

Preliminary Assessment of EGS Potential in South-Central South Dakota

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ABSTRACT

South-central South Dakota exhibits elevated heat flow (up to 130 mW/m²) and steep geothermal gradients (greater than 100 °C/km), indicating substantial geothermal potential. Nevertheless, the region remains underexplored; past development has been largely confined to small direct-use systems (e.g., hot-water heating). In our previous work (Ye et al., 2025), we compiled the most comprehensive dataset to date, nearly 3,000 borehole temperature measurements, to reconstruct higher-resolution geothermal-gradient maps, and then performed preliminary techno-economic analysis (TEA) of direct-use applications in two shallow aquifers. These results are encouraging and point to considerable opportunities for geothermal development in South Dakota. In this paper, we further evaluate the technical feasibility and economic viability of the deployment of enhanced geothermal systems (EGS) within the deep crystalline basement using a doublet well configuration with approximately 100 m injection-production spacing. Thermal transport analysis shows that realistic fracture apertures enable rapid heat transfer, allowing produced fluid temperatures to approach reservoir conditions at depths of ~3 km, and deeper. A grid-based techno-economic assessment quantifies the leveled cost of electricity (LCOE), net present value (NPV), and internal rate of return (IRR) under varying production flow rates and Investment Tax Credit (ITC) levels. The TEA results suggest that EGS in South-Central South Dakota are technically viable and hold considerable long-term potential, but their near-term economic success remains sensitive to reservoir performance and the presence of policy incentives. This study aims to provide a first-hand perspective on the techno-economic viability of geothermal energy development in South Dakota and highlights key parameters affecting its future development.

1. INTRODUCTION

South-central South Dakota represents a uniquely promising but underexplored geothermal resource within the midcontinent region. This area, including Lyman, Tripp, and Gregory counties, is characterized by elevated geothermal gradients and unusually high heat flow. Heat flow values in this region commonly exceed 80 mW/m², with some localized zones reaching up to 130 mW/m² (Blackwell et al., 2011; Gosnold, 1987, 1999). In combination with high geothermal gradients exceeding 100°C/km (Gosnold, 1999; Gries, 1977; Schoon & McGregor, 1974), these conditions point to a significant geothermal resource within the upper Midwest. Temperature projections at depths of 3 to 5 kilometers suggest values surpassing 250°C (Blackwell et al., 2011), making the region highly suitable for geothermal development. Unlike the widespread geothermal resources found in the western United States, the anomaly in south-central South Dakota represents the only major high heat flow zone within the broader midcontinent region. Neighboring states such as Nebraska, Kansas, and Iowa typically show lower heat flow values, averaging between 40 and 60 mW/m². This contrast highlights the unique nature of South Dakota's geothermal potential.

Historically, geothermal use in the state has been limited to small-scale, direct-use applications, drawing from shallow hot water aquifers such as those in Philip and Midland (Chiasson et al., 2012; Lund, 1997). However, the possibility of developing utility-scale geothermal applications in the south-central region remains largely untested and represents a significant opportunity. One reason for the limited development is uncertainty surrounding the mechanisms driving the anomalously high heat flow observed in the south-central region. Previous studies have been inconclusive, relying mainly on hydrological models supported by limited subsurface data from sparse drilling and temperature measurements. Early interpretations, such as those by Gosnold (1987, 1999), suggested that regional groundwater flow and advective heat transport were the dominant mechanisms. This interpretation contributed to the long-standing view that geothermal resources in the area are limited to low-to-medium temperature systems suitable primarily for direct-use applications.

More recent geological and geophysical investigations challenge this view (Blackwell et al., 2011; McCormick, 2010; U.S. Geological Survey, 2002), suggesting that the high heat anomaly may instead originate from the deeper granitic basement. Notably, U.S. Geological Survey (2002) identified a strong spatial correlation between the geothermal hotspot and a pronounced low in the Bouguer gravity anomaly. These gravity lows are often associated with zones of reduced density caused by deep crustal features such as fracturing, hydrothermal alteration, or igneous intrusions (Atef et al., 2016). The co-occurrence of high heat flow with both gravity lows and weak aeromagnetic signals further suggests the presence of deep-seated structures, such as faults or intrusive bodies, which may enhance vertical heat transport (Basantaray & Mandal, 2022). Together, these findings support the hypothesis that the geothermal anomaly may be associated with a fractured and thermally active granitic basement, which provides conditions favorable for Enhanced Geothermal System (EGS) development. This interpretation aligns with the U.S. Department of Energy's EGS Resource Potential Estimate (Augustine, 2016;

Augustine et al., 2023), which identifies this region as having significant potential for engineered geothermal systems (Figure 1). Despite favorable subsurface indicators, the geothermal potential of South Dakota remains underexplored and under-assessed. Early studies primarily evaluated the energy content of sedimentary aquifers, such as the Dakota Formation, Madison Limestone, and Deadwood Formations, using hydrological models. Estimates suggest these aquifers contain more than $12,250 \times 10^{18}$ joules of thermal energy (Gosnold, 1987, 1999; Sorey et al., 1983), underscoring the state’s suitability for direct-use geothermal heating. However, the potential for deeper, high-enthalpy geothermal resources, suitable for enhanced geothermal systems (EGS) and power generation, remains largely untapped and warrants further investigation.

