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Techno-Economic Evaluation of Hot Sedimentary Geothermal Systems using GEOPHIRES-X

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INTRODUCTION

The geothermal potential of hot sedimentary basins has been studied for some Western US States (Johnston et al, 2020). There are gigawatts of potential geothermal power production from low enthalpy sedimentary basins in U.S. and Canada, based on drilling new dedicated geothermal wells. There are additional challenges in sedimentary basin plays including over and under pressured resources, artificial lift and parasitic load optimization, high salinity brines, and multi-use basins with competing resources such as oil and gas. Some of these challenges are also opportunities that can change the economics of projects. Most studies to date rely on simple heat in place or power density calculations applied to hot sedimentary aquifers (HSA). These methods fall short in appropriately characterizing the opportunities. Johnston et al used the GEOPHIRES v2.0 tool developed by the National Renewable Energy Lab (Beckers 2019) to evaluate the techno-economics of the Marys River Basin in Eastern Nevada. RESPEC used GEOPHIRES-X, the 2023 successor to GEOPHIRES v2.0, to study another US sedimentary system. The Python open-source tool proved its versatility through simple customizations to adapt to geo-pressures, reservoir simulation integration, and custom unit cost assumptions. The additional metrics for project economics and the use of a Monte-Carlo analysis to predict the probabilities of possible outcomes were beneficial to further geothermal analysis. GEOPHIRES could be used for pre-feasibility evaluations, feasibility studies and due diligence evaluations. In addition to further customization for HSA project due diligence RESPEC helped develop a regional sedimentary basin analysis workflow using GEOPHIRES in partnership with an internship program with South Dakota School of Mines and Technology funded by the National Science Foundation and Department of Energy. A test case in the Williston Basin of North Dakota was used to develop the workflow. It is our opinion that the methodology used for this study and spatial analysis could be extended to other hot sedimentary geothermal systems.

1 CODE VERIFICATION

The resource calculations and cost assumptions built into the GEOPHIRES tool were verified against those included in a publicly funded US Trade and Development Administration (USTDA) bankable feasibility study in Turkey. It was found that the resource calculations matched the reported 3rd party techno-economic study, with some minor adjustments for capital expenses (CAPEX) required. The operating expenses (OPEX) assumed in GEOPHIRES, however, were found to significantly differ from those used in the USTDA project because the US labor costs are significantly more expensive than in Turkey. Adjustments to the wells, gathering system and plant CAPEX, as well as OPEX, are easily made in GEOPHIRES using adjustment ratios.

2 CODE MODIFICATION FOR HOT SEDIMENTARY SYSTEMS

The GEOPHIRES tool has been originally developed for fault-hosted geothermal systems found in the Western US or for Enhanced Geothermal Systems (EGS). However, thanks to its open-source nature, it could easily be modified for Hot Sedimentary Geothermal Systems. For example, the temperature drawdown was assumed to be nil with proper well spacing. For geo-pressured reservoirs, the parasitic load calculations were modified to remove load from production pumps and re-injection into shallower reservoirs was allowed with the definition of a secondary reservoir with its own temperature and pressure. Once these code modifications are made, the code runs within a few seconds and inputs can be modified very quickly, which allows for many sensitivity runs as shown in a Tornado chart, Figure 1. Finally, GEOPHIRES can also run the TOUGH reservoir simulation package (it is called internally) provided that the TOUGH executables are provided. The TOUGH input files can be generated and easily modified within GEOPHIRES which allows the economic model to be coupled with a TOUGH model for a geothermal doublet for example.

