Investigation of the Medium - Deep Geothermal Potential of Various Locations in the Upper Rhine Graben using COMSOL

Naga Lokesh Gunturu Venkata[1], Leandra Weydt[2], Johann Holler[2], Bastian Welsch[1], Ingo Sass[2,3]

[1]Department of Civil and Environmental Engineering, Hochschule Bochum, Am Hochschulcampus 1, 44801 Bochum, Germany

[2]Department of Geothermal Science and Technology, Technische Universität Darmstadt, Schnittspahnstraße 9, 64287 Darmstadt, Germany

[3]GFZ Helmholtz Centre for Geosciences, Section 4.3 - Geoenergy, Telegrafenberg, 14473 Potsdam, Germany

Introduction

Medium-deep (~400m - 2000m) geothermal energy could play an important role in contributing to Germany's heating sector as its potential enables to supply reliable, low carbon, base-load heat with compact spatial footprint that integrates into urban networks. Germany have successfully explored the deep geothermal for heat and electricity, however medium - depth reservoirs with low temperatures are less explored (Weydt et al., 2023). The ArtemIS project intends to reduce the gap and enhance our understanding towards medium-deep energy by expanding the GeotIS platform (www.geotis.de) through integration of subsurface data and building 3D reservoir models using COMSOL software and simulating different scenarios like doublet and ATES to evaluate the heat extraction potential of medium-deep reservoirs across all play types (Weydt et al., 2025). This thesis focuses on the "Harthausen" site situated in the Northern Upper Rhine Graben region, where the statigraphic, petrophysical and log data drawn from literature, and data from other projects were incorporated into the 3D numerical reservoir model and the resulting potential heat data is analysed.

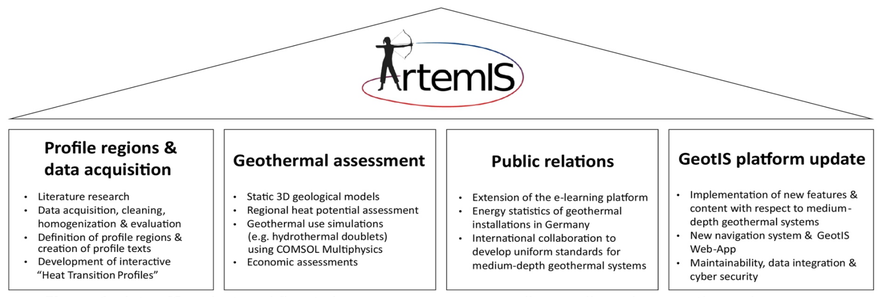

Figure 1: ArtemIS project workflow to increase awareness regarding medium-deep geothermal energy.

Figure 2: GeotIS platform with interactive maps, e-learning, and statistics.

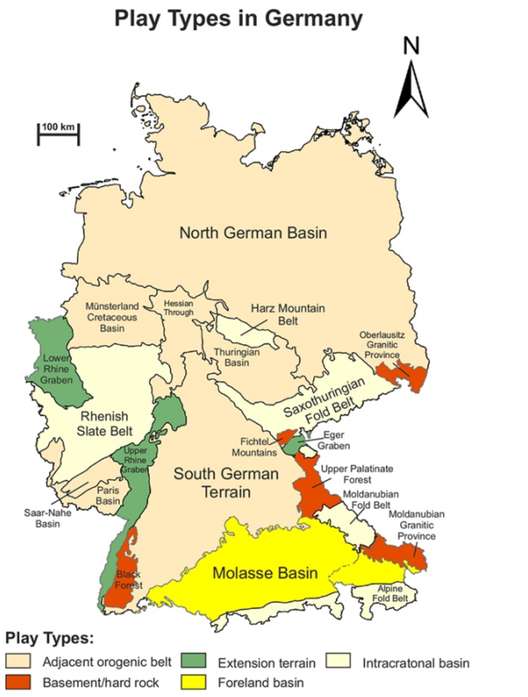

Figure 3: Geothermal play types in Germany (modified after Moeck et al., 2019).

Methods

- Datasets from various sources and projects, including well logs and maps, were compiled to create a PETREL dataset. This dataset was then used to develop a site-specific model for COMSOL using Python.

