *	2. Underground Thermal Energy Storage (UTES)
Title of Abstract	The effect of doublet operation on well performance
Abstract (up to 300 words)	The cyclic operation of two boreholes simultaneously, in practice commonly addressed as a doublet or in theoretical treatments as a dipole, is central to heat and cold storage, and also geothermal energy provision. We examine pressure and flow records from operating a dipole configuration in a test field of four boreholes located close to the northwestern banks of an artificial freshwater reservoir, the Kemnader See, at the southern city-limits of Bochum, Germany, for the effect of the simultaneous periodic pumping in two boreholes on the hydraulic performance of either pumping well. We focus on the wells' injectivity, determined from spectral characteristics of flow rate and pressure. As references, we employ an analytical solution of the radial diffusion problem for a single borehole and a numerical solution of the corresponding superposition of analytical solutions. The derived solutions allow us to assess the effects of the injecting well on the yield of the producing well and vice versa. Solving and investigating this hydraulic problem constitute the necessary first step towards a thermal performance analysis.
Keywords	Geothermal, Doublet, Dipole, Injectivity, Periodic pumping

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Selected Session *	4. DEEP GEOTHERMAL
Title of Abstract	Assessment of the Geothermal Potential of a Petroleum Mature field in the Ecuadorian Amazon Region using Machine Learning Methods
Abstract (up to 300 words)	Energy multigeneration systems have gained worldwide attention for this reason this research aim is to quantify the potential geothermal energy yield through the application of machine learning methodologies within a mature petroleum reservoir situated in the Amazon region of Ecuador. The study compares the effectiveness of the Kozeny and Carmen algorithm in conjunction with Principal Component Analysis, Kriging, and upscaling against the K-nearest Neighbor Density estimation algorithm, Kriging, and upscaling in simulating a Sacha field area in Ecuador. The paper encompasses the entire simulation process, and the historical matching is achieved using the Particle Swarm Optimization Algorithm, with a focus on an objective function that emphasizes water production. Additionally, the Volumetric method is used to delimit the power production of the area. Furthermore, the paper proposes three scenarios for future power production strategies. The results demonstrate excellent history matching, with a water volume produced of 2.625 E+06 sm3 closely aligning with a simulation of 2.642 E+06 sm3 using the KyC-PCA-Kriging methodology. The reservoir has the potential to generate a maximum power of 1.39 MW based on Volumetric methodology. The average produced power may vary from 0.66 to 0.67 MW, depending on which of the three future scenarios will be applied until 2040.

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Selected Session *	6. Other
Title of Abstract	System Dynamics for Techno-Economic Evaluation of Geothermal Heating and Cooling
Abstract (up to 300 words)	In geothermal systems of many kinds there are shared system parameters which define the technical and economic feasibility of heating and cooling developments. These parameters exist in non-linear complex system interactions. It is often true that design and feasibility assessments take place in linear space without considerations for demand divergence, reservoir sustainability, or varying performance of equipment efficiency, among others. For example, future geothermal system assessment should operate in a space which allows developers to quickly quantify the impacts of climate change, grid emissions impacts, parasitic loads, or equipment lifetimes. This effort employs a preliminary working model of techno-economic assessment using System Dynamics. System Dynamics is a modeling framework developed by Massachusetts Institute of Technology staff in the 1950s which allows analysis to take place cyclically with dynamic feedback loops across component parts. In the context of geothermal heating and cooling systems, this preliminary work showcases component System Dynamics groups for aquifer characteristics, production and injection, central plants, cost and economics, demand models, pipe sizing, pipe flow, and heat exchangers. Together, the component groups allow users to perform broad sensitivity analysis and optimization within operational system boundaries or reality checks. This presentation will discuss the current component groups, benefits and limitations of the modeling framework, and a brief roadmap for future development of the model.

