Book of Abstracts – EGW 2024, UiS Stavanger, Norway

#ID	ABSTRACTS
#3	**Kim Gunn Maver**

Versatile applications operating a closed loop horizontal geothermal solution

Closed loop horizontal co-axial geothermal well solutions can be completed in most geological settings. However, the final energy output is dependent on the thermal conductivity of especially the rock where the horizontal well section is completed and both the geothermal temperature gradient and the hardness of the rock will impact the drilling costs.

With the very limited geological requirements and as no fluids will circulate in the geological formation, operations of this geothermal solution are versatile.

For district heating a heated fluid can be delivered for direct usage in both 3rd and 4th generation grids.

There is a whole range applications in industrial processes where the heated fluid can be delivered for direct usage.

Districted cooling is predicted to become a larger market than district heating. Using an absorption chiller the heated fluid can be cooled to 6 degrees Celsius and distributed through a district cooling grid similar to a district heating grid.

Finally, the flow direction in a co-axial solution can be changed and a fluid, heated by excess power, can be circulated through the solution to re-heat the geothermal reservoir for later usage.

The basic geological requirements for a successful completion of a co-axial closed loop horizontal geothermal well solution will be reviewed and each of the energy applications will be described in detail.

#4	**Fredrik Skaug Fadnes** **Mohsen Assadi**

Developing the Geothermal Energy Plant at University of Stavanger - From Concept to Operation

The New Geothermal Energy Plant at University of Stavanger, now in its first year of operation, significantly enhances sustainable energy production on campus. With targets set for substantial reductions in CO_2 emissions and operational costs of thermal energy production, this presentation will cover the plant’s foundational design principles and research goals. A key design choice involves the strategic integration of a geothermal borehole configuration that is undersized relative to the heat pump capacity, emphasizing the essential balance between economic and sustainability considerations. Furthermore, peak load ambient air coolers are effectively used to maintain desirable borehole temperatures.

Alongside the construction of the plant, a comprehensive research initiative has been developed. This initiative includes drilling semi-deep boreholes and replacing standard collectors with alternative designs in eight of the 300-meter boreholes. Equipped with an advanced sensor scheme, including fiber-optic temperature measurements on the inside of both legs of the heat exchanger in several boreholes, the project is thoroughly equipped to deepen our understanding of geothermal heat exchange. The academic institution has unrestricted access to all measured data from the main project, facilitating detailed monitoring and potential optimization of the plant's performance.

We will detail the development of these research activities and tackle the challenges of integrating a research project under a financially motivated main contractor. Key issues such as budget constraints and coordination complexities will be highlighted.

The presentation offers a comprehensive technical overview and delves into the economic and technical challenges of implementing a research project.

#5

OYKUM BERFIN GULERGUL
ALPER BABA

Assessment of Geothermal Resources for Agricultural Applications: Enhancing Regional Development Through Geothermal Heated Greenhouses

The growing world population and the escalating effects of climate change have increased the need for sustainable food security and reliable energy solutions. Geothermal energy, a renewable and versatile resource, offers continuous availability and stability throughout the year, regardless of weather conditions. It is both environmentally friendly and economically feasible, making it a significant resource for power generation, direct applications and agricultural purposes. In agriculture, geothermal energy is particularly effective in heating greenhouses, as it creates a stable internal environment for optimal plant growth. Geothermally heated greenhouses reduce operating costs and ensure year-round agricultural production, increasing productivity and competitiveness. These systems are gaining momentum in Türkiye, where geothermal resources are being utilized to support agricultural development. This study evaluates geothermal resources in regions with agricultural potential, focusing on their use in Agriculture-Based Specialized Organized Industrial Zones (TDIOSB) designed for greenhouse farming. Geothermal greenhouses integrated into TDIOSBs not only increase local agricultural production, but also play an important role in regional economic development. The assessment includes environmental and technical factors such as water consumption, infrastructure needs and CO_2 emission reduction. In addition, the study examines future employment opportunities and the broader socio-economic impact of these greenhouses. The findings highlight the importance of geothermal energy in promoting sustainable agricultural practices, fostering regional development and contributing to the national economy. By utilizing geothermal resources to heat greenhouses, regions can make significant progress in agricultural efficiency and environmental sustainability.

#6

Yuriy Maystrenko
Marco Broenner
Odleiv Olesen
Trond Slagstad
Bjørn Eskil Larse

Norway's deep geothermal potential as indicated by borehole data

Over the past decades, more than 30 relatively deep boreholes were drilled onshore in Norway, providing valuable insights into the subsurface thermal pattern across different regions. Thermal logging from these boreholes revealed significant variations in temperature, reflecting the diverse geological and tectonic characteristics of the country.

On the Svalbard archipelago, which exhibits signs of Quaternary magmatic activity, the highest temperatures were recorded, reaching up to 28.2°C at a depth of 800 meters. This region's geothermal gradient is high due to its tectonic activity and magmatic influences, which resulted in the thinning of the lithosphere there. In contrast, the northernmost part of Norway, known for its tectonic quiescence (reflected by thick lithosphere), recorded the lowest temperatures, with measurements slightly exceeding 9°C at a depth of 650 meters. This significant difference indicates the important effect of tectonic activity on subsurface temperatures.

Central Norway's highest temperature, 22.2°C at 800 meters, was recorded on Innveien island, influenced by the development of nearby offshore deep sedimentary basins. The southwestern part, including areas near Stavanger, shows lower temperatures, such as 17.6°C at 800 meters. This lower temperature is probably a result of the relatively low concentration of radioactive elements in the bedrock of the Rogaland igneous province. The cooling effect of groundwater flow may also partially contribute to the reduced temperature of the uppermost crust in this region.

The area around the Oslo Fjord presents a more complex thermal pattern. Here, temperatures at 800 meters depth range from 16°C to 24°C, reflecting a combination of different geological factors. The primary factor is the difference in radioactive element content. There is a straightforward relationship: the higher the radiogenic heat production of the bedrock, the higher the measured temperature, and vice versa.

These variations in the subsurface temperature indicate the interplay between tectonic evolution, groundwater flow, and subsurface rock composition. Moreover, the paleoclimatic cooling effect also influences boreholes from 300 to 1500 meters deep. This paleoclimatic thermal influence must be carefully considered when evaluating the geothermal potential of any site in Norway. Therefore, a detailed assessment of these factors is essential for planning Norway's first deep geothermal site, ensuring successful geothermal energy utilization for sustainable solutions.

#7 **Pejman Shoeibi Omrani**
Yifan Yang
Huub Rijnaarts
Shahab Shariat Torbaghan

Monitoring the performance of geothermal production facilities under uncertainties

Monitoring the condition of geothermal production and facilities is an essential element in geothermal energy production systems for maintaining their reliability and cost-efficient operations. Challenges such as scaling, corrosion, erosion, and injectivity decline can significantly affect the operational expenditure (OPEX) of geothermal plants. Sensors installed during the operational phase provide real-time data and insights into the asset's condition, helping to inform decision-making. However, there are uncertainties associated with the data collected by sensors which are either caused by sensor accuracy and precision or the changes in the processes and production regimes of the geothermal plant.
In this work, we emphasize the importance of real-time data-driven condition monitoring and proactive maintenance planning in geothermal assets under uncertainty. A new data-driven workflow is proposed to monitor the performance of geothermal assets under uncertainties by making use of machine learning models, statistics and expert knowledge. The workflow is accounting for uncertainty to evaluate the degradation or onset of failure in equipment and facilities. Ensemble machine learning models are trained and tested to provide confidence in the prediction models for the condition monitoring and explainability is integrated to provide insights on the parameters causing such degradation and/or failures.
This method was applied to field data from a geothermal plant to monitor Electrical Submersible Pumps (ESPs). The workflow was capable of systematically detecting the onset of the ESP degradation up to prior to its failure, with an estimated confidence for the performance of the ESP. The explainability provided insights on the cause of the failure which was not associated to ESP malfunctioning but to the restriction of production inflow into the well. The workflow's ability to accurately assess equipment condition under uncertainty supports more informed maintenance decisions, ultimately improving geothermal facilities reliability and efficiency.

#8 **Ivar Stefansson**
Inga Berre, Eirik Keilegavlen, Jakob Both, Omar Duran, Ingrid Kristine Jacobsen, Veljko Lipovac, Micheal Oguntola

Multiphysics simulation of fractured geothermal systems using PorePy

Many geothermal sites are situated in low-permeable rock and strongly influenced by the presence and behaviour of fractures. Mathematical models must therefore account accurately for the fractures and their interplay with the physical processes at play. Modelling and simulating said interplay comes with certain challenges related to the fractures' high aspect ratio and strong material heterogeneity between fractures and the surrounding matrix.
The open-source research simulation toolbox PorePy is tailored to the challenges characteristic of fractured porous media. By explicitly representing fractures as two-dimensional surfaces in the three-dimensional simulation domain, appropriate physical

laws may be enforced for both matrix, fractures and intersections. Solving the multiphysics equation systems in a fully coupled manner yields reliable simulation results. We consider this a prerequisite for our simulation research investigating governing mechanisms of geothermal systems.
Recent developments have enhanced PorePy's flexibility in terms of definition of new equations and constitutive laws. Herein, we showcase recent and ongoing work at the University of Bergen's Porous Media Group applying PorePy for four different physical processes related to geothermal energy. First, we look at seismic wave propagation in a heterogeneous and fractured medium. Secondly, we demonstrate different modes of fracture dilation and stimulation due to cooling of the surrounding rock. Thirdly, we consider compositional flow in a multiphase setting. Finally, we show an application to the Reykjanes geothermal field combining seismic analysis with slip events computed by poromechanical simulations of the fractured formation.