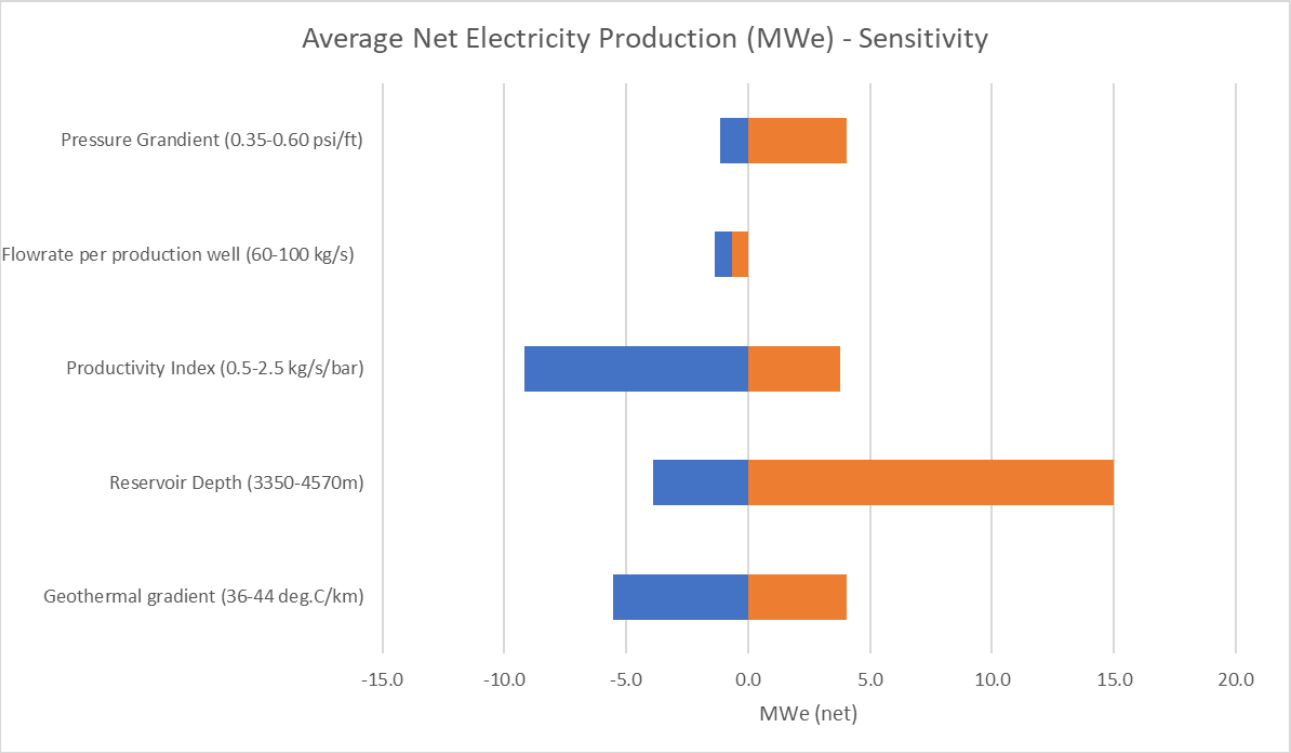


Figure 1: Example of Tornado Chart for a Hot Sedimentary Geothermal System using GEOPHIRES

3 IMPROVEMENTS OF ECONOMIC MODULE WITH GEOPHIRES-X

GEOPHIRES-X is the 2023 update to GEOPHIRES v2.0. The code architecture has been significantly modified and a comprehensive economic module added. This module allows considerable flexibility in the economic assumptions such as the revenue from sales time series. The tool now includes all the regular project economic metrics such as Net Present Value (NPV) Internal Rate of Return (IRR), capital efficiency, etc. in addition to the Levelized Cost of Electricity (LCOE).

3.1 Monte-Carlo Analysis with GEOPHIRES-X

GEOPHIRES-X also includes the capability for Monte Carlo analysis through the use of the GEOPHIRES input file that was used for a single deterministic run and a simple text file that specifies the probabilistic distributions. The computer processing is very efficient through parallel processing allowing a large number (for example: 10,000) realizations. The probabilistic distributions for the output parameters are stored in the code and statistics / charts for these distributions can easily be made through customization of the code. A future improvement to the code would be to allow GEOPHIRES to run a Monte-Carlo analysis on a GEOPHIRES model using TOUGH for the reservoir simulations.

3.2 Wilcox Formation Test Case

RESPEC's improved version of GEOPHIRES with modifications for HSA geothermal resources was used to run a example analysis of the Wilcox Formation in Southwest Texas. TOUGH3 was used to simulate multiple production, five, and injection wells (3) in the Wilcox Formation sands for a specific project location. The TOUGH3 output was used to calculate well performance which was input into the GEOPHIRES power calculation module. Final simulation outputs are presented in Table 1 comparing economic results for a base case and application of geothermal federal tax credits under the Investment Tax Credit (ITC) program. Calculated capital costs and operational costs along with resulting LCOE ranges where well aligned with published International Renewable Energy Association (IRENA) Geothermal project data.

Table 1. Example GEOPHIRES simulation output for Wilcox Formation test case. Output shows a comparison of base case versus application of the tax credits. Base input parameters in black, calculated output in blue text.

GEOPHIRES SIMULATION OUTPUT WILCOX FORMATION TEXAS	NO TAX CREDIT	WITH ITC
TEMPERATURE RESERVOIR (C)	180.9	180.9
THERMAL POWER (MWTH)	131.1	131.1
GROSS ELECTRICITY GENERATION (MWE)	20.5	20.5
CONVERSION RATE	15.6%	15.6%
PROD WELLS DRAWDOWN (BAR)	32	32
PARASITIC LOAD (MWE)	3.5	3.5
NET ELECTRICITY GENERATION (MWE)	17.0	17.0
CAPEX EXPLORATION (MM USD)	5.0	1.9
CAPEX WELLS (MM USD)	45.9	25.6
CAPEX GATHER (MM USD)	14.7	8.1
CAPEX PLANT (MM USD)	51.9	28.8
CAPEX TOTAL (MM USD)	**117.5**	**64.3**
TIC PROJECT CAPEX $/KW (IRENA 2022 = $2000-$6000 /KW)	5,740	3,142
OPEX TOTAL (MM USD/YEAR)	3.01	2.80
O&M USD/KW/YEAR (IRENA 2022 = $110/KW/YEAR FOR ORC)	147	137
ELECTRICITY BREAKEVEN PRICE - LCOE - NPV=0 (USD/MWH) (IRENA 2022 = $50-$100/MWH)	**107.4**	**64.4**