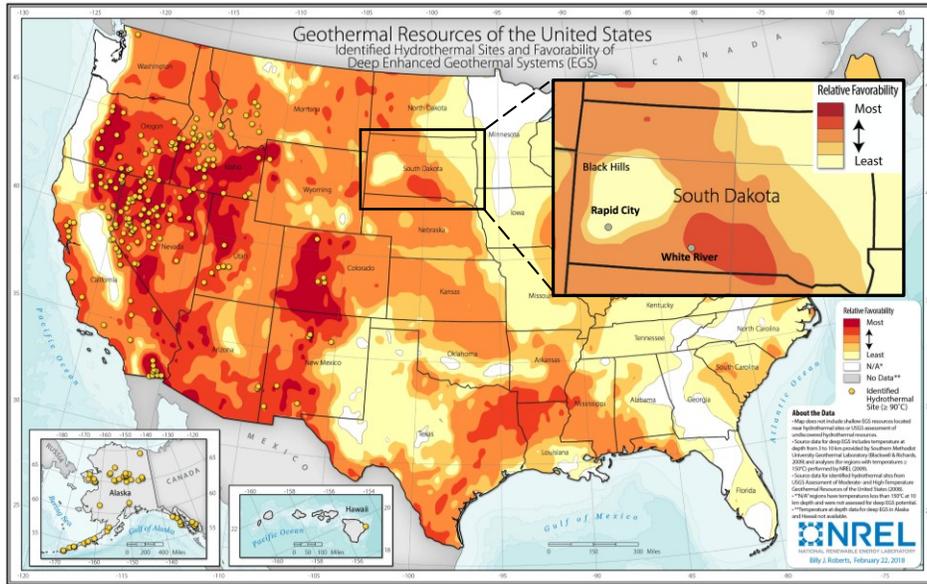


Figure 1: Favorability for Enhanced Geothermal Systems (EGS) in U.S. (modified from U.S. Geothermal Assessment Map, NREL, 2023)

To support the strategic development of geothermal energy in South Dakota, we previously compiled the most comprehensive borehole temperature dataset available, totaling nearly 3,000 measurements across the state (Ye et al., 2025). This dataset was used to construct a high-resolution geothermal gradient map (Figure 2). Compared to earlier models (Blackwell et al., 2011; Schoon & McGregor, 1974), this updated map offers a more detailed and reliable representation of the subsurface thermal structure by leveraging a broader and more site-specific dataset. Using this refined gradient map, we then performed a techno-economic assessment (TEA) to evaluate the upper-bound potential for direct-use geothermal heating. The analysis targeted two reservoir intervals at depths of approximately 400 m and 650 m, corresponding to the Dakota Sandstone and Inyan Kara Group, and the Minnelusa and Red River Formations, respectively. The identified high-gradient zone in south-central South Dakota spans approximately 1,000 km², representing a substantial thermal resource base. Preliminary capacity estimates indicate that the modeled system could supply heating to over 9,600 households, underscoring its potential for community-scale or institutional deployment.

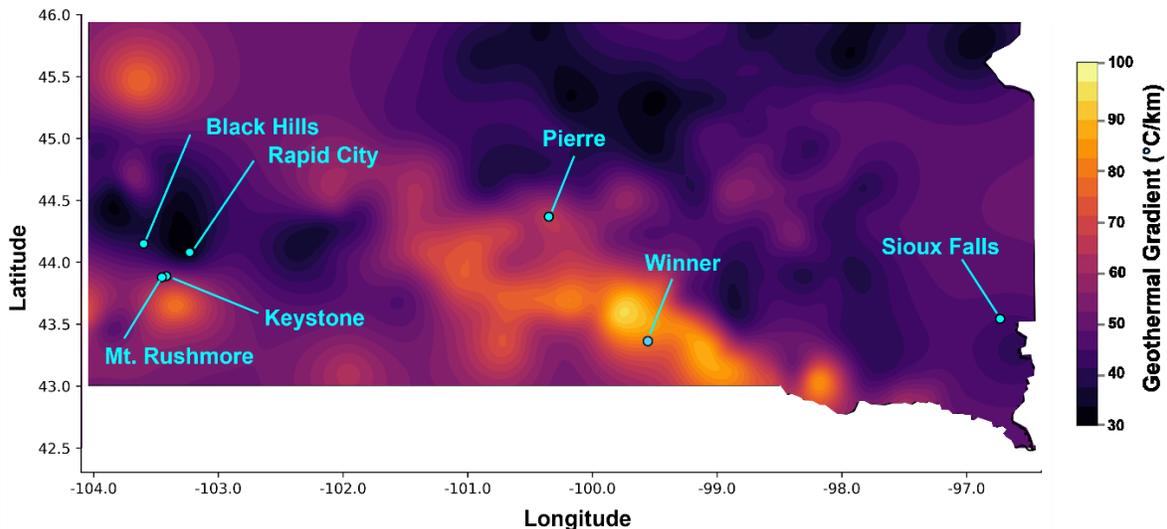


Figure 2: Updated geothermal gradient map of South Dakota based on an expanded borehole temperature dataset.