#10 **Carola M. Buness**
Fabian Nitschke
Thomas Kohl

Influence of Fracture Roughness on Fluid Flow

In deep geothermal reservoirs, fluid transport occurs primarily through fractures, especially in crystalline rocks with a nearly impermeable matrix. Particularly near boreholes, moderate to high flow velocities are observed in these fractures. Yet common hydraulic models often simplify the fluid dynamics, neglecting also the roughness of the fractures. To investigate the influence of flow rates and fracture roughness on the hydraulics, experiments were conducted in the F^{4}aT-Laboratory (Forced-Fracture-Fluid-Flow and Transport Laboratory). The roughness of various rock surface samples was analyzed. Key parameters, such as the Hurst exponent and height standard deviation, are measured. Several rock surface samples were compared and the results showed notable variations in roughness based on sample type. These values served than in boundary conditions for the hydraulic experiments. There, the hydraulics are tested in a flow-through setup at various flow rates ($0.1 < Re < 100$) with 3D-printed, upscaled roughness replica. We show the results of the roughness analysis from the measured rock samples, the upscaling process for the replica, the hydraulic results and their deviation from the simplified Cubic law at higher flow rates.

#11 **Vlasios Leontidis**
Justin Pogacnik
Edgar Hernandez

Controlling the energy production from a deep coaxial closed well heat

Deep geothermal coaxial closed wells offer potential advantages over conventional geothermal applications (i.e., independence from the geology, no risk of induced seismicity, choice of heat transfer fluid etc.), and interest in them has grown in recent years due to technological advantages (e.g., drilling processes, energy conversion systems). However, concerns, have been raised about their economic viability and longevity, because of their limited output temperature and energy production, which decreases over time.

Due to the highly transient nature of the diffusive heat transfer from the rocks to the wellbore, which is the core mechanism of the process, the outlet temperature of the fluid can drop by several degrees, even within a few months of heat extraction. For given wellbore configuration and geological conditions, the rate of deterioration depends on the flow rate and inlet temperature of the fluid. Reducing the flow rate, thus the residence time, the production temperature increases at the expense, however, of the produced energy. Decreasing the injection temperature, increases the heat losses due to larger temperature differences, but at the same time, more energy is extracted due to the higher heat flows from the formation.

Two numerical tools were used to predict the evolution of the temperature and the produced energy over a 20-year period considering an existing well in Mol, Belgium and the complete geological morphology of the site. Simulations were performed either to deliver a constant power or to cover irregular thermal demands of two buildings by applying three process control operations: (1) inlet temperature control, (2) flow rate control and (3) successively both controls.

The simulations showed that continuous adjustments of the injection temperature and/or the injection flow rate are needed to supply a specific heat demand, constant or irregular, during long periods. By adjusting the inlet conditions of the fluid, the production of excess energy can be limited, with the system supplying only the energy demanded, thereby increasing the sustainability of the system. In fact, the combination of both controls could be the ideal strategy for supplying the demand at the highest COP.

The present research was funded by the European Union's Horizon Research and Innovation Program under grant agreement No 101083558 (HOCLOOP Project).

#12

Harun Bitlis
Erika Salmenvaara
Rami Niemi

The Coaxial Reversable Medium-Deep Geothermal Heat Well Technology: An Innovative Approach to Sustainable Heating

Heating systems are significant contributors to carbon emissions, particularly in Northern Europe, where they account for up to 30% of CO2 emissions. This situation necessitates a comprehensive re-evaluation of heating practices, especially those reliant on fossil fuels. Transitioning to sustainable alternatives, including the electrification of heating systems, is critical. Central to this transition is the integration of industrial-scale heat pumps, which require reliable heat sources. Medium-deep geothermal heat wells (MDGHWs), located at depths of 1,000 to 3,000 meters, present a promising solution.

MDGHWs facilitate a multifaceted approach to energy management within local low-temperature heating networks, providing essential heating, cooling, and thermal energy storage year-round. The coupling of MDGHWs with industrial-scale heat pumps enables the establishment of efficient networks that operate continuously. In winter, these systems supply necessary heat, while in summer, they provide cooling services and recharge geothermal wells. A key advantage of this approach is the utilization of waste heat generated within the local network for thermal storage, enhancing overall efficiency and minimizing energy waste. When powered by renewable energy sources, MDGHWs can operate sustainably, offering a carbon-neutral solution for district heating.

QHeat is pioneering the transformation of heating and cooling systems through innovative geothermal technology. The advanced coaxial deep geothermal system has undergone extensive testing in collaboration with leading Finnish experts. This patented

design optimizes energy extraction from deep thermal wells while mitigating performance issues. The coaxial MDGHW technology generates heat equivalent to approximately 40 traditional geothermal wells, significantly enhancing thermal exchange and reducing energy losses. Furthermore, the thermal well design allows for the underground storage of waste heat, ensuring stability within heating networks.
This technology not only reduces operational costs but also enhances the environmental performance of buildings. The integration of coaxial flow technology improves heat pump efficiency by enabling lower temperature differentials, extending system lifespan, and reducing maintenance costs. This approach achieves significantly higher Coefficient of Performance (COP) rates compared to conventional systems while also reducing land use by 97%, a critical factor in densely populated areas. Additionally, the technology facilitates the underground storage of excess renewable energy, effectively balancing supply and demand. This capability is essential in today's energy landscape, where variability in renewable energy generation poses challenges for grid stability. Ultimately, this approach ensures that local geothermal networks can adapt to fluctuating energy availability while maintaining reliable service delivery.
In conclusion, local geothermal low-temperature heating networks utilizing MDGHWs and industrial-scale heat pumps represent an innovative approach to achieving sustainable, carbon-neutral heating. By leveraging geothermal resources, efficient systems can be created to meet today's energy needs while supporting future climate goals.

#13 **Jean Schmittbuhl**
Javier Abreu-Torres
Gergö Hutka
Guido Blöcher
Mauro Cacace
Hannes Hofmann
Olivier Lengliné
Vincent Magnenet

The 2019-2022 sequence of induced seismicity below the city of Strasbourg, France: Insights from large-scale reservoir modeling

Between November 2019 and November 2022, a series of seismic events were felt by the population of the city of Strasbourg, France. The first main event (MLv 3.0) that occurred on November 12, 2019, was part of a seismic swarm (the southern cluster) that has been initiated a few days before, lasted four months, and was located by the BCSF-Rénass (EOST), below La Robertsau area at a depth of 5 km. In October 2020, after a new series of hydraulic tests, second cluster of seismic events with more felt earthquakes (the northern cluster) developed closer to the geothermal wells (<1 km) below the La Wantzenau area. It includes the largest event (MLv 3.9) that was induced on June 26, 2021, 6 months after the shut-in of the wells. Two important features of the induced seismicity were unexpected : the large distance to the wells of a cluster of seismic events (4-5km) and the occurrence of the largest event Mlv3.9 at the bottom of the wells, six months after shut-in. To better understand the mechanisms of seismicity, we develop within the framewo-rk of the DT-GEO project, a large-scale model (8kmx8kmx6km) of the area. We aim at performing in-silico experimentation to reproduce the geophysical responses of the geothermal reservoir. The model is based on the MOOSE/GOLEM framework (finite element approach) and integrate the public regional geological model GEORG that includes major lithologies and large-scale faults of the area. We will discuss the preliminary of coarse-grained simulations of the natural fluid circulation and fluid injections in light with the high resolution monitoring of the seismicity.

#14 **Alexander Jüstel**
Michael Kettermann
Oliver Ritzmann

New evidence from seismic data on the effect of Late Cretaceous deformation on geothermal systems in the Münsterland Cretaceous Basin, NW Germany

The Münsterland Cretaceous Basin, North Rhine-Westphalia, Germany, has become an area of focus to exploit medium-deep to deep geothermal energy to provide climate-neutral, sustainable, and regional heat for residential, commercial, and industrial purposes. Despite hydrocarbon exploration during the last century and studies at the margins of the basin, the tectonic deformation in the central part of the basin and its effect on fluid pathways in the scope of hydrothermal systems, requires further investigation. In this study, we aim to characterize the deformation of the Cretaceous strata linked to underlying structural elements of the folded and faulted Paleozoic subsurface. We, therefore, interpret vintage seismic data of the hydrocarbon industry and the DEKORP project, recently acquired seismic data by the Geological Survey of North Rhine-Westphalia, and well data. The interpretations of Cretaceous marker horizons and structural elements indicate three SW-NE trending zones of intense deformation interpreted as inversion/wrench tectonics-related flower structures. Similar structures displaying evidence of polyphase deformation, a transtensional phase followed by a transpressional phase, have already been described for the southern part of the basin. The flower structures are located above Paleozoic anticlines, which we interpret to be tectonic weak zones. The formation of these features is explained by the regional stress field during reverse faulting activity along the Osning Fault Zone (Late Cretaceous) and the inversion of the Lower Saxony Basin during the Subhercynian inversion phase. Distinctly increased impedance contrasts in these fault zones and within their damage zones indicate enhanced porosity and possibly resulting permeability and is linked to the migration of fluids from deeper strata to the surface. The potentially enhanced petrophysical properties along the flower structures present preferential exploration targets for medium-deep geothermal systems in the central part of the Münsterland Cretaceous Basin.

#15 **Justin Pogacnik**
Edgar Hernandez
Damian Janiga
Pawel Wojnarowski
Virginie Harcouet-Menou

A Risk Management Toolbox for Minimizing Induced Seismicity and Maximizing Production – HEU URGENT Update

Traditionally, in faulted/sedimentary systems, geothermal injection wells are drilled away from known faults to reduce the risk of induced seismicity, e.g., in the VITO geothermal project in Mol, Belgium. Unless there is high layer/matrix permeability in the area, this can limit the well capacity and result in prohibitively high injection pressures that can induce high stress changes on smaller potentially unknown faults in the area. The use of Artificial Intelligence (AI) and Machine Learning (ML) techniques is growing rapidly in O&G and geothermal applications. AI techniques have been used for well placement studies in geothermal; for well flowrates in field management; for fractured reservoir structural characterisation; and for seismic risk analysis in EGS systems. Yet, in sedimentary geothermal systems, where financial margins are extremely slim, AI techniques have not been leveraged to maximize heat production while simultaneously reducing the seismic risk in prone areas.