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Selected Session *	5. Ultra Deep Geothermal (UDG)/ Enhanced Geothermal Systems (EGS)
Title of Abstract	Geothermal energy prospecting in radiothermal granites in the Cairngorms, Scotland, using an integrated geological, geophysical and petrophysical approach
Abstract (up to 300 words)	The Cairngorm pluton granites, in NE Scotland, have the highest recorded heat-production values in the UK [1]. Despite these high values, geothermal exploration in the region has not progressed due to a combination of low heat-flow values measured from four shallow wells in the 1980s, and unknown flowrates at depth. A recent study [2] applied a more rigorous approach to revise heat-flow estimates from these wells, indicating a significantly increased temperature prediction at depth compared to the initial estimates. However, uncertainties regarding reservoir permeability, the presence of hot fluids, and the overall pluton structure still persist. A better understanding of these is vital in determining if economical flowrates of hot fluids can be sustained from depth. We plan to address these uncertainties by conducting a 3D broadband magnetotelluric (MT) survey and integrating the results with petrophysical data, observed on rock samples in the laboratory and in situ. We will investigate if zones of enhanced porosity and permeability will be detectable at depth by the MT survey. The initial field campaign, scheduled for summer 2024, aims to collect data at approximately 50 sites across the study area with a desired site spacing of 1-5 km. A subsequent campaign in 2025 is proposed to enhance the resolution in targeted regions. A 3D model of electrical resistivity extending to depths relevant for deep geothermal energy projects (>5km) will be derived from the MT data using sophisticated 3D inversion algorithms. The electrical resistivity, porosity, and permeability of granite samples will be measured in the laboratory under varying pressure and temperature conditions. The data will be integrated with legacy wireline data and the MT survey results. This project will contribute to the de-risking of geothermal energy development in Scotland and decarbonising local industry, with the workflow and knowledge gained being applicable to similar systems worldwide. [1] Webb, P.C. & Brown, G.C. 1984. The Eastern Highlands granites: Heat production and related geochemistry. Report in series: Investigation of the Geothermal Potential of the UK. British Geological Survey, Keyworth, Nottingham [2] Busby, J., Gillespie, M. and Kender, S., 2015. How hot are the Cairngorms?. Scottish Journal of Geology, 51(2), pp.105-115.

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Selected Session *	3. Shallow Geothermal (Application) or 4. Deep Geothermal (Exploration)
Title of Abstract	The seismic observation and deep borehole heat exchanger drillings RWE EB1 and EB2 located on the Weisweiler Horst within the Lower Rhine Embayment, Germany
Abstract (up to 300 words)	The area around Weisweiler is one of the locations within the Lower Rhine Embayment that is currently explored for its potential for medium-deep (> 400 m) to deep (> 1,500 m) geothermal energy production. In cooperation with Fraunhofer IEG and the Geological Survey of North Rhine-Westphalia, RWE Power AG has drilled a first 100 m borehole (RWE EB1) in October 2023 on the premises of the Weisweiler power plant. It penetrated the Upper Carboniferous rocks of the Rhenohercynian Fold-And-Thrust Belt below a 70 m thick cover of Cenozoic deposits of the Lower Rhine Embayment. It is equipped with a fibre optic cable and a seismometer in the Paleozoic section of the borehole to measure natural events in the seismically active region and induced seismic events at the geothermal site. A second 500 m deep borehole (RWE EB2) was drilled in February 2024 in the immediate vicinity of the first borehole. After reaching the final depth and an extensive geophysical logging program, a deep borehole heat exchanger (double U-tube) and a fibre optic cable were installed. The borehole heat exchanger will serve in combination with a heat pump as heat source for the planned research site of Fraunhofer IEG at their Weisweiler location. In order to further promote the development of medium-deep geothermal systems in the region, a thermal response test (TRT) will be performed during summer 2024 and long-term measurements will be conducted to estimate the thermal conductivities and performance of the Paleozoic rocks of the Rhenohercynian Fold-And-Thrust Belt. Both boreholes conclude the Interreg NWE-funded project DGE-ROLLOUT. In addition, the 500 m borehole will also provide valuable information for a planned deep exploration borehole penetrating the geothermally potential Dinantian and Devonian carbonates and the thrusts of the fold-and-thrust belt to develop geothermal systems in the region between Aachen and Cologne.