These results demonstrate that shallow direct-use geothermal systems could offer a viable heating solution in south-central South Dakota. However, a key limitation lies in energy distribution: the majority of South Dakota's population resides in the eastern and western regions, while the highest geothermal gradients are concentrated in the central part of the state. This geographic mismatch limits the practicality of large-scale direct-use deployment without substantial investment in heat transport infrastructure. To overcome this barrier, utilizing these geothermal resources for electricity generation via Enhanced Geothermal Systems (EGS) could be a promising alternative. Although further studies are needed to evaluate the technical feasibility, geological suitability, local energy demand, infrastructure capacity, and regulatory environment for EGS deployment, a targeted techno-economic assessment (TEA) of EGS development in south-central South Dakota is a critical first step. In this study, we evaluate the feasibility of EGS in the region by modeling a range of mass flow rates and operational scenarios to assess system performance and cost variability. The analysis incorporates current U.S. policy incentives, including investment tax credits (ITC), to establish a realistic financial framework. Building on our previous study, which evaluated the techno-economic feasibility of shallow geothermal direct-use applications, this work extends the analysis to deeper, high-enthalpy systems suitable for Enhanced Geothermal Systems (EGS). Together, these complementary assessments aim to provide a first-hand perspective on the techno-economic viability of geothermal energy development in South Dakota.

2. BACKGROUND

The study begins by evaluating the performance of previous geothermal well injection and production systems, such as those at Utah FORGE and Cape Station. The goal is to determine whether injected water can reliably achieve the desired production temperature over a given distance between injection and production wells. Next, a grid block is defined to represent a feasible project scale and reservoir area within the potential development zone in south-central South Dakota. For each grid block, the geothermal gradient, surface elevation, and required drilling length to reach the target temperature are estimated using averaged values. A techno-economic assessment is then completed using a Python-based modeling tool to calculate the net present value (NPV), levelized cost of energy (LCOE), and internal rate of return (IRR) under multiple development scenarios. Figure 3 provides a flowchart summarizing the overall workflow.

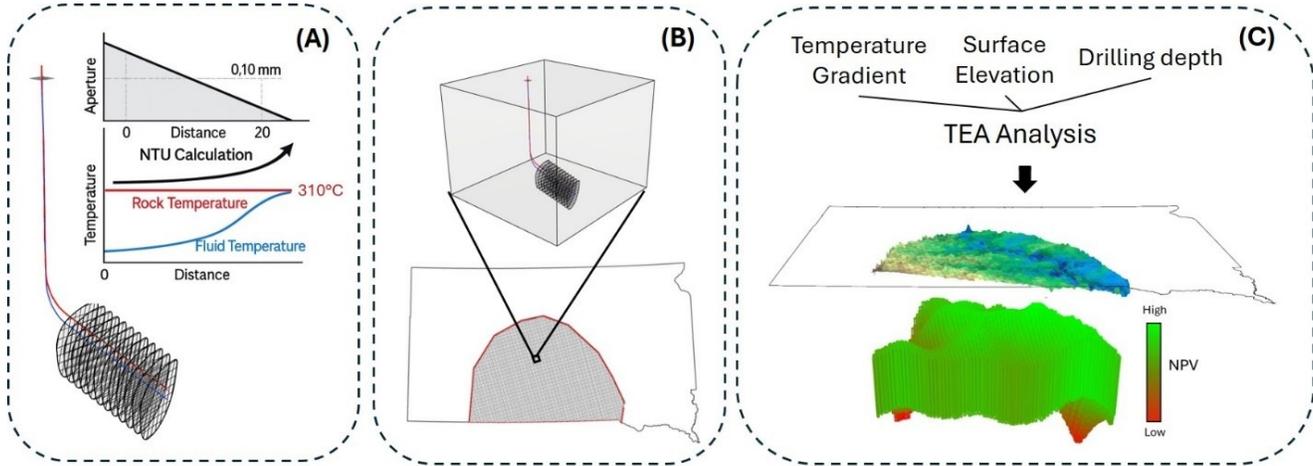


Figure 3: (A) Evaluation of well configuration and performance; (B) Grid block representation of the potential development basin area in south-central South Dakota; (C) Techno-economic assessment using averaged parameters for each grid block.