As part of the HEU-URGENT project, we will develop a risk management toolbox to allow for more effective placement of geothermal wells in doublet systems to maximize heat production while minimizing the risk of induced seismicity. We seek to apply and extend the ML frameworks tested in previous works targeting O&G applications to a geothermal setting. The novel part of this analysis is in the inclusion of mechanical effects, with a focus not only on maximizing well output but also on minimizing the seismic impact. ML-based control may be needed to ensure that thermal stresses on faults remain below critical thresholds, as temperature change is mostly a non-reversible process. The balance between thermal and pressure stress on faults will have to be managed in the ML coupling to maximize heat output and minimize seismic risk. In this presentation, we present an update of the toolbox from the first 3 months of the HEU-URGENT project.

#16 **Christopher Schifflechner**
Andreas Schuster
Martin O. Saar
Hartmut Spliethoff

Reversible high-temperature heat pumps / ORC: increasing the plant utilization and flexibility of geothermal systems

In June 2024, the European Research project FlexGeo has started. The project aims to develop solutions for innovative geothermal energy system designs to maximize system performance and flexibility. The key innovation is the development and operation of a modular rev. 200 kWel high-temperature heat pump / Organic Rankine Cycle (ORC) unit at a real district heating. The first-time demonstration of this innovative technology on a TRL 7 level will directly path the way to its market entry after the project since, due to the attractive modular approach, the demonstrator already has the same capacity as the future commercial product. Furthermore, innovative geothermal system designs considering high- and low-temperature Underground Thermal Energy Storage (UTES) systems, advanced closed-loop systems (AGS) and enhanced flexibility of district heating (DH) and district cooling (DC) networks (DHCN), are pathing the way to a broad spread of the FlexGeo solutions across Europe and the world, resulting in largescale CO2 emission reductions. The contribution will present first experimental results of the reversible heat pump test rigs at TU Munich and outline the planned experimental and numerical activities within this project to improve the flexibility potential of geothermal systems.

#17 **Behshad Koohbor**
Ali Bozorgpour
Mahdi Rajabi

Uncertainty analysis of coupled phase transport and heat transfer within explicitly fractured thermal aquifers

This study investigates the impact of uncertainties in fracture and matrix parameters on coupled heat transfer and phase transport within fractured thermal aquifers through a numerical simulation. First, 1000 multi-physics simulations are performed using a hybrid-dimension (i.e., two dimensional matrix elements and one dimensional fracture elements) finite elements package COMSOL Multiphysics®. The injected fluid is supercritical CO2, while the produced fluid is brine, potentially rich in lithium from an application perspective. The results of these simulations are then used to construct a sparse polynomial chaos expansion meta-model that facilitates the calculation of Sobol' indices for performing global sensitivity analyses. We assess how variations in fracture length, aperture, rotation angle, longitudinal and transverse dispersivity, reservoir permeability, anisotropy, and van Genuchten-Mualem parameters influence key flow and transport output metrics such as stored CO2 mass, reservoir heat loss, brine-based heat flux, and CO2 travel time. Our results show that fracture properties, particularly length and aperture, along with matrix permeability, have the greatest influence. Specifically, the van Genuchten-Mualem parameter has the most significant effect on CO2 storage, followed by fracture length and reservoir permeability. The probability density functions for these metrics exhibit varying degrees of skewness and uncertainty, with CO2 travel time having the highest coefficient of variation. The sensitivity analysis reveals that while matrix properties dominate CO2 flow early on, fracture characteristics become increasingly influential over time, affecting both CO2 sequestration efficiency and geothermal energy production. This study improves our understanding of coupled phase transport and heat transfer in fractured media, highlighting the sensitivity of output parameters to the most critical input variables.

#18 **Taylan AKIN**
David BRUHN
Alexandros DANIILIDIS

Open-Source Techno-Economic Modeling for ATES, BTES, and MTES Systems

This study is part of the Horizon Europe-funded PUSH-IT project, which aims to develop and promote sustainable heating and cooling technologies through innovative underground thermal energy storage systems. As part of this project, an open-source code has been developed to conduct techno-economic modeling for Aquifer Thermal Energy Storage (ATES), Borehole Thermal Energy Storage (BTES), and Mine Thermal Energy Storage (MTES) systems. These technologies utilize wells for heat extraction and injection, and understanding their economic viability is crucial for broader adoption. The main goal of this study is to present the development of an open-source techno-economic modeling tool that allows users to evaluate ATES, BTES, and MTES systems.

Our method offers flexibility by allowing analytical or numerical input for the reservoir response. Input includes technical and economic parameters, such as flow rate, pressure, temperature data for wells, and economic indicators like electricity price, annual discount rate, and heat price. For the numerical input, reservoir simulation results can be used directly, and any inconsistencies related to the solver time steps are automatically resolved, thus enabling the analysis and optimization of highly dynamic control schemes. Additionally, users can provide a comprehensive list of all expenditures, specifying their frequency and nature, which is categorized as either capital expenditures (Capex) or operational expenditures (Opex). This flexibility allows the tool to automatically group and calculate expenses based on the provided input, offering a dynamic approach to expense categorization. Key outputs include metrics such as Net Present Value (NPV), Levelized Cost of Energy (LCOE), and net income.
The open-source techno-economic assessment tool offers a valuable resource for assessing underground thermal energy storage. It provides both a scalable code and a user-friendly way to evaluate the financial and operational aspects of ATES, BTES, and MTES systems, contributing to developing more efficient and cost-effective heat storage solutions. The built-in adaptability supports decision-making processes, empowering users to model different scenarios and adapt to site-specific conditions.

#19 **Ola Vestavik**

HOCLOOP project – Verification test at Ullrigg in Stavanger

A new drilling and completion technology has been proposed for geothermal energy production through a horizontal closed loop well, acronym HOCLOOP. The HOCLOOP project, funded by the EU Horizon Europe research and development programme, aims to demonstrate this technology in a full-scale operation. The project is conducted in a co-operation between the industry and research institutions in Finland, Belgium, France, Italy, Germany, Poland and Norway. The project includes the development and validation of models for heat flow, investigation of using alternative fluids to water and investigation of potential EU pilot sites, environmental assessment, and social acceptance. As the project has entered the full-scale well test phase, including the evaluation of the solution in a thermal response test programme, this presentation will provide an overview of the project's goals and partial results. It will also focus on the analysis of the proof-of-concept results, such as verifying the performance of the new equipment components and configurations and validating thermal flow models through the thermal response test in the well. The test program is planned to be conducted at the Ullrigg Drilling and Well testing facility in Stavanger, starting in October 2024.
It is expected that the solution will enable geothermal energy exploitation in new regions, with or without hydrothermal reservoirs. The solution is anticipated to integrate with other renewable energy sources, enhancing power supply reliability and grid stability, while being applicable to various geological conditions. Furthermore, it aims to address key challenges in geothermal energy, including emissions, seismicity, and environmental concerns.

#20

Val Maverick Abecia
Sonia Salah
Mirela Vasile
Ben Laenen
Simona Regenspurg
Valérie Cappuyns

Mitigation of Pb scale deposits in geothermal installations by Pb sorption onto natural clinoptilolite: the effect of acetate and Cl ions

Mineral scale deposits and other amorphous solids generated by geothermal installations can contain elevated activities of Naturally Occurring Radionuclides (NORs) originating from 238U and 232Th and their progeny (e.g., 226/228Ra, 210Pb, and 210Po) in the reservoir rocks. The NORs-containing deposits can be classified as Naturally Occurring Radioactive Material (NORM) Waste posing a health and environmental hazard. Anti-scalants/inhibitors are used to mitigate the scale deposition, which comprise organics adding to natural organic matter coming from the reservoir rocks. Little is known about the role of organic matter in NOR fractionation and mobility and its possible contribution to NORM Waste generation. As a possible alternative to chemical inhibition, the feasibility of using natural clinoptilolite as a sorbent material for NORs such as 210Pb is being assessed as part of the PERFORM II Project (Horizon 2020 Europe). This study investigates the effect of organic matter on the Pb sorption efficiency onto natural clinoptilolite, using acetate (OAc-) and stable Pb as proxies for organics and NORs, respectively. The experiments were conducted at room temperature, a fixed pH of 5.0 in a background electrolyte of 0.1 M NaCl, a fixed solid-to-liquid ratio of 5 g clinoptilolite/L solution, and a 14-day sorption time. The results reveal that at baseline conditions (no OAc-), the adsorbed Pb fraction (%Pbads) is between ~49~100%. With a fixed amount of OAc- added, a minimal decrease of 2-9 %Pbads is observed, which can be associated with the effect of Pb-OAc complexation. In comparison, chloride complexation results in a more drastic decrease in Pb sorption by ~20%. Based on sorption modeling in PHREEQC using a modified version of the ThermoChimie 12A database and the extended Debye-Hueckel activity model, sorption is revealed to be partly linked to surface complexation onto the amphoteric basal sites of clinoptilolite and partly to cation exchange. The performed sorption tests demonstrate the feasibility of using natural clinoptilolite as a sorbent material for NORs removal, but further tests using real geothermal brine and simulated real conditions in geothermal installations should be conducted to fully evaluate its performance as a viable alternative to chemical inhibition.