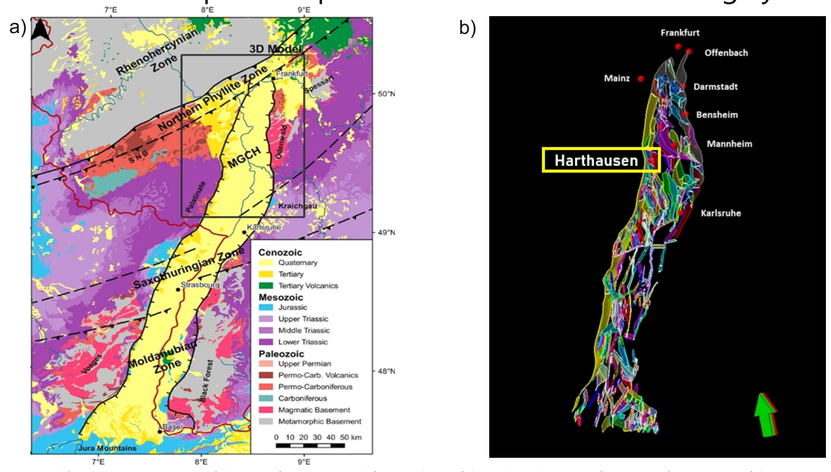

Figure 4: a) Upper Rhine Graben map with stratigraphic units (Frey et al., 2022). b) Upper Rhine Graben Petrel Model extended fault system with the target area.

- The literature indicates geological heterogeneity within each horizon. Taking this into consideration, material properties are defined using min, mean and max values as a part of uncertainty analysis approach.

Table 1: Subsurface properties of the top layer in the model.

Landau Formation	Min	Mean	Max
Density [Kg/m³]	2700	2150	2000
Permeability [mD]	0.9	50	109
Porosity [-]	0.1	0.2	0.35
Thermal Conductivity [W/(m*K)]	1.5	2	2.5
Heat Capacity [J/(kg*K)]	800	900	1000

Table 2: a) For the heat potential assessment along with the subsurface properties other operational parameters are also taken and simulated with around 324 combinations for 30 years continuous operation. b) ATES is simulated with around 48 combinations in total to assess the systems efficiency over a period of 30 years.

a)

Operational Parameters Hydrothermal Doublet			
Mass Flow Rate [L/s]	20	50	80
Depth [m]	500	1000	1500
Well Distance [m]	500	1000	1500
Injection Temperature [K]	283.15	293.15	
Screen Length [m]	50	100	

b)

Operational Parameters ATES				
Mass Flow Rate [L/s]	2.5	5.0	7.5	10
Depth [m]	500			
Injection Temperature [K]	318.15	333.15	348.15	363.15

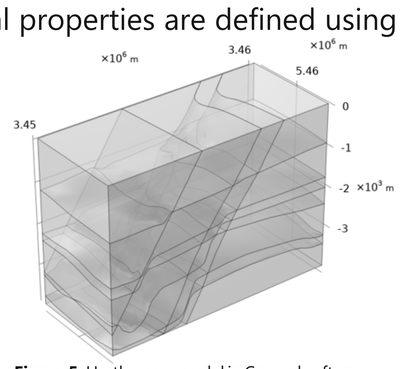

Figure 5: Harthausen model in Comsol software.

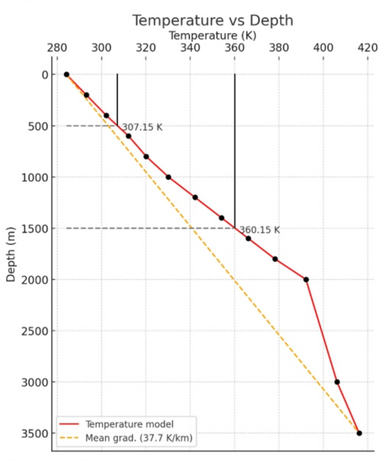

Figure 6: Temperature profile at Harthausen site for different depths is taken from GeotIS website to integrate the geothermal gradient in the model.