2.1 Enhanced Geothermal System (EGS) Well Configuration

The fundamental principle of an Enhanced Geothermal System (EGS) is that heat can be extracted from a multi-fractured hot-dry-rock reservoir by injecting cool water at depth, allowing circulation through thermally conductive fractures, and producing the heated fluid back to the surface. This concept has been tested in several field experiments, including the early Hot Dry Rock Project at Fenton Hill (Brown, 2009) and the recent the Utah FORGE project (Moore et al., 2019). This study adopts the same fundamental EGS configuration approach by simulating fluid circulation and heat absorption from the reservoir. The objective is to evaluate how injected fluid extracts heat from the surrounding rock, based on site-specific properties in the potential development area of south-central South Dakota.

2.2 Thermal Energy Extraction through Fracture Flow

Based on the fundamental EGS concept introduced by Gringarten and Witherspoon (1973), the evolution of temperature within a fracture is primarily governed by fracture geometry, particularly fracture length and aperture. In this study, the well configuration follows a design similar to that implemented at the Utah FORGE project, in which the injection and production wells are spaced approximately 100 m (\approx 330 ft) apart. Consequently, the fracture aperture becomes a key parameter influencing thermal energy absorption.

The Number of Transfer Units (NTU) is used to characterize the effectiveness of heat transfer between the reservoir rock and circulating fluid in a geothermal system. NTU provides a simplified measure of how efficiently the system transfers heat, and it has been applied previously to fractured geothermal media (Iregui, 1978; Nelson et al., 1980). Under the assumption that the rock temperature remains nearly constant, NTU describes the heating of the injected fluid as it flows through the fracture network:

$$NTU_{required} = -\ln\left(\frac{T_{rock}-T_{out}}{T_{rock}-T_{in}}\right) \quad (1)$$

where T_{rock} is rock temperature, T_{in} is injection temperature, and T_{out} is outlet temperature.

Based on the updated geothermal gradient map in South Dakota and a well depth configuration similar to Utah FORGE, the reservoir temperature at a depth of approximately 3 km is about 310 °C. To achieve a target production temperature of roughly 90-95% of this value (≈ 307 °C), the required NTU value is estimated to be in the range of 5-6.

For a system with 20 fractures and a total production flow rate of 80 kg/s, the average mass flow per fracture is approximately 4 kg/s. Assuming an injection-to-production well separation of 100 m, the maximum allowable fracture aperture that still enables sufficient heat transfer is calculated to be about 6.7 cm, based on Equation 2 (Incropera et al., 1996; Nelson et al., 1980). This value is relatively large, indicating that at this flow rate and distance, the circulating fluid would readily absorb heat before reaching the production side.

$$b_{max} = \frac{Nu \cdot k_f \cdot W \cdot L}{NTU_{required} \cdot m \cdot c_p} \quad (2)$$

where $Nu = 7.54$ (Nusselt number for laminar flow between two infinite parallel plates; Lienhard, 2025; Turkyilmazoglu, 2021), the fluid thermal conductivity is $k_f = 0.6$ W/(m·K) (Ramires et al., 1995), $W = 15$ m (assumed fracture height), and the specific heat capacity of water $c_p = 4,200$ J/(kg·K).

The calculation and simulation of fracture aperture are essential to verify that, at the selected injection-production spacing, the resulting fracture aperture remains below the maximum allowable limit required to ensure adequate thermal energy uptake by the circulating fluid before reaching the production well. To evaluate this constraint, the KGD model for hydraulic fracturing is adopted as the theoretical basis for estimating fracture dimensions.

According to McCormick (2010), the basement rock underlying the potential geothermal zone in south-central South Dakota (near Tripp county) is primarily composed of quartz monzonite. The material properties applied in this study are consistent with reported values for the crystalline basement, including a Young's modulus of 70 GPa, a fracture toughness of 1.6 MPa·m^{0.5}, and a Poisson's ratio of 0.23 (Swanson et al., 2020; Tarokh et al., 2017).

The KGD model under plane-strain conditions is applied to estimate fracture aperture using the material properties representative of Quartz Monzonite. In addition, a coupled multi-physics simulation is conducted with an injection rate of 0.1 m³/s using GEOS, an open-source C++ framework developed by Lawrence Livermore National Laboratory (Settgast et al., 2024). Based on the simulation results, the predicted fracture apertures at the injection and production points are approximately 0.8 mm and 0.5 mm, respectively (Figure 4).