#21 **Bastian Rudolph**
Mr Nicolas Neuwirth
Katharina Schätzler
Prof. Thomas Kohl
Olaf Kolditz
Prof. Ingo Sass
Prof. Christoph Schueth
the GeoLaB-Team

GeoLaB – an URL for Geothermal Energy is on its way

The GeoLaB (Geothermal Laboratory in the Crystalline Basement) project represents a significant step forward in geothermal energy research. As a joint initiative of the Helmholtz Association, GeoLaB aims to address the critical challenges associated with deep geothermal energy extraction in crystalline bedrock formations.
Currently in its exploratory phase, GeoLaB is focused on identifying a suitable location within the Schwarzwald-Odenwald complex in Germany. Through a combination of seismic surveys, potential geophysical methods, rock property analysis, and borehole drilling, the project is seeking to pinpoint a site with optimal research potential. Key factors under consideration include fracture density and the stress field. The initial seismic campaign concluded in September this year and geophysical surveys are underway. Exploration drilling is anticipated to begin in early 2025, with a final site decision expected in the second half of 2025.
Once the subterranean GeoLaB research facility is established at a selected location, it will serve as a pivotal platform for investigating the intricate interplay of thermal, hydraulic, mechanical, and chemical processes within deep geothermal reservoirs. By collaborating and working in tandem with existing research facilities, such as the FORGE project and the Bedretto underground laboratory, GeoLaB will conduct controlled experiments and collect comprehensive data to gain invaluable insights into reservoir behavior, borehole stability, and stimulation techniques.
Beyond deepening our understanding of crystalline reservoir processes, GeoLaB will prioritize the development of cutting-edge monitoring and diagnostic tools. These tools will empower researchers to continuously track reservoir conditions, identify potential issues proactively, and refine production strategies. By harnessing the latest advancements in data analytics, machine learning, and digital twinning, GeoLaB seeks to extract maximum value from the collected data.
The overarching goal of GeoLaB is to contribute to a sustainable and decarbonized energy future. By advancing our understanding of deep geothermal systems, GeoLaB aims to pave the way for the widespread adoption of this renewable energy source. Through its research and development efforts, GeoLaB has the potential to make a significant impact on the global energy landscape.

This presentation will provide an overview of the GeoLaB project, including our current activities and a timeline for future milestones.

#22

Nadezda Meier
David Bruhn
Martin Bloemendal
and the PUSH-IT consortium

PUSH-IT – high-temperature underground heat storage in urban areas

Decarbonisation of heating systems is key to a net-zero greenhouse gas economy. The main challenge here is the seasonal mismatch between heat demand and generation from sustainable sources. The optimal solution is to store the energy for later use. Low-temperature large-scale heat storage in shallow aquifers and boreholes is routinely applied for this purpose. Extending storage temperatures can improve system efficiency and reduce levelised cost of energy (LCOE).

The EU-H2022 project PUSH-IT (2023-2026) aims to demonstrate the full-scale applications of high-temperature underground thermal energy storage (HT-UTES; up to 90°C) in geothermal reservoirs using 3 different technologies: aquifers (ATES), boreholes (BTES) and mines (MTES). Each technology will be developed at a demonstration site, where the full storage system will be implemented, and a follower site, where selected elements of novel technologies will be tested.

Technology **demonstration** /follower	Site	Description	Depth, m	Stored temperature, °C
ATES	Delft	sand layers of Maassluis formation; storing heat from a geothermal doublet	120-200	75-88
ATES	Berlin	sand layers of Lower Jurassic; using surplus heat from a wood-fired power plant	350-400	< 90
BTES	Darmstadt	crystalline granodioritic reservoir; to store excess heat from a super-computer and summer heat surplus	750	55-75
BTES	Litoměřice	impermeable Carboniferous siliciclastic sediments; integrating several sustainable heat sources	500	n/a
MTES	Bochum	abandoned Bochum-Mansfeld colliery; using summer surplus heat from university campus and from IT centre	120	30-80
MTES	United Downs	abandoned Consolidated Mines; storing heat from a geothermal plant (~180°C)	n/a	n/a

n/a – not assessed

PUSH-IT focuses on developing and testing enabling technologies, i.e., newly developed monitoring and water quality control, novel drilling and completion and novel control systems, to reduce environmental impact, LCOE and risks, and improve HT-UTES performance and robustness. In-depth efforts are being made to investigate the socio-economic drivers and barriers associated with UTES, to develop guidelines for integrating the novel technologies into society, and to develop recommendations for improving existing regulatory frameworks.

Acknowledgements: Funded by the European Union under grant agreement 1011096566 (PUSH-IT project). Views and opinions expressed are those of the author(s) only and do not necessarily reflect those of the EU or CINEA. Neither the EU nor CINEA can be held responsible for them.

#23 **Tom Hambley**
Mel Rohse
Rosie Robison

Practical considerations for geothermal project developers planning engagement with local communities

Due to the ongoing climate crisis, development of geothermal energy technologies will need to increase to support an energy transition. Community engagement around geothermal energy is an important facet of sectoral development. Geothermal project developers will need to conduct engagement to successfully develop projects which, depending on the approach adopted, could facilitate wider societal change by empowering publics through early and consequential inclusion. Throughout engagement, project developers often need to interact with communities with unique and complex relationships with their places. Existing research has focused on how these relationships inform how communities receive projects and project developers. How project developers interact with communities and their place relationships is comparatively under-researched, resulting in literature dominated by one side of a two-way interaction.

Here, we report on the findings from a PhD study conducted in partnership with the British Geological Survey: Place Relationships in Geothermal Project Developer Approaches to Engagement, which addresses this research gap. It investigated how project developers experience and interpret theoretical understandings of place relationships. Qualitative data was collected through 32 interviews, and workshops with staff that delivered engagement between 2017-2021 for three projects in the nascent UK geothermal sector: UKGEOS Cheshire, UKGEOS Glasgow, and the United Downs Deep Geothermal Power Project.

The study found that geothermal project developers construct narratives portraying successful implementation of geothermal projects as aligned with place histories by following an identified characteristic (e.g. historic mining culture or industrial heritage) through time. Developers establish boundaries for engagement using geographical and social perimeters which evolve as developers experience communities, and interpret interactions with communities as ‘concern’ with their project. We recontextualise ‘concern’ as attempts to ascertain if place relationships will be negatively impacted by the project. We end with four practical recommendations for developers regarding engagement: 1) Clarify and Consider Engagement Early, 2) Scope the Surface as well as the Subsurface, 3) Take Publics Seriously to Mitigate Place-Washing in Top-Down Engagement, and 4) Create an Organisation Trained to Engage, and briefly signpost ongoing work on the topic in the UK and across the EU.

#24 **Syed Hamza Hussain Shah**
Nestor Cardozo
Lothar Schulte

Mapping Geothermal Heat Flow in the Barents Sea

Abstract: Since the 1970s, petroleum activities on the Norwegian Continental Shelf (NCS) have significantly contributed to CO2 emissions. With growing concerns on environmental sustainability and the need to reduce greenhouse gases, harnessing geothermal energy has emerged as a promising solution by providing a sustainable power source for platform. This study evaluates the reliability of geothermal parameters —subsurface temperature, rock thermal conductivity, and heat flow— in the Barents Sea, to access the possibility for geothermal energy development. The described methodology is equally applicable to geothermal exploration in offshore and onshore settings.

We use a comprehensive dataset comprising multiple temperature measurements from 23 wells and single bottom hole temperature readings from 48 wells. In addition, well logs, completion reports, and other relevant data are incorporated (all data from Diskos database). Bulk thermal conductivity was calculated by interpreting various lithologies based on well logs response and applying lithology-specific equations (Fuchs et al., 2015). Temperature corrections were applied using the Central Danish Basin and Horner correction techniques (Waples et al., 2004; ZetaWare, 2002), with the most reliable method selected based on its correlation with bulk thermal conductivity. For wells with multiple temperature measurements, heat flow was calculated, while in wells with a single temperature reading, we used the average heat flow derived from the multiple measurement wells.

The reliability of the corrected temperatures is strongly influenced by the time since the end of mud circulation (TSC), with longer TSC yielding more accurate temperatures. Thermal conductivity values varied by lithology, with higher mean values recorded for carbonates (5.2 W/m·K), followed by sandstones (3.2 W/ m·K), and shales (2.5 W/m·K). The estimated average heat flow is 71 mW/m^2, which matches the published average of 72 mW/m^2 for the Barents Sea (Pascal, 2015).

The heat flow exhibits a distinct pattern, with higher values in the northern part of the Barents Sea, and gradually decreasing towards the south. This can be explained by oceanic-continental crust heat transfer, as well as crustal thinning, uplift and erosion (Pascal, 2015).

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#26 **Emmanuel Gaucher**
Clara E. Fraile

Monitoring HT-ATES using FWI: a feasibility study

This study focuses on the monitoring of high-temperature aquifer thermal energy storage (HT-ATES) systems, where geothermal fluids undergo cyclic injection and production. It evaluates the effectiveness and sensitivity of the Full-Waveform Inversion (FWI) technique in mapping the anticipated changes within the reservoir using forward modeling. The feasibility study is applied to the DeepStor HT-ATES project in Karlsruhe, Germany, which aims at storing high-temperature fluids at circa 1.3 km depth across multiple layers between 7 and 10 meters thick. A baseline elastic model of the site was created, followed by a second model that includes the geomechanical changes expected after five years of fluid injection and extraction. Due to the depth and the narrow thickness of the layers, surface seismic methods have not been considered; instead, four different cross-well seismic configurations are examined. Distributed Acoustic Sensing (DAS) on fiber optic cable is used as receiver line. Applying acoustic FWI in such a cross-well configuration would not be appropriate nor provide any reliable image. Hence, an elastic rheology in the FWI modeling and inversion processes was used, which leveraged the information contained in shear-wave data (including P-to-S wave conversions) leading to increased spatial resolution and sensitivity in detecting the changes within the target layers. The findings indicate that placing receivers across the reservoir greatly enhances the ability to image thin layers and improves the detection of anomalies. In configurations where the receiver line do not intersect the reservoir layers, the best results are obtained when the FWI is applied with tighter constraints and more precise initial models. Independently of the seismic survey geometries, the single-component-receiver-like optical fiber makes difficult to capture the full lateral extent and magnitude of the changes. However, all geometries consistently detect variations at the reservoir depth. These results emphasize the importance of optimizing the design of the monitoring survey and demonstrate the potential of elastic FWI methodologies to enhance the detection, mapping and, under favorable conditions, quantification of subtle geomechanical changes expected in HT-ATES systems.