Results

Hydrothermal Doublet - Harthausen

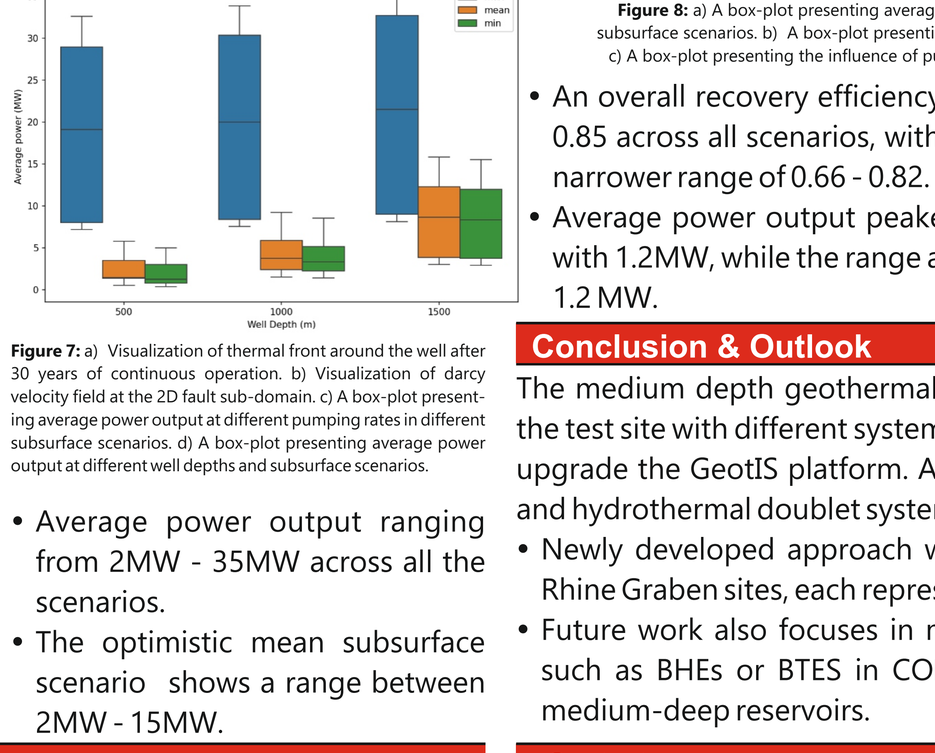

Figure 7: a) Visualization of thermal front around the well after 30 years of continuous operation. b) Visualization of darcy velocity field at the 2D fault sub-domain. c) A box-plot presenting average power output at different pumping rates in different subsurface scenarios. d) A box-plot presenting average power output at different well depths and subsurface scenarios.

- Average power output ranging from 2MW - 35MW across all the scenarios.
- The optimistic mean subsurface scenario shows a range between 2MW - 15MW.

Aquifer Thermal Storage - Harthausen

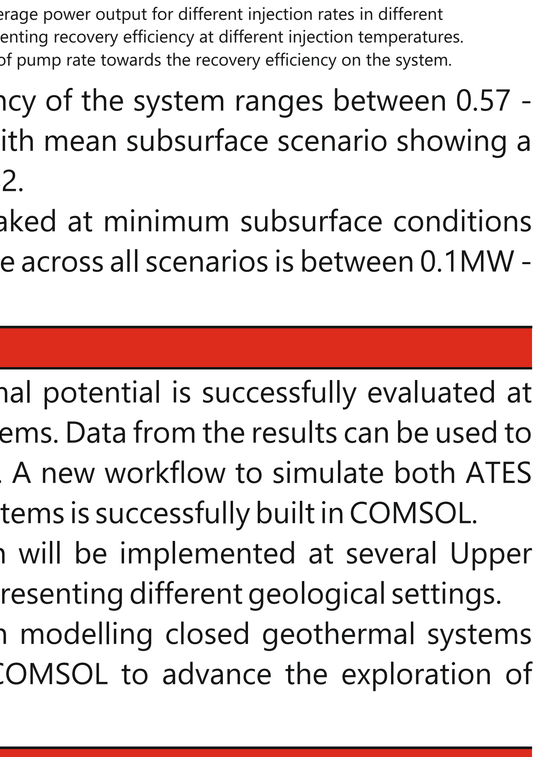

Figure 8: a) A box-plot presenting average power output for different injection rates in different subsurface scenarios. b) A box-plot presenting recovery efficiency at different injection temperatures. c) A box-plot presenting the influence of pump rate towards the recovery efficiency on the system.

- An overall recovery efficiency of the system ranges between 0.57 - 0.85 across all scenarios, with mean subsurface scenario showing a narrower range of 0.66 - 0.82.
- Average power output peaked at minimum subsurface conditions with 1.2MW, while the range across all scenarios is between 0.1MW - 1.2 MW.

Conclusion & Outlook

The medium depth geothermal potential is successfully evaluated at the test site with different systems. Data from the results can be used to upgrade the GeotIS platform. A new workflow to simulate both ATES and hydrothermal doublet systems is successfully built in COMSOL.

- Newly developed approach will be implemented at several Upper Rhine Graben sites, each representing different geological settings.
- Future work also focuses in modelling closed geothermal systems such as BHEs or BTES in COMSOL to advance the exploration of medium-deep reservoirs.

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ArtemIS

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Contact

Hochschule Bochum
Fachgebiet Geothermie

Am Hochschulcampus 1
D-44801 Bochum
Email:
naga.gunturu-venkata@stud.hs- bochum.de
Bastian.Welsch@hs-bochum.de

TU Darmstadt
Fachgebiet Angewandte Geothermie

Schnittspahnstrasse 9
D-64287 Darmstadt
Email:
weydt@geo.tu-darmstadt.de
holler@geo.tu-darmstadt.de