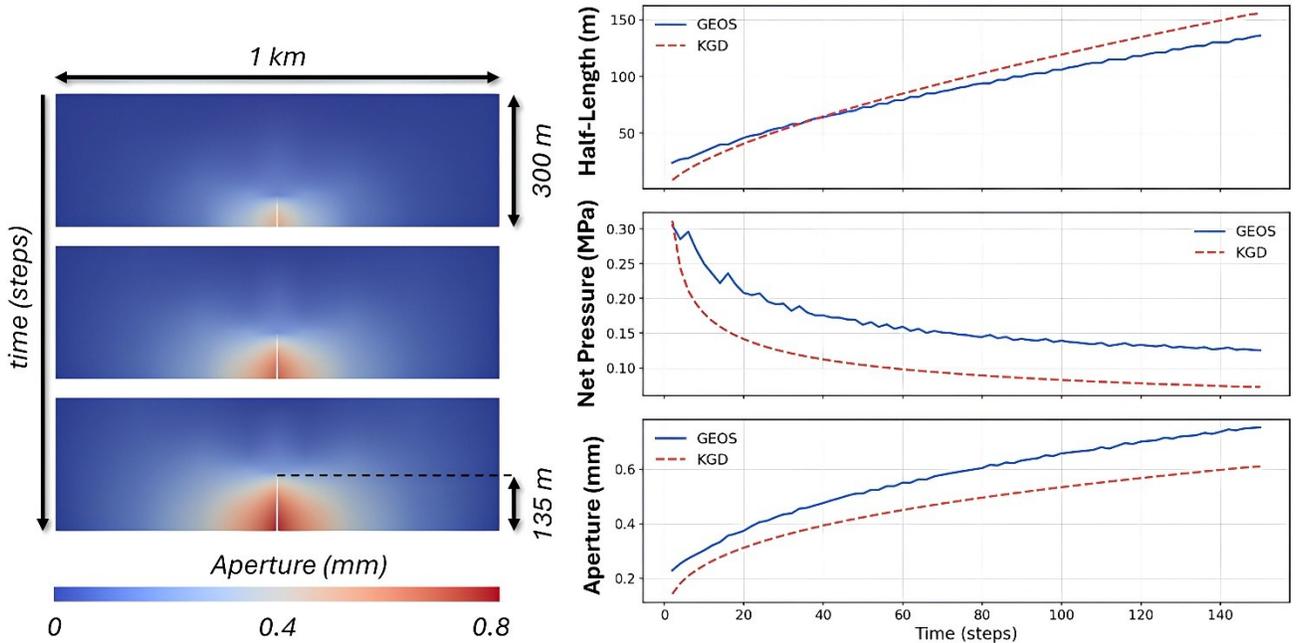


Figure 4: The simulated fracture aperture is approximately 0.8 mm at the injection point and 0.5 mm at the production point. Overall, the difference in aperture between the theoretical prediction and the simulation results is on the order of 20%. In practice, however, the actual aperture may be larger or smaller due to variations in in-situ stress and the presence of pre-existing fractures.

Using Equation 3 to evaluate the thermal evolution along the fracture, the reduction of the aperture significantly accelerates heat transfer from the rock to the injected fluid. The results indicate that the fluid temperature approaches the reservoir temperature within approximately 20 m from the injection point (Figure 5). Consequently, a 100-m spacing between the injection and production wells is thermally feasible, supporting the use of a doublet configuration in this region.

$$T_f(x) = T_{f,0} + \int_0^x \frac{Nu(x') \cdot 2k_f}{Q \cdot b(x') \cdot \rho_f \cdot c_p} (T_r(x') - T_f(x')) dx' \quad (3)$$

where $T_f(x)$ represents the fluid temperature at position x along the fracture, and $T_{f,0}$ is the initial fluid temperature at the injection point. The term x' denotes the temperature-driving interval, which is governed by the progressive reduction in fracture aperture from the injection side toward the production side.

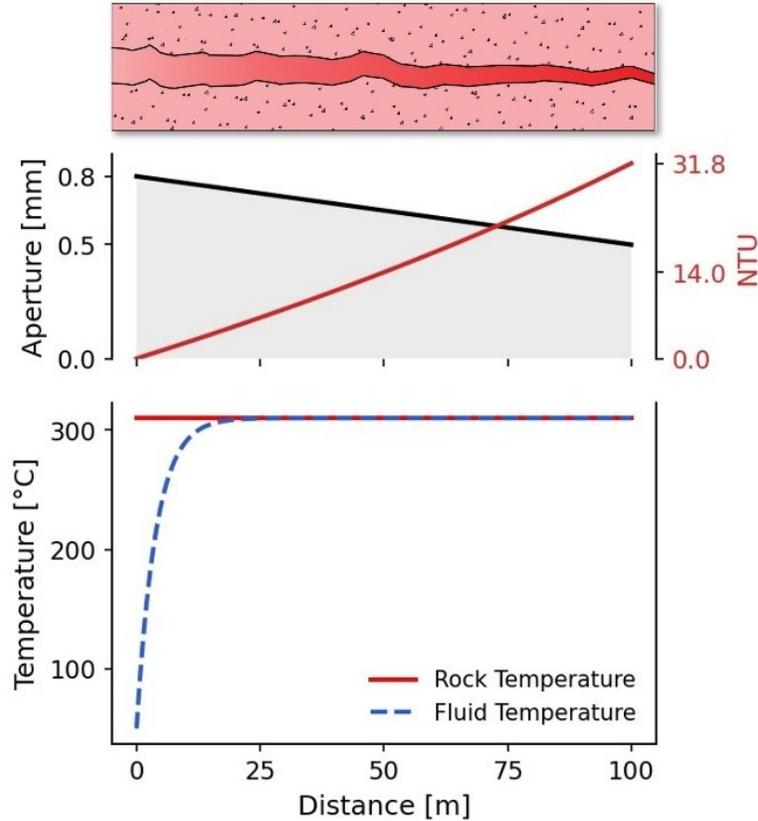


Figure 5: Fluid temperature and NTU evolution along a geothermal fracture as the aperture narrows from 0.8 mm to 0.5 mm. The injected fluid reaches near-reservoir temperature within approximately 20 m from the injection point.