#27 **Vlasios Leontidis**
Nathalie Collard
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Christine Souque

Mineral scaling risk prediction in geothermal wells by integrating a geochemical tool into a well flow simulator: Application to production wells in different magmatic contexts

Mineral scaling is a well-known problem in geothermal applications often caused by changes in the temperature of the fluid while moving to the surafce and/or by alterations in its composition and chemistry. If no precautions are taken, geothermal power plant components (wells, pipes, equipment) can be subject to the formation of deposits. More precisely, precipitation may disturb flow regimes, limit fluid flow, have an impact on the efficiency of geothermal energy production and increase maintenance costs. Thus, the ability to predict mineral precipitation can lead to active reservoir management strategies and better design of the process with the ultimate aim of improving production and minimizing costs. Obviously, precise calculation of the local temperature, pressure and composition of the fluid is crucial. In this study, a geochemical model is integrated into a thermo-hydraulic model to draw scaling risk tendencies in the production wells as a function of the host rock composition and aqueous solution chemistry while producing from magmatic geothermal systems.

The approach includes the coupling between three internal tools: the well flow model GWellFM, the geochemical calculator Arxim, and the thermodynamic library Carnot to estimate the deposition under subcritical conditions. Initially, different representative fluid compositions associated with magmatic systems are defined, and then the scaling risk along the production wells is estimated based on a calculated temperature-pressure path. Fluids from different geothermal fields were chosen to cover chemical compositions representative of different magmatic geothermal systems that may be encountered, considering the following ranges: (1) aqueous solutions characterized by salinity ranging from meteoric water to seawater, (2) log(pCO2) and log(pH2S) ranging from near equilibrium to undersaturated concentrations, and (3) host rock compositions covering the calc-alkaline and alkaline magmatic series. Three groups of minerals as potential scaling risks in the production wells are considered in the study: carbonates, sulfates, and amorphous silica.

#28 ***Giuseppe Mandrone***
Alessandro Sciullo

AN OUTLOOK ON GEOTHERMAL RENEWABLE ENERGY COMMUNITIES

The transition towards renewable energy is an urgent matter. Heating and cooling of buildings contributes substantially to the emission of greenhouse gasses today. Geothermal energy provides a way to change that. Utilizing the geological layers of the underground, either near the surface or deep into the ground, the underground acts a huge thermal battery that provides a balance between heating and cooling. Renewable Energy Communities is a new instrument of the society, based on sharing energy and social responsibility, that pairs well with geothermal district heating networks, regardless of the type of technology used and the fraction of renewable energy used.

In fact, after the release of the EU directive REDII and IEM, Renewable Energy Communities have been rapidly gaining relevance in the public discussion and policy agendas. Although they clearly have a great potential to foster the energy transition both in terms of societal engagement and RES technologies diffusion, their current unique/main focus is on electricity while the heating/cooling is almost completely ignored by the regulatory provision as well as by the practical implementation. Photovoltaic is and easy to install way to develop such Communities, but other renewables can also contribute to this purpose. Geothermal energy both for power but especially for heat gives ready to use technologies to be integrated with traditional and innovative solution for enhancing power production and to store energy peaks transforming power to heat thought efficient heat pumps or using underground as heat storage.
Renewable Energy Communities (RECs) are open, voluntary, and non-commercial entities that produce, share, and consume renewable energy. Basically, they are associations of local citizens, small and medium enterprises, public administrations, territorial government agencies, etc. (Soeiro et Dias, 2020; Campos, 2020). Energy communities require some of their members to produce more electricity than needed (prosumers) and some others to consume more than produced (consumers).
This allows the community to optimize the use of energy within the community itself and to avoid drawing electricity from the grid. RECs are designed to receive an economic incentive for each MWh of energy shared within the community thus, the greater the amount of energy shared and the higher the economic incentive received.

#29 ***Zanne Korevaar***
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Maartje Koning
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GeoLoop – a depth-dependent closed-loop ground-source heat pump performance model

Closed-loop ground-source heat pump (GSHP) systems have become a popular technology in The Netherlands for electric heating of homes. Particularly in newly built neighborhoods, individual GSHP systems are often installed for each household, leading to a high borehole density in the subsurface, and degraded performance due to interference. In addition, the high density of boreholes poses a potential risk of leakage, potentially compromising groundwater and drinking water reserves. To increase performance, mitigate these risks and significantly reduce the initial investment cost per household, deepening boreholes for improved system performance and collective use can reduce the number of boreholes required.
While various tools are available for GSHP performance calculations, they typically assume homogeneous subsurface thermal properties and temperature—a simplification that overlooks the heterogeneous nature of subsurface properties which can be particularly important for design considerations for deepened boreholes. In The Netherlands, the subsurface down to ca. 500-1000 m depth consists of a sequence of heterogeneous sedimentary layers, mostly deposited in the Tertiary and Quaternary. To account for the effects of subsurface heterogeneity on the performance of GSHP systems, we developed the GeoLoop model, which integrates depth-dependent subsurface properties, thermal gradient and system design parameters for more accurate GSHP performance calculations. Using GeoLoop, we determined the best

performing GSHP system design, considering multiple standard and custom loop designs, for a wide a range of maximum borehole depths (100-800m) and a depth-dependent subsurface model, based on detailed information including underlying uncertainty on subsurface thermal properties and geothermal gradient. In consultation with industry partners, practical challenges, limitations and financial feasibility were considered in optimizing the GSHP system design and the definition of the simulation boundary conditions. The study results facilitated in discussing various design options with the industry partners and helps them to make data driven decisions. Results further showed that an optimized design can increase and extend the energy yield from a single borehole, improving the sustainability of these systems.
Acknowledgments: GeoLoop was developed as part of an innovation project with industry partners, grant nr. MOOI322009.

#30 **Niccolò Losi**
Giorgio Balirano
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Magnus Wangen
Pietro Ungar

Comparison of ideal work between CO2 and H2O as working fluids in a Coaxial Borehole Heat Exchanger (CBHE)

We conducted simulations to compare the performance of a coaxial Borehole Heat Exchanger (BHE) using two different thermal fluids: H2O and CO2. Our goal was to assess the ideal work output from a geothermal resource based on the flow rate for each thermal fluid, assuming the same inlet temperatures and power plant configuration. The objective was to characterize the quality of the heat extracted in both scenarios and its potential conversion to electricity. The simulation was performed using the code GTW from the Institute of Energy Technology (IFE), which provided all the necessary data for our analysis. We calculated the ideal work by using the surrounding environment temperature (10°C) and the temperature of the fluid leaving the well as reference thermal sources. The data used for the simulation pertains to the plant's condition after 20 years of use. For a vertical well, we found that at lower flow rates, using H2O as thermal fluid yields more heat compared to CO2. However, this trend weakens as the flow rate increases, mainly due to the difference in specific heat of the two fluids. Water's higher specific heat allows the system to perform better at low flow rates. We will also analyze the importance of the thermal gradient along the well which can yield different results between the two fluids.

#31 **Virgine Harcouët-Menou**
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claudio Strobbia
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Mark Beker

Sustainable and affordable URban Geothermal Exploration Novel Technologies and workflows, the Horizon Europe URGENT project

The URGENT project aims to accelerate the decarbonization of Europe's heating sector by leveraging geothermal energy as a key alternative to fossil fuels in urban areas. Despite its potential, geothermal energy development is hindered by limited knowledge of subsurface resources and risks in complex urban environments, where conventional exploration methods fall short. The URGENT project addresses this gap by providing sustainable and affordable solutions for urban seismic exploration of geothermal resources. Low-impact innovative technologies, consisting of an electric seismic source and novel MEMS based sensors integrated into autonomous nodes, will be designed, built, and tested on 3 sites: the VITO geothermal site (BE), Konin (PL), Batta (HU). They will enable high-quality data recording including low frequency signals resulting in high resolution imaging up to 4000m of depth.
By improving reservoir characterization, URGENT aims to reduce geological uncertainties and enhance drilling success rates by 20%. Additionally, the project will optimize survey designs using techniques such as compressive sensing and simultaneous shooting, ultimately cutting exploration costs by 30%. To further streamline data analysis, AI and machine learning (ML) methods will be developed and tested for automated fault and fracture detection. These insights will feed into structural models for geomechanical simulations, allowing for more accurate assessment of fault reactivation and associated seismic risks.
The project will also adapt and refine ML techniques from the oil and gas sector, combining them with thermo-hydro-mechanical (THM) reservoir modeling to optimize well location and design. This approach will maximize heat extraction, minimize seismic risks, extend plant lifetimes by up to 40 years, and boost revenue. In addition to its technical innovations, URGENT will support the broader adoption of urban geothermal projects through tailored exploration workflows, market uptake analysis, and strategies to strengthen community acceptance. This presentation will outline the key objectives, methodologies, and expected outcomes of the HEU URGENT project.

#32 **Margie Maria Gonzalez**
Metehan Acikgoz
Lisa Langø Karlsen

"Is geothermal ready for digitalization? The potential and challenges for applying AI and other computing technologies in the industry."