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Country	Belgium
Selected Session *	4. Deep Geothermal
Title of Abstract	Bayesian Evidential Learning Approach to Uncertainty Quantification in THM Model of Geothermal Energy Extraction in Deep Mines
Abstract (up to 300 words)	Utilizing existing deep mining systems for geothermal extraction not only facilitates the development of geothermal systems but also helps meeting the cooling requirements for deep mining operations. In this study, a thermo-hydro-mechanical model of geothermal extraction in deep mines is developed to investigate the evolution of mine galleries stability and temperature, and the temperature changes in geothermal production wells. The uncertainty in system responses is predicted through the Bayesian Evidential Learning framework. Ideally, a comprehensive uncertainty analysis would be conducted to predict all possible outcomes and assess any risks. However, In light of the intractability of performing comprehensive uncertainty analyses in scenarios with vast unknown data, particularly due to the computational overhead of multiple inverse problem-solving, we employ the Bayesian Evidential Learning framework, which provides a feasible and rapid alternative for approximating prediction post-distributions and choosing the most informative data sets. Before implementing BEL, we employed Latin Hypercube Sampling to create 500 sets of realizations for forward simulations, and subsequently utilized global sensitivity analysis to evaluate the data's informational value, aiming to diminish the uncertainty in predictions. In this paper, the BEL framework is utilized to achieve two: firstly, to stochastically predict the responses of the system (stability and temperature) within the BEL framework, using machine learning to discover direct correlations between predictors (sensitive parameters) and targets (system responses). Subsequently, newly collected data can be utilized to predict the approximate posterior distributions of the corresponding gallery stability, temperature, and production well temperature, thus circumventing traditional data inversion steps. This framework can be adjusted to accommodate any predictions related to subsurface conditions; our second goal involves predicting the system's long-term responses within the BEL based on short-term data collection, forecasting posterior distributions from the acquired short-term data, and validating the efficacy of this approach. Our study indicates that in practical engineering, by (1) obtaining data of material properties and (2) key responses of short-term simulation, it is possible to predict the critical responses of the system in long-term geothermal extraction, thereby maximizing the information content of any measurement data while minimizing budget constraints and computational costs.

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Country	Belgium
Selected Session *	3. Shallow Geothermal
Title of Abstract	Global sensitivity analysis of model parameters, heat transport processes and design parameters in ATES Systems
Abstract (up to 300 words)	Shallow geothermal energy has not only great potential to mitigate CO_2 emissions associated with the heating and cooling of buildings but also offers wide applicability. Thick productive aquifer layers have been targeted first, as these are the most promising areas for aquifer thermal energy storage (ATES). Nevertheless, there is an increasing trend to target more complex aquifers such as low-transmissivity and alluvial aquifers or fractured rock formations. However, the uncertainty and thus the risk of failure in these contexts is significantly higher and it is therefore often not sufficient to rely on experience when designing the ATES system. In this context, a distance-based global sensitivity analysis was carried out for ATES. The analysis focused on one promising thick productive aquifer, used as a reference, as well as two more complex settings involving a low transmissivity and a shallow alluvial aquifer. Through this method, multiple random model realizations are generated by sampling each parameter from a predetermined range of uncertainty. A distance measure between the different model realizations can then be used to determine the relative importance of the uncertain parameters. Not only hydrogeological parameters but also operational and design parameters and boundary conditions were considered uncertain. The parameter distributions were also further analysed to make a connection with the ATES efficiency. Finally, specific attention was paid to exploring the thermal energy exchange between the soil and the aquifer and its significance for ATES efficiency in shallow aquifers. The results of this study give insight into how the sensitive parameters change when the setting becomes more complex and if it is required to include heat transfer processes that are commonly ignored in traditional settings. This nuanced understanding contributes to the optimization of ATES systems, offering practical guidance for enhanced efficiency of feasibility studies, especially in challenging environments. Keywords: sensitivity analysis, uncertainty, Aquifer Thermal Energy Storage, recovery efficiency, heat transfer processes