2.3 Techno-economic Assessment

The prospective region in south-central South Dakota, which includes the Kennedy Basin and the southern margin of the Williston Basin, has been subdivided into medium-sized blocks of 25 km² each (Figure 6), consistent with spatial resolution commonly used in previous geothermal reservoir assessments. For each block, key parameters are compiled: the average geothermal gradient derived from the refined geothermal gradient map (Ye et al., 2025), surface elevation obtained from a digital elevation model (DEM), and the estimated drilling depth required to reach a target reservoir temperature of 310 °C. These drilling depths are determined based on the localized geothermal gradient values and their spatial distribution (Figure 7).

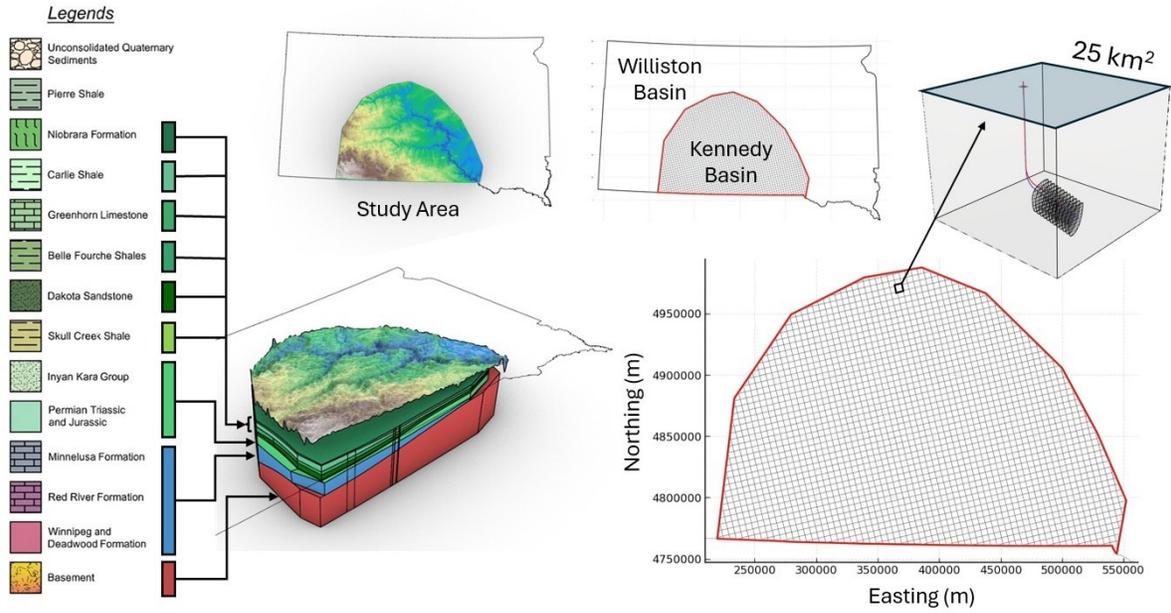


Figure 6: The study area, outlined by the half-oval region in south-central South Dakota, covering the Kennedy Basin. The stratigraphic column (left) illustrates the representative geological units of the study area. The main map (bottom right) illustrates the modeled region, subdivided into 2,409 grid blocks of 25 km² each.