Geothermal energy is a key renewable resource driving the shift to a zero-emissions global energy industry thanks to its reliable baseload power. While geothermal resources are abundant and unaffected by climate, utilizing them efficiently still

requires a great deal of technological development for their expanded technical and economic feasibility at a larger scale. eDrilling has been developing and leveraging software that supports decision-making in drilling operations for O&G, and more recently CCS, for over 15 years. Our core technologies such as digital twins, dynamic modeling, machine learning and AI have resulted in safer and more economically and environmentally efficient drilling operations over the years. This presentation will explore the potential and key challenges for applying eDrilling's core technologies in deep geothermal drilling operations.
Throughout an ongoing market research mainly based on collecting data through semi-structured interviews to engineers and other drilling professionals from the geothermal field in Asia, Europe and the U.S, we will present our key findings about the most common issues in geothermal drilling, that either we are already addressing with our current software, or with the potential to be tackled by a new tailor-made solution. In addition, we will also present the shortcomings that are currently hindering such potential for software development and application in the field due to a variety of factors including budget constraints, lack of proper hardware, and even the personal views of engineers regarding software use and overall digitalization.

#33 **Kirsti Midttømme**
Hans de Beer
Randi K. Ramstad

Monitoring Geoenergy-Related Subsidence and Ground Movements Using InSAR Technology

Norway has approximately 75,000 geoenergy installations, with around 4,000 new systems established annually. The majority of geoenergy wells are drilled in urban areas. Except multi-wells installations in Oslo municipality, local authorities do not require permits to drill geoenergy wells.

However, there have been cases where geoenergy drilling and implementation has caused significant structural damage to nearby buildings, leading to lawsuits against the drillers and developers involved. This damage is primarily associated with the depletion of the groundwater table in sedimentary layers, leading to significant land subsidence.

NORCE and the Geological Survey of Norway (NGU) have developed a national Ground Motion Service (GMS) platform that uses spaceborne Synthetic Aperture Radar Interferometry (InSAR) technology. Since 2014, this platform has been actively monitoring ground movements, and has provided insight into issues related to land subsidence and land uplift related to geoenergy activities.

The application of InSAR technology enables early detection of ground motion caused by changes in groundwater levels or permafrost formation due to geoenergy drilling and operations. This ability is important in understanding the movements associated with the installation and operation of geoenergy systems. It will also help formulate effective mitigation strategies, such as borehole grouting and advanced casing techniques, which can help reduce the risk of economic loss and enhancing public acceptance of geoenergy

#34 **Leszek Pająk**
Karol Pierzchała
Maciej Miecznik
Magdalena Tyszer

A simple and user-friendly wellbore flow calculator

Advanced reservoir simulators usually work on comprehensive datasets that accurately define many physical properties of geological formations. It is important to emphasize that most of the advanced reservoir simulators typically generate output at the depth of the production liner, and the flow within the wellbore is not considered. The article presents a simple tool for determining fluids' wellhead properties based on the reservoir conditions, well construction, geological profile and operation schedule of the well. The wellbore flow algorithm was developed using Python and uses the finite difference method in the cylindrical coordinates (2D model) to calculate unsteady heat exchange between the fluid and the rock matrix. The algorithm has a built-in library that can determine a set of basic fluid properties (density, dynamic viscosity, heat capacity, convective heat transfer coefficient), considering temperature, pressure, and mineralisation in a high range of application, based on formulations taken from recent literature review. As a result of simulation, user obtain not only the wellhead temperature but also the temperature distribution of the rock formation near the borehole - both as a function of time. Generated data are exported to excel file and charts are generated to visualise the process. The program does not require advanced knowledge of Python. Most user interaction with the program is done via Excel files and a couple of basic parameters set in the main file in Python. User can define production schedule by setting the bottomhole temperature, pressure and flow of geothermal brine that may change over time. The code can be adapted for both production and injection well. For user who are more advanced in programming, open source code can be customized as needed.
The authors sought to create a user-friendly calculator that converts the parameters of brine entering the well into the wellhead values, taking into account the operational conditions of the well. Detailed user guide and documentation of calculator is under development as well as the programme code itself. The tool is being developed as part of the GeoModel project [https://geomodel.pl/en/] aimed at supporting sustainable management of low and medium temperature geothermal resources.

#35 **Fabio Iannone**
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Susan Onyango
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Jacques Varet
Winnie V. Mitullah
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Energy access in rural communities in East Africa: socio-economic analysis and technical perspectives from the Geothermal Village project

Lack of energy access is affecting over 660 million people in Africa (Ambole et al.,2021; IEA,2022) limiting health, education, and economic opportunities, particularly in rural areas (Adenle,2020). The Geothermal Village (GV) concept (Varet et al.,2014), envisions community-driven geothermal resource (GR) management directly benefiting local populations. GV emphasizes energy justice, equity, and sustainability, enabling communities to shape their own energy futures.

Through field data collection (e.g. surveys, interviews, focus groups) in 4 sites in East Africa, this research funded by the LEAP-RE – in parallel with geoscience studies – examined socio-economic factors and technical perspective:

- Homa Hills (KE) is suffering mainly poverty, food conservation, water supply, and energy access. GRs are used in local cultural practices. The HHGCBO can partner with Capital Power Ltd., in a community-led model with international partnerships. Drilling to 500m for 130°C brine should provide electricity to pump fresh lake water, refrigerate meat and fish, heat to dry fish whereas a spa will benefit from direct use of thermal water.
- Era Boru (ET), a pastoralist area in the Afar region, displays low literacy and limited-service access, including energy. GRs are used to supply water through steam condensing. AGAP works with APDA and government, looking for fundraising for local use of GRs. Drilling to 300m for ~150°C steam will provide electricity for light, clean cooking, etc., and fresh water for humans, livestock, agriculture, sanitation/spa, etc.
- Lac Abhé (DJ) is similar in socioeconomics and energy uses to Era Boru. ODDEG – owning deep drilling equipment – should prioritize local governance and cultural respect. Project implementation, besides government support, relies on external funding and international partnerships. Drilling to 800m for ~135°C brine will provide electricity, heat, as well as water.
- Bugarama (RW) faces challenges for food conservation, water supply and energy access. GV's vision includes support from EDCL , CIMERWA and rice cooperatives; the latter can work as a CBO. International partnerships and local engagement are suggested. Drilling to ~200m for 60°C water can answer the thermal needs of drying rice, coffee, tea, and limestone dehydration, improving the touristic spa, and favouring positive local synergies.

These 4 different site studies confirm GV's potential to enhance energy access and advance socio-environmental goals, prioritizing clean energy and sustainable resource management. Partnerships, local community respect and engagement, capacity building actions, and public financial support are fundamental.

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Acronyms:

AGAP: Afar Geothermal Alternative Power
APDA: Afar Pastoralism Development Association, also owning water drilling equipment
HHGCBO: Homa Hills Geothermal Community Based Organization .

LEAP-RE, Horizon2020, Grant Agreement n.963530.
ODDEG: Office Djiboutien de Développement de l'Energie Géothermique.

#36 **Anne-Sophie Esneu**
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Samuel Marre

Clogging of colloids during fluid reinjection in porous media: implications for injectivity under geothermal conditions

Geothermal fluids are often loaded with mineral and organic particles in suspension, various additives, microorganisms, heavy metals, etc. These compounds often result in significant problems on the sustainability of production and the maintenance of injectivity.
As the migration and deposit of fines concern numerous industrial applications, the physics of colloidal particles in porous media has been widely studied. Historically, most of experimental studies were based on macroscopic measurements, mostly with corefloods. Since the media (rocks) are opaque, mechanisms occurring at the pore scale are difficult to obtain. Lately, interesting results on colloidal deposition and permeability damage have been obtained using microfluidic devices. However, experiments are often conducted on simplified pore-network micromodels that are not reproducing real porous media. Thus, in this work we focus on micromodels representative of a rock-like porous medium from the intrinsic properties point of view (permeability, porosity, geometry of the pores...), to describe the characteristics of permeability damage processes under conditions similar to those of geothermal energy (high flow rates, high permeability ...). The use of microfluidics, which allows direct visualization of the phenomena involved at the pore scale and their quantification through advanced optical methods, was coupled to other important measurements such as pressure.
More particularly, two experimental set-ups have been developed and used, based on different visualization techniques: optical imaging and laser-induced fluorescence (LIF) imaging. The use of these two technics allows us to access complementary information at various scales. With fluorescence, we obtain the concentration field that includes the depth of the micromodel, whereas with classical optical imaging we obtain a better resolution of the images and therefore a better understanding of the mechanisms that result from the interaction between hydrodynamics (velocity, pore geometry, ...) and DLVO forces (particle-particle and particle-surface).
Here, we show how the multiscale interactions between particles and the solid matrix control the distribution of colloids, with a major mechanism involving the shear-induced formation of aggregates at flow conditions that were not investigated so far. Clogging of pore-throats is a key mechanism for reducing permeability, but pore bodies can also be critical deposition zones under certain conditions and stages of injection. Significant hydrodynamic effects have thus been observed.

#37

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Leszek Pająk
Karol Pierzchała

Elimination of the Thermal Lift Effect from Pumping Observations in Deep Geothermal Wells

The interpretation of well tests or long-term observations of wellhead parameters is an extremely valuable tool in the correct assessment of the hydraulic capacity of geothermal reservoir. Despite using the same relationships describing mechanisms of water flow as in the case of freshwater or oil, an important factor that introduces a certain correction to the interpretation of pumping data in geothermal wells is the influence of temperature on the water density. Large fluctuations in water or brine temperature while pumping the well significantly disturb the readings of recorded data - the dynamic water level or the wellhead pressure. This phenomenon is called thermal lift effect.