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Country	Germany
Selected Session *	5. Ultra Deep Geothermal (UDG)/ Enhanced Geothermal Systems (EGS)
Title of Abstract	Geological Characterization and Modelling of Maastrichtian Calcarenites in the North German Basin Regarding Their Potential as a Medium-Depth Geothermal Reservoir
Abstract (up to 300 words)	The North German Basin (NDB) holds untapped potential for mid-depth geothermal resources, providing a sustainable and carbon-neutral heat supply opportunity. Despite promising indications within the Maastrichtian Calcarenites, their geothermal potential remains inadequately explored. Past hydrocarbon industry wells, intersecting these Calcarenites. Occasionally they were used for wastewater disposal, suggest significant porosity and permeability. This research aims to document Calcarenites' distribution, characterize their geological properties, and assess geothermal potential. Data from the hydrocarbon database, a 3D seismic survey, and a subsurface model will undergo collection, analysis, and re-evaluation. The emphasis lies on examining well data to classify facies types, characterize rock properties, and analyze geological structures for precise identification of potential reservoir zones. Core samples will undergo analysis for petrophysical properties, and seismic data will be interpreted to detect geological patterns. All acquired data will integrate into a detailed geological model, and numerical simulations will evaluate economic reservoir parameters for doublet operation, considering thermodynamics, hydraulics, and mechanics. Strategies for harnessing the geothermal potential of the Maastrichtian Calcarenites will be derived from these results. The study's findings will be made public through the GeotIS platform. Analysis of well reports confirms facies distribution, revealing a transition from the proximal Steinförder facies to the distal Schreibkreide facies, with the intermediate Reitrooker facies marked by Calcarenites. The Calcarenite can be divided into Upper and Lower zones, separated by a marl-rich layer consistently observed across the study area. A trend indicates that the higher stratigraphic Calcarenite exhibits greater porosity and permeability, making the Upper Calcarenite potentially suitable as geothermal reservoir rocks. The reservoir's thickness depends on the preserved Upper Calcarenite during the Tertiary transgression, with halokinesis and associated processes affecting diagenesis, structure development, and reservoir rock quality. Seismic analysis is expected to provide additional insights.

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Selected Session *	6. Other
Title of Abstract	Li Recovery from Geothermal Sources via Adsorption using MnO_2 Polymorphs as Sorbent Material
Abstract (up to 300 words)	Lithium, a critical industrial mineral, is experiencing a surging demand driven by its diverse applications, particularly in battery production. While traditionally sourced from mining, the feasibility of extracting lithium from natural sources like geothermal waters is rapidly gaining attraction. Geothermal fluids offer significantly higher lithium concentrations compared to conventional sources like seawater or groundwater, prompting commercial exploration of this extraction method. However, a major challenge lies in efficiently capturing lithium directly from operational geothermal power plants without disrupting energy generation. This study investigates the extraction of lithium (Li) from synthetic and geothermal brine using an adsorption technique utilizing manganese oxide (MnO_2) as a sorbent for Li ions. In particular, the study focuses on γ-MnO_2, a commercially available and cost-effective polymorph of MnO_2 used normally in battery cathodes, and the more expensive but lithium-selective commercial spinel λ-MnO_2. Experimental assessments were conducted in a mini pilot system located near the reinjection well of Tuzla Geothermal Power Plant. Following treatment of the sorbent powder with geothermal brine from 1-20 h, lithium adsorption and subsequent desorption in an acidic aqueous solution resulted in a Li concentration of 25 ppm. A four-step enrichment process by repeated treatment of the desorption solution with fresh brine-treated powder achieved a lithium concentration of approximately 250 ppm. Field trials are in progress to enhance the system's efficiency, including the investigation of a commercial lithium-selective λ-MnO_2 polymorph. To enhance economic feasibility, a lithium-selective spinel-MnO_2 was synthesized by a hydrothermal method utilizing γ-MnO_2 and its adsorption capabilities were evaluated in laboratory experiments with synthetic solutions. The synthesized spinel exhibited a remarkable capacity of 23.1 mg/g, exceeding the capacities of γ-MnO2 (8.4 mg/g) and commercial spinel-MnO_2 (22.4 mg/g).