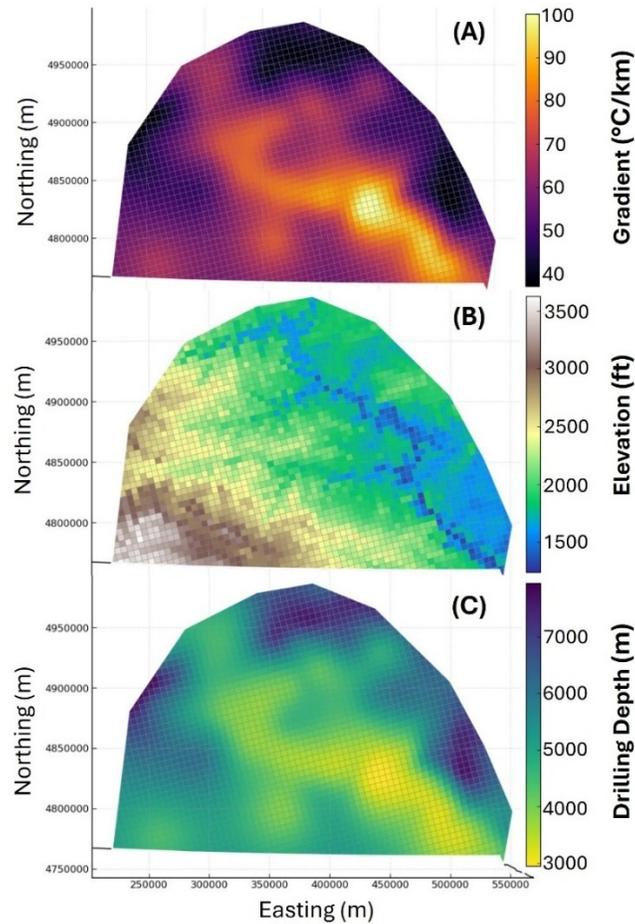


Figure 7: Spatial distribution of (A) geothermal gradient (°C/km) (from Ye et al. (2025)); (B) surface elevation (ft); and (C) required drilling depth to reach the target temperature (m) for each grid block.

GEOPHIRES, an open-source Python package for geothermal techno-economic modeling developed and operated by NREL (Ross & Beckers, 2023), is employed to estimate the levelized cost of electricity (LCOE), net present value (NPV), internal rate of return (IRR), and power generation in this study. The model incorporates multiple system components, including the reservoir, wellbore, operation and maintenance (O&M), capital expenditures, and financial considerations, thereby providing a comprehensive and practical framework for economic evaluation (Beckers & McCabe, 2019). GEOPHIRES is applied to each grid block to evaluate different scenarios of mass flow production and tax credit utilization, using the parameters listed in Table 1.

Table 1: Summary of subsurface and surface parameters used in GEOPHIRES simulations, including reservoir properties and well configuration.

Parameter	Applied and Description
Reservoir Model	Multiple Parallel Fractures Model
Reservoir Depth	Drilling Depth [m]
Geothermal Gradient	30 - 100 [$^{\circ}\text{C}/\text{km}$]
Number of Injection/Production Wells	1/1
Well Diameter	9 inches
Production Wellbore Temperature Drop	5 [$^{\circ}\text{C}$]; Default
Injection Wellbore Temperature Gain	3 [$^{\circ}\text{C}$]; Default
Production Flow Rate per Well	40, 60, 80 [kg/s]
Fracture Area	200,000 [m^2]
Number of Fractures	20
Fracture Separation	30 [m]
Injection Temperature	50 [$^{\circ}\text{C}$]
Reservoir Heat Capacity, Density, and Thermal Conductivity	1000 [$\text{J}/\text{kg}/\text{K}$], 2700 [kg/m^3], and 2.7 [$\text{W}/\text{m}/\text{K}$]; Quart Monzonite

In addition to subsurface conditions, the surface system is defined using electricity-only end use, a subcritical ORC (binary-cycle) power plant, an 80% circulation pump efficiency, and a surface temperature of 15 $^{\circ}\text{C}$. Financial assumptions include a 35-year project lifetime and the Bi-Cycle levelized cost model, which accounts for interest, inflation, and income rate. The investment tax credit (ITC) is evaluated across a range from 0% to 30%.

3. RESULT

The techno-economic performance of enhanced geothermal systems (EGS) in south-central South Dakota was assessed under three production flow scenarios (40, 60, and 80 kg/s) and four Investment Tax Credit (ITC) levels ranging from 0% to 30%. Spatially resolved results for Levelized Cost of Electricity (LCOE), Net Present Value (NPV), and Internal Rate of Return (IRR) illustrate the sensitivity of project feasibility to both subsurface reservoir productivity and financial incentives. Higher flow rates enhance heat extraction and improve overall economic returns. In parallel, application of ITCs substantially shifts the economic landscape, turning previously marginal zones into viable targets for commercial development. The following sections present a detailed summary of each economic indicator.

3.1 Levelized Cost of Electricity (LCOE)

Spatial distributions of LCOE reveal a strong dependence on both subsurface thermal performance and the presence of federal tax incentives (Figure 8). In the absence of an Investment Tax Credit (ITC), LCOE values range from approximately 3.3 to 9.0 cents/kWh (equivalent to \$33 to \$90/MWh). The highest costs are observed in areas with lower production flow rates and weaker geothermal gradients, particularly in the northeastern portion of the study area, where thermal gradients are significantly lower compared to the more favorable conditions in south-central South Dakota. Increasing the production flow rate significantly reduces LCOE across the region; at 80 kg/s , most blocks achieve LCOE values below 6 cents/kWh (\$60/MWh) when supported by a 20–30% ITC.

The inclusion of federal ITC support further enhances the economic viability of EGS projects. Under a 30% ITC scenario, nearly all modeled grid blocks exhibit LCOE values under \$60/MWh, with a substantial portion falling between 3.3–5.0 cents/kWh (\$33 and \$50/MWh). These findings highlight that both reservoir productivity (flow capacity and thermal resource) and policy incentives (e.g., tax credits) play critical roles in achieving cost-competitive EGS development in South Dakota.