It often happens that in the case of deep wells with good filtration parameters of the aquifer, the shape of the drawdown curve is far from expectations, because the effect of water expansions masks the true drawdown. The deeper the well and the higher the bottomhole temperature, the more significant this effect is. In any case, the thermal lift effect always causes the drawdown to be smaller than it would be observed if there was no volumetric expansion of water. This in turn can lead to overestimation of resources and unsustainable exploitation, because the real drawdown is often miscalculated. Therefore, it is good practice to separate the thermal lift effect from the raw data when interpreting both short- and long-term pumping data. This allows to filter out noise, correctly assess the actual drawdown, and as a result - the correct transmissivity of the aquifer.

As part of the GeoModel project, THERMALIFT calculator was developed. This Python tool allows for the correction of raw pumping data and graphical representation of results on charts. The only input data required are temperature and water or pressure level during pumping and the temperature profile along the well under natural conditions. The tool was designed to work with vertical and deviated wells with freshwaters and brines. However, the tool is not designed for 2-phase wells. The Python code is in the advanced phase of development and the documentation and user’s manual should be soon available on project website www.geomodel.pl/en

#38

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Daniele Fiaschi
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Pietro Ungar
Martina Zucchi

On the effect of non-uniform permeability on the heat transfer between a wellbore and the surrounding rock formations

The presence of a moving fluid can significantly enhance heat transfer between a geothermal well and the hosting rocks. Although several studies have been carried out to examine the behavior of closed loop systems in hot dry rock geological environment, the knowledge on the effects of directional hot fluid flow involving the surrounding of the wellbore is still affected by the assumption of uniform permeability across the computational domain, which is unlikely to reflect the real conditions of rock deformation that is not homogeneous. The borehole is insisting in a regional shear zone, of which permeability varies depending on fracture density and fracture connectivity, evaluated considering analogue outcrops.
To make the simulation closer to observations, this study aims to investigate the impact of nonuniform permeability distribution around the well, assessing the associated uncertainty in overall heat transfer. This influences flow rate and consequently heat transfer from the natural system to the borehole.

#39 **Adib Kalantar**
Fredrik Fadnes
Mohsen Assadi

Development of a Novel Borehole Heat Exchanger for the Semi Deep Geothermal Energy System

Climate changes and rising energy costs are driving forces for researchers and practitioners to introduce competitive and clean energy supplies. Shallow geothermal energy and ground source heat pumps systems have shown an attractive alternative to common energy sources. The borehole heat exchanger is an efficient and economic tool for extracting geothermal energy within ground source heat pump systems. Recovering a higher temperature for heating or a lower temperature for cooling not only increases the amount of energy required, but it also increases the efficiency of the heating or cooling system. The amount of heat can be transferred between the ground and heat exchanger depends on many factors mainly physical properties of ground such as thermal conductivity and borehole thermal resistance. The layout, cross-section, tube configuration, raw material of the borehole heat exchangers are the most crucial aspects that strongly influenced the effectiveness and lifetime expectancy of the system, which recently attracted numerous attentions. Special care should be taken in hydraulic design of borehole heat exchanger system, particularly laminar flow can occur in the borehole heat exchangers due to usage of heat carrier fluid at low temperature with inadequate flow rate. This can lead to lower heat extraction and rejection rates of the exchanger because of higher thermal resistances. This phenomenon is more dominate for the deeper boreholes since the heat short cut in the up part of the borehole would increase. Furthermore, by increasing flow rate to achieve turbulent flow and satisfactory heat transfer rate can lead to increase the pressure drop of the system and over sizing of circulation pump which leads to impairment of seasonal coefficient of performance at the heat pump.

In this ongoing project, different applications of the borehole heat exchangers is reviewed, then the novel geothermal borehole heat exchangers with appropriate characterization are introduced and investigated.

#41 **TAYGUN UZELLİ**

Innovative Modeling Approaches for High-Temperature, High-Pressure Geothermal Systems: A Case Study of the Menderes Massif

Geothermal reservoirs in the Mediterranean region are predominantly composed of carbonate units, which possess significant potential for extracting and storing geothermal fluids. Despite their importance, the interactions between geothermal fluids and carbonate rock surfaces under varying temperature and pressure conditions remain insufficiently understood. In particular, the impact of reinjecting cooler geothermal fluids into these carbonate reservoirs —especially in medium-to-high temperature systems—has not been thoroughly investigated in Türkiye. Understanding the resulting chemical and physical changes within the reservoir is critical for optimizing geothermal energy extraction and ensuring the long-term sustainability of these systems.
This study presents a new methodological approach for modeling high-temperature and high-pressure geothermal systems, focusing on the Menderes Massif's carbonate reservoirs in the Aegean region of Türkiye. The approach integrates analytical laboratory experiments with conceptual and numerical modeling techniques, providing a comprehensive framework for geothermal reservoir analysis.
For the conceptual modeling phase, the Seequent-Leapfrog software was utilized to develop a detailed geological model, capturing the complex structures and lithological variations within the geothermal field. The model serves as a basis for subsequent numerical simulations, enhancing the understanding of fluid flow and heat transfer within the carbonate reservoirs.
Numerical modeling was conducted using the PetraSim-Toughreact software, which allowed for the simulation of reactive transport processes under high-temperature and high-pressure conditions. This study stage aimed to predict the behavior of geothermal fluids, including mineral dissolution and precipitation reactions, which are critical for understanding long-term reservoir sustainability.
The combination of different techniques provides a novel, integrated approach to geothermal system analysis, offering insights into the geological and chemical processes occurring within the system. The results of this study will contribute to optimizing geothermal energy extraction from complex carbonate reservoirs while providing a robust framework for future research in similar high-temperature geothermal fields.

Acknowledgments: The work presented is a part of the project "Analytical and numerical modelling of chemical reactions and CO2 re-injection processes due to physical changes in high temperature and pressure geothermal systems: A Case Study from Menderes Massif" and funded under the Scientific and Technological Research Council of Türkiye (TUBITAK)'s International Postdoctoral Research Fellowship Program-2219 (Project No:1059B192301691).

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Geothermal Atlas for Africa: characterisation of the geothermal resources in Africa and maps for sustainable exploitation

European and African institutions initiated in 2020 the Long-term Europe-Africa Partnership for Renewable Energies (LEAP-RE). In LEAP-RE the Geothermal Atlas for Africa (GAA) has been developed, aimed at the visualization of geothermal energy potential of the African countries, and based on a comprehensive compilation of available data, subsurface models jointly with many key R&D and geological survey partners in Europe and Africa*.

All the GAA geoscientific data and maps, as well as resource characterization and performance assessment are available in the Geothermal Atlas of Africa website (https://www.geothermalatlasforafrica.org/).
In this paper we present the novel integrated techno-economic and environmental resource assessment approach which has been developed for the GAA. It is designed in such a way that it a) allows for continental scale assessment at the face of limited and very heterogenous subsurface data density, b) is capable to estimate optimized potential reservoir performance and exploitation depth dependent on exploitation use-case/scenarios (i.e. direct heat, direct heat including a heat pump, refrigeration or power production).
The workflow takes into account complementary information from tectonics and heat flow for geothermal gradient, basin analysis for hydrological parameters of sediments as well as zones of active faults and volcanism to be indicative for fracture related permeability. Subsurface information has been used subsequently processed to quantitatively to define best possible potential reservoir depths and performance potential (including both technical , economic, and environmental performance indicators, i.e. LCOE, power produced, gCO2/kWh), including uncertainty.

*) Project partners are as follows: Netherlands Organisation for Applied Scientific Research (TNO), Deutsches, Geo Forschungs Zentrum (GFZ), Addis Ababa University (AAU), University of Florence (UNIFI), University of Nairobi (UoN), Sant'Anna School of Advanced Studies (SSSA), University of Torino (UNITO), Fraunhofer Institution for Energy Infrastructures and Geothermal Systems (Fh IEG), Utrecht University (UU), British Geological Survey (BGS), Bureau de Recherches Géologiques et Minières (BGRM), National Council of Research Italy (CNR), Ressources Géol. Pour le Dévelopment Durable (Geo2D), Djiboutian Office of Geothermal Energy Development (ODDEG), Dedan Kimathi University of. Technology (DeKUT), Eduardo Mondlane University (UEM), National Authority for Remote Sensing and Space Sciences (NARSS), University of Dar es Salaam (UDSM).

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Lumped parameter modelling of pressure response data with Lumpfit++

The Lumpfit program has been used for modeling of pressure response data from low-temperature geothermal reservoirs in Iceland and worldwide. It is based on a lumped parameter method that simulates the pressure response of a reservoir by using a small number of linearly connected homogenous volumes and a single source of production. The method has been successful in predicting pressure changes and has been applied as a resource management tool for production fields since it's firs release in 1989. We present a new software tool, Lumpfit++, based on an updated method that can simulate pressure response in systems with multiple production and re-injection wells. For testing and refinement of the software, rich datasets from Eyjafordur N-Iceland and North-Western Poland have been used. The result of this collaboration between Icelandic and Polish partners is a time-efficient workflow and robust tools to perform reliable reservoir modelling in low-temperature fields.

The work presented is a part of project "Optimal management of low-temperature geothermal reservoirs – Polish-Icelandic cooperation on reservoir modelling" (acronym GeoModel), financed under the Fund for Bilateral Relations through the European Economic Area Financial Mechanism (EEA FM) and the Norwegian Financial Mechanism (NFM) 2014-2021.

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Modelling of the Hjalteyri low temperature geothermal system in N-Iceland

The Hjalteyri low-temperature geothermal system is located on the western shore of Eyjafjördur, 20 km north of the town of Akureyri in northern Iceland. The system lacks surface manifestations and
was discovered by chance during a drilling operation for sediment-filtered seawater intended for fish farming. The well revealed a geothermal gradient of 100-110°C/km, leading to further exploration. Hjalteyri is one of Iceland's most productive geothermal fields, capable of yielding around 200 L/s of 90°C hot water with moderate drawdown. Increased hot water consumption of Akureyri and nearby communities has been met by expanded production from the field. However, invasion of saline waters in recent years has raised concerns about the system's long-term sustainability and prompted further research into its characteristics. The source of the system's recharge remains unclear, and its relationship to other geothermal systems in Eyjafjörður, including one on the seafloor northeast of Hjalteyri, is still unknown. To better understand the system and explore potential recharge scenarios, various modelling efforts are currently underway.