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Selected Session *	2. Underground Thermal Energy Storage (UTES)
Title of Abstract	Utilizing Depleted Hydrocarbon Reservoirs for Underground Thermal Energy Storage in Battonya, Hungary
Abstract (up to 300 words)	The transition towards sustainable energy systems necessitates innovative approaches to energy storage. This study explores the feasibility of transforming depleted hydrocarbon reservoirs into efficient Underground Thermal Energy Storage (UTES) facilities. Located in Battonya, Hungary, our research area presents a unique opportunity to repurpose subsurface geological formations that once served as hydrocarbon reservoirs. Employing a Multi-Criteria Decision Analysis (MCDA) approach, we evaluate potential sites within the reservoir based on a range of geothermal parameters. The parameters are modeled using Rockworks software, followed by a Python-based program to calculate a scoring system ranging from 1 to 10 for the P10, P50, and P90 values and visualize the outcomes. This scoring system aids in identifying the most promising locations for UTES implementation in three different scenarios. The outcome of this research contributes to the field of geothermal energy and also demonstrates a methodical approach to site selection for geothermal applications. By presenting this study, we aim to shed light on the criteria and processes that underpin the successful conversion of depleted hydrocarbon reservoirs for geothermal use, aligning with the broader goals of energy sustainability and carbon footprint reduction.

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Selected Session *	4. Deep Geothermal
Title of Abstract	Phillip J. Vardon[1], Guy Drijkoningen[1], Anne-Catherine Dieudonné[1]
Abstract (up to 300 words)	Distributed acoustic sensing (DAS) is increasingly gaining popularity particularly in the area of vertical seismic profiling and micro-seismic monitoring. The use of DAS to monitor micro-seismic events during downhole operations has multiple advantages over conventional monitoring techniques (e.g. geophones), such as a higher data fold from a single DAS cable, intolerance to extreme conditions, and the capability of long-term monitoring. However, one of the challenges faced in micro-seismic monitoring results from its 1-component feature, which means DAS can only measure axial strain. Therefore, lots of information cannot be obtained from a single vertical DAS cable. To aid better the monitoring, DAS is generally installed in two closely-located wells or in deviated wells. In this paper, we propose a dual-cable DAS installed in a single vertical well. Numerical study is performed in COMSOL Multiphysics to investigate how are the signals related to key parameters such as frequency, moment tensor, source distance, and how do the noises and velocity heterogeneity influence the results, and finally how much information can we obtain from the dual-cable DAS signals.

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Selected Session *	3. Shallow Geothermal
Title of Abstract	Optimizing Steel Energy Piles – Performance Test Stand for Steel Geothermal Probes
Abstract (up to 300 words)	Steel energy piles integrate structural integrity with energy usage, offering a sustainable foundation alternative that utilizes the ground for heating and cooling. This significantly reduces CO2 emissions and enhances energy efficiency. The focus of this research is on creating optimized heat transfer and storage solutions that utilize steel's recyclability, thus advocating for a circular economy in construction. This study explores the application of geothermal energy in various building scenarios, with the goal of enhancing the efficiency of steel energy piles and assessing their economic benefits over traditional methods. The research employs a detailed multi-stage methodology, incorporating theoretical research, analytical preliminary studies followed by detailed Computational Fluid Dynamics (CFD) analyses und experimental investigations in a performance test stand. This approach aims to provide deep insights into the steel energy piles' physical, technical, and economic aspects. A pivotal element of this research is the establishment of a 'Hardware in the Loop' performance test stand for ground heat exchangers (GHEs), scaled to 1:2 to simulate 1-2 meters of the subsurface, with the remainder emulated via the 'Hardware in the Loop' approach. This includes external temperature control and introducing a temperature difference into the subsurface. The stand, featuring a container diameter of 0.8m and a probe scaled to 75mm, allows for the meticulous assessment of various probe types (Single-U, Double-U, and Coaxial pipes) under controlled conditions. This setup provides a thorough analysis of the efficiency with which each probe type transfers heat between the GHE and the surrounding soil. To enhance the pipe-soil interface for improved heat extraction, adding welded ribs or metal plates is conceivable. Significant focus is also placed on examining the probe's base and enhancing the probe head connection to ensure the carrier fluid's optimal hydraulic flow within the system.