4 BASIN SCALE TECHNO-ECONOMIC ANALYSIS

A workflow was developed using basin scale data as input to a custom version of GEOPHIRES to quantify geothermal resource and economic outputs across a sedimentary basin with changes in regional geothermal resource parameters. A test case was used to create a workflow, evaluating the techno-economic feasibility of geothermal energy production from HSA in the Williston Basin, North Dakota. Subsurface well and formation data were used to define reservoir input parameters, Herrboldt (2025). The workflow integrates TOUGH3 for reservoir simulation, GEOPHIRES for techno-economic simulation, and ArcGIS Pro for spatial analysis. Reservoir models for TOUGH3 simulation were created to simulate variably well completion configurations for geothermal systems. Key outputs from GEOPHIRES—Net Power Production and LCOE—were mapped across the basin to assess geothermal potential. The final deliverables were sets of techno-economic feasibility maps for the Mission Canyon, Lodgepole, Red River, and Deadwood formations. These maps illustrate the spatial distribution of geothermal potential across selected formations.

Conclusions

The open-source nature of GEOPHIRES allows some relative simple customization for engineers with some intermediate knowledge of Python thanks to a good documentation throughout the code. The most recent version, GEOPHIRES-X, offers significant improvements compared to GEOPHIRES v2.0 including a comprehensive set of economic metrics and the capability of Monte-Carlo analysis.

The GEOPHIRES tool runs fast on a standard laptop and is particularly suited for pre-feasibility / scoping studies with an appropriate level of detail and inputs that can be very quickly modified. This was verified against an

existing USTDA bankable feasibility study in Turkey. GEOPHIRES could also be used to double-check the calculations of usually very complex economic model spreadsheets, for example in the case of due diligence reviews. Creative application of ArcGIS, GEOPHIRES, and TOUGH3 can be used to simulate basin scale HAS resources.

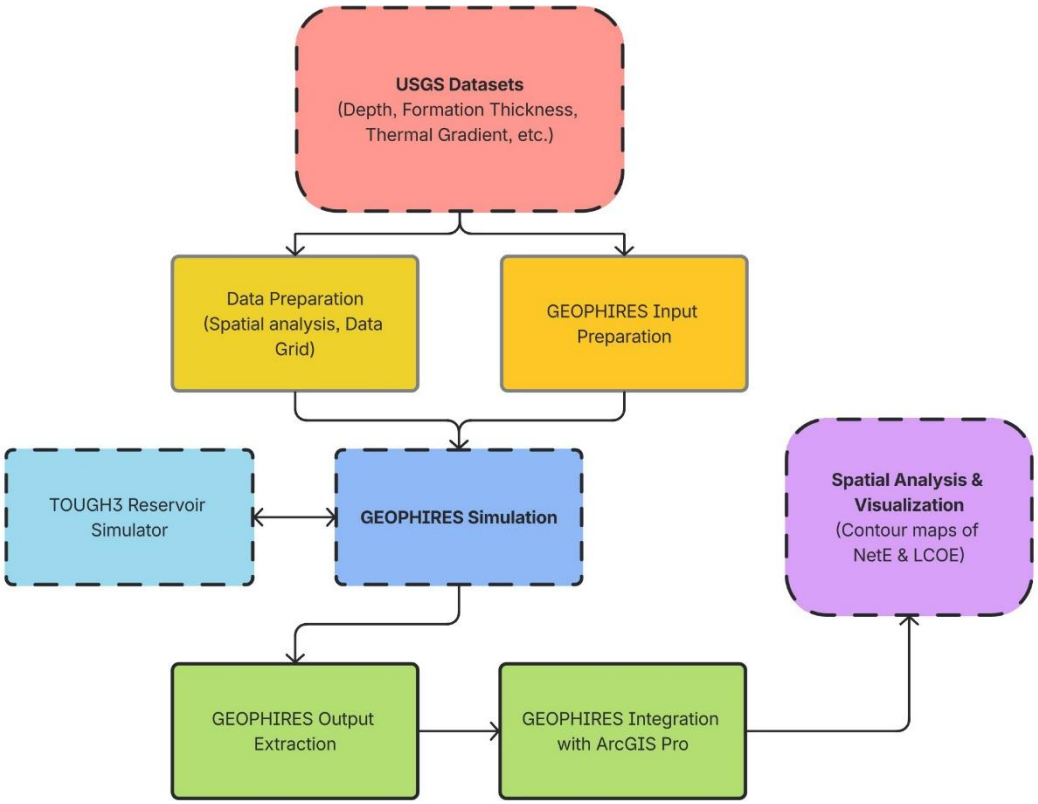


Figure 1. Flowchart for workflow developed for spatial analysis from techno-economic simulations.

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