The present modelling effort is part of project "Optimal management of low-temperature geothermal reservoirs – Polish-Icelandic cooperation on reservoir modelling" (acronym GeoModel), financed under the Fund for Bilateral Relations through the European Economic Area Financial Mechanism (EEA FM) and the Norwegian Financial Mechanism (NFM) 2014-2021.

#45 **Walter Wheeler**
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The LEAP-RE Geothermal Village project: Geoscience perspective on 4 sites in the EARS

The Geothermal Village project envisions off-grid community-exploitation of shallow geothermal resources, which in Africa are commonly found along the East African Rift System (Varet et al. 2014). Co-funded by the H2020 LEAP-RE program (Grant Agreement 963530), 4 sites were chosen for feasibility studies. This abstract focuses on the resource.

Lake Abhe Village, Djibouti, lies on the E. side of Lake Abhe, on basaltic ridges formed by ENE-trending faults. To the west, on exposed lake beds, fields of hydrothermal chimneys, steam vents and hot springs (71 to 99.7°C) are inferred to form over a buried N-trending fault system bounding the lake basin, consistent with electric resistivity tomography, induced potential and magnetotelluric (ERT, IP, MT) measurements used to map the 3D hydrothermal plumbing. Well doublets would spud on basalt 1km from the fractured-basement target 800m beneath the unconsolidated lake beds, for ~135°C brine, to provide ORC electricity, heat and fresh water.

The Mashyuza hot springs, in Bugarama, Rwanda, lie in the Tanganyika-Kivu accommodation zone. They emit 51°C carbonate-rich water and gas (99%CO2), depositing travertine and carbonate mud in excess of 50m thickness. Flow from natural springs approximately 140l/s; a 60°C shallow source is inferred. The springs are adjacent to a NE-trending oblique-slip fault bounding the N-trending graben. ERT, IP and MT delineate low-resistivity zones inferred to be fluid-rich basement faults. Targeting these zones at 200m depth with doublets would allow high-flow 60° water for direct use while maintaining natural spring heads.

Homa Hills, Kenya, at the NE corner of Lake Victoria, is underlain by a carbonatite volcano complex (12-1.3 Ma). Hot spring temperatures range from 88 to 43°C. Magnetotelluric data identify both shallow (200m) low resistivity by the hot springs (200 m depth) and deep (4 km) low resistivity zones but no connection between. The spring water indicates a deep high temperature (up to 200°C) source. Relatively shallow drilling (500m) for 130° brine should allow village-scale ORC electricity and direct-use heat, likely at several locations.

At Era Boru, Ethiopia, in the Afar triangle, steam emerges from open faults, used for millenia to condense fresh water. IR drone surveys show the hottest areas along fault systems, where drilling to 300m, likely with a modified water-drilling rig, should provide ~150°C steam for electricity as well as direct heat and condensed fresh water.

#46

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THE EU SAPHEA PROJECT - SAPHEA – ACCELERATING GEOTHERMAL ENERGY INTEGRATION IN HEATING AND COOLING NETWORKS ACROSS EUROPE

Heating and cooling (H&C) in buildings and industry account for half of the EU's energy consumption, primarily from fossil fuels. Across all energy carriers, renewable energy sources (RES) provide 18% of the primary energy supply for HC in the EU-27. The IEA forecasts that the global share of RES in heat consumption will increase from 11% in 2020 to 13% in 2026. While the EU has set ambitious targets to increase the RES share in H&C by 2030 (2018/2001/EU), growth remains constrained by insufficient policies, financial incentives, and public funding for renewable heat.
District heating and cooling ('DHC') holds significant potential for decarbonizing the HC sector. However, their penetration remains limited in several European countries, currently supplying only 8% of the total final energy demand for HC - mainly in the residential (55%) and tertiary (30%) sectors.
SAPHEA seeks to advance the integration of geothermal energy in multivalent DHC networks by creating a durable Digital Market Uptake hub for GeoDHC. This Hub offers a toolbox, a gamebook, and various reports and guidelines designed to support stakeholders in early-stage investment decisions and strategic planning. SAPHEA builds upon and extends existing knowledge, datasets and tools like Hotmaps and Geophires to deliver targeted training, enabling stakeholders to draft low-carbon development scenarios that leverage geothermal energy.
SAPHEA engages a network of public and private market actors and researchers, including local authorities, community services, and energy suppliers, ensuring long-term results beyond the project's duration.
SAPHEA addresses the market uptake of geothermal energy and underground heat storage in multivalent heating and cooling networks, which operate at temperatures ranging from below 30° C to approximately 100°C. The range of applications of geoHC networks starts at local-scale networks with capacity levels of at least 500 kWth, including sub- and peri-urban regions across Europe. SAPHEA supports both the installation of new geoHC networks – whether greenfield installations or replacements for individual heating and cooling systems - and the retrofitting of existing fossil-fuel-supplied networks. Through a comprehensive survey of geoHC installations across Europe, SAPHEA has developed a scenario catalogue that highlights different types of systems in operation..
SAPHEA's overarching goal is to overcome the prevailing barriers to renewable heat by developing and promoting market uptake measures, enabling geoHC networks to play a significant role in the European H&C sector. In doing so, the project SAPHEA contributes to the gradual replacement of fossil fuels while at the same time increasing the use of low-exerg, on-site RES, supporting the EU's objective of achieving net-zero emissions by 2050.

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Ground source heat in Norway – on the value gained by firm, renewable, carbon neutral, local and areal effective thermal resources by the Geothermal Energy Association of Norway

Norway lacks oversight of ground-source thermal energy in its national energy budget, largely due to (a) the absence of regulatory measures for automatic heat extraction reporting and (b) undervaluing this heat, since it is free and untaxed. Its contribution to the national energy stability is therefore overlooked. Additionally, since energy wells are largely invisible with minimal areal footprint, it is overlooked in land-use planning. Without a comprehensive national ground-source heat database, estimates of its contributions rely on top-down approaches. To improve accuracy, large and small ground-source heat systems are analyzed to develop conversion factors, allowing for thermal power and annual energy estimates based on drilling data from the NGU Granada database, supplemented by an in-house Midttømme database. These estimates are cross-referenced with data from the national heat pump association (NOVAP) to reflect heat pump sales.

Annual assessments indicate that, in 2023 alone, 50 MW of thermal power, generating 170 GWh of heat, was added through 4,300 newly drilled wells. Since the 1980s, ground-source wells have contributed a peak capacity of approximately 620 MW, producing around 2.0 TWh of energy annually. When factoring in heat pump sales, these estimates increase to 728 MW of power and 2.55 TWh of annual heat production, though actual values may be higher due to underreporting. These estimates are sensitive to assumptions around heat extraction per meter drilled, annual capacity factors, and the exclusion of seasonal storage.

Expanding ground-source heat solutions could be further accelerated. Current pricing mechanisms do not equitably distribute costs among stakeholders who benefit from this resource. With escalating climate change impacts, stringent emission targets, and the ongoing nature and material scarcity crises, only select energy technologies can be deployed at scale.

The value of ground-source heat is estimated for the stake holders:

a) Lower electricity demand for building owners

b) Reduced infrastructure demand for regional energy providers

c) Reduce price fluctuations, supporting decarbonization and industrial growth nationally

d) Lower climate emissions and enhanced energy transfer capacity between countries

Assessing the full societal value of ground-source heat can inform new cost-sharing mechanisms to bridge gaps between upfront costs and long-term benefits.

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Monitoring geochemical changes of low temperature geothermal systems in northern Iceland

Sustainable management of geothermal resources includes long-term geochemical monitoring. Chemical changes in the geothermal fluids often reveal potential issues with the reservoir before operational problems, e.g. scaling, or physical effects, e.g. lowering of the temperature or pressure, are observed. The Hjalteyri low temperature geothermal system on the western shore of Eyjafjörður in northern Iceland is one such system. While this system's discovery and development is a boon for the region's district heating system, operational problems will occur if its utilization continues with no adjustments. As a result of long-term geochemical sampling, changes in water chemistry were observed before the occurrence of potential issues, thereby allowing time and research to make necessary modifications for its continued usage.

#49

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Investigating the impact of wellbore lateral heat transfer on the performance of high-temperature aquifer thermal energy storage system by the coupling of wellbore and reservoir simulators

This study investigates the often-overlooked impact of wellbore lateral heat transfer on high-temperature aquifer thermal energy storage (HT-ATES) systems, focusing on the Swiss Bern project. We coupled our in-house wellbore simulator (MOSKIO) with the reservoir simulator (PorousFlow) under the MOOSE framework to analyze wellbore heat loss. Utilizing both numerical and analytical approaches, we reveal how wellbore heat loss affects HT-ATES performance compared to previous studies that ignored it. Our analysis also examined various wellbore configurations and operational parameters. It is found that the wellbore lateral heat loss can diminish the energy recovery efficiency of the HT-ATES system by around 7%, which reflects the necessity of considering the wellbore in the ATES performance evaluation rather than ignoring the wellbore. In addition, the sensitivity study shows that small wellbore diameter (e.g., 6.75 inches) can improve energy recovery efficiency by increasing the fluid extraction volume. Moreover, low thermal conductivity of wellbore casing material (e.g., 0.045 $W \cdot m^{-1} \cdot K^{-1}$) is able to reduce the wellbore lateral heat loss by 51.4%, compared to the high wellbore thermal conductivity. Nevertheless, economic costs must be also taken into account for the choice of the wellbore parameter selection.