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Selected Session*	5. Ultra Deep Geothermal (UDG)/ Enhanced Geothermal Systems (EGS)
Title of Abstract	Numerical modelling of fracture dynamics induced by hydro-mechanical processes
Abstract (up to 300 words)	For deep geothermal production to be sustainable, an essential element is injection of fluids to stimulate the reservoir by inducing deformation and propagation of fractures, thus increasing the permeability. However, a naive injection of geothermal fluid has a substantial risk of triggering significant earthquakes. The objective of the project is to grasp the underlying mechanics by constructing a numerical model of fracture propagation combined with multiphase flow in thermo-poroelastic porous media using a finite volume approach. We present a step-by-step initial 3 years PhD workplan describing how we will gradually increase the complexity of the model. Firstly, we aim to investigate in-plane fracture propagation fracture propagation and opening in a homogenous medium. Motivated by the development of a consistent numerical spatial discretization for coupled hydro-mechanics, we will use the multi-point stress approximation (MPSA) finite volume method for the mechanics discretization. The next step is then to consider coupled hydro-mechanical processes for discrete fracture propagation in porous media for an incompressible single-phase fluid flow regime. The final step will be to introduce multiphase flow and phase change. This will enable the simulation of complex scenarios in high-temperature systems, where fracture propagation interacts with multiphase fluid flow.

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Selected Session*	1. Above the Surface
Title of Abstract	A universal scale inhibitor to mitigate multiple geothermal scales
Abstract (up to 300 words)	Scale inhibition is of vital importance in harvesting geothermal energy, an attractive, renewable and sustainable energy source. The majority of the geothermal reservoir waters around the world contain a variety of anions and cations, which are prone to precipitation when subjected to vast transformations of both temperature and pressure, causing failures to many parts of the plant. This is a common phenomenon that the deposits encountered in geothermal systems are multi-component inorganic solids and they are described by the term “composite fouling”. In an effort to discover a “universal scale inhibitor”, it has studied the inhibition efficiency of four polymeric inhibitors that contain the functional groups polyethylene glycol and phosphonic acid to combat a multitude of scaling salts. These are: amorphous silica, magnesium silicate, aluminum silicate, iron (III) silicate, zinc sulfide, lead sulfide, iron (II) sulfide, and calcium carbonate. In this presentation, it is discussed the inhibition results for each scale separately and combined together in four brines of variable severity. Data are discussed and structure/activity relationships are drawn.

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Selected session*	3. Shallow Geothermal
Title of Abstract	Developing a Geothermal Research Initiative within a Large-Scale Heat Pump Plant at the University of Stavanger
Abstract (up to 300 words)	The University of Stavanger is currently constructing a geothermal energy plant to provide heating and cooling across the campus. This initiative utilizes 119 boreholes, each 300 meters deep, to establish an extensive thermal storage system. Besides supplying thermal energy, the boreholes efficiently store excess heat from the university's cooling systems and heat from ambient air using the peak cooling dry coolers. Key to our project is the integration of two state-of-the-art heat pumps that operate using the natural refrigerant ammonia, designed to manage and distribute thermal energy in response to the campus's specific demands. Alongside the plant's construction, we are developing a comprehensive research project to investigate the effectiveness and potential at various borehole depths and heat exchangers. Our upcoming presentation will offer insights into the progress and goals of this research, including findings from the drilling of two semi-deep boreholes at 650 meters. We will discuss the techno-economic analysis of these semi-deep boreholes in comparison to the traditional 300-meter options, highlighting their potential advantages and challenges. Collaborating closely with experts in borehole exchange design, drilling operations, and electromechanical systems, our team adopts a hands-on research methodology. Our main research objectives are: • To pioneer the introduction of "semi-deep" borehole drilling in Norway, presenting it as an innovative solution in the geothermal energy sector. • To develop a digital twin for the geothermal plant, enabling us to simulate and optimize operational strategies through mathematical models. This holistic approach not only enhances the efficiency and sustainability of campus energy use but also contributes significantly to the broader adoption and understanding of geothermal technology in Norway.