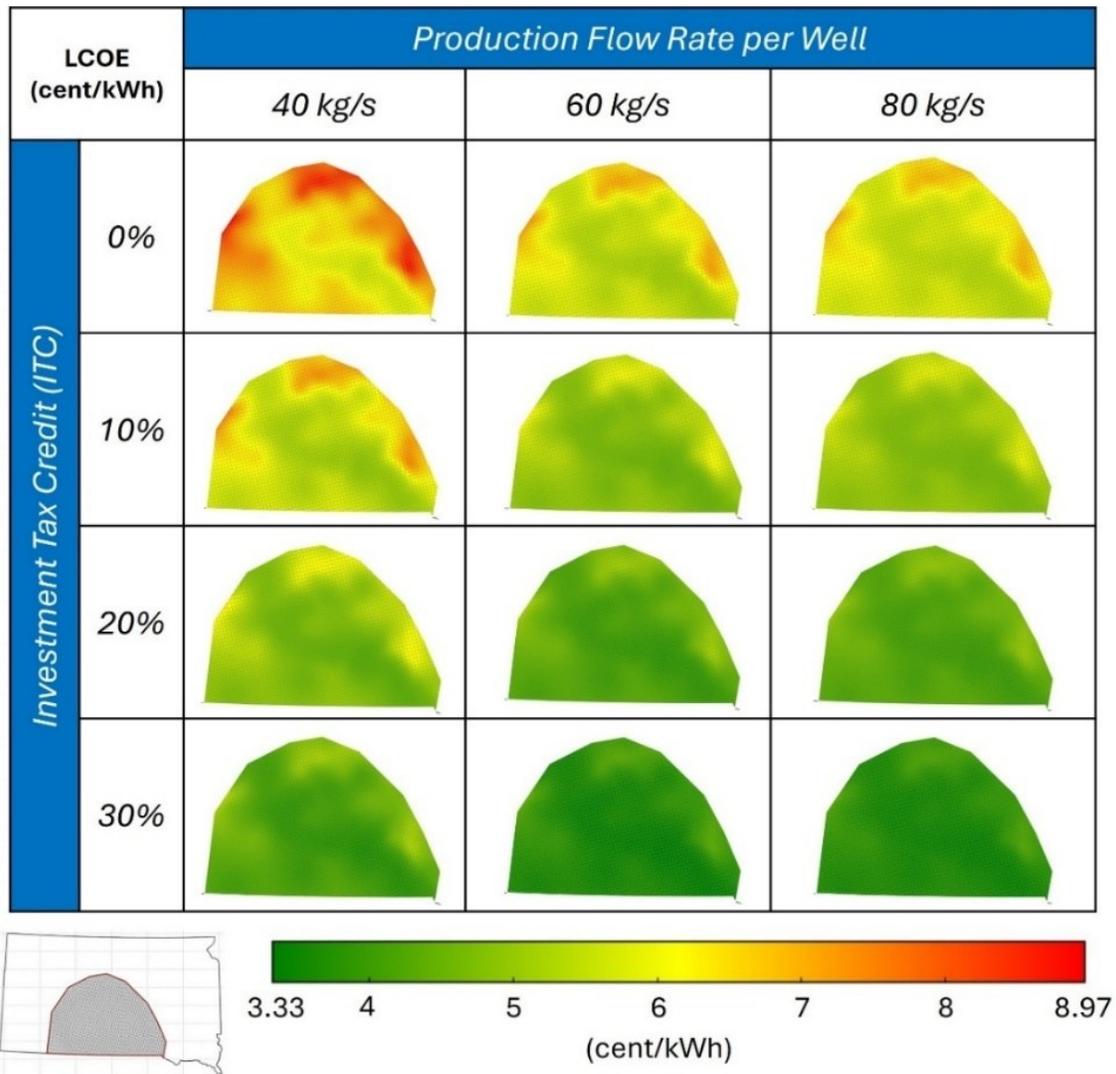


Figure 8: Spatial distribution of Levelized Cost of Electricity (LCOE) for South-Central South Dakota as a function of production flow rate (40, 60, and 80 kg/s) and Investment Tax Credit (0-30%). Lower flow rates and no financial incentives are associated with the highest LCOE values, while higher flow rates and tax credits reduce cost and increase commercial competitiveness.

3.2 Net Present Value (NPV)

Net Present Value (NPV) results reveal a clear transition from economically unviable to viable conditions as both production flow rate and Investment Tax Credit (ITC) increase (Figure 9). At 0% ITC, NPV remains negative across the entire region, indicating that revenue from power sales would not offset capital and operating expenses under baseline policy conditions. Introducing a 10% ITC generates isolated zones of positive NPV, primarily at higher flow rates (60 and 80 kg/s). With a 20% ITC, these profitable regions expand significantly, particularly in the western and central parts of the study area. The most favorable outcome is observed under a 30% ITC scenario, where nearly the entire region at 60 and 80 kg/s achieves positive NPV values, reaching up to 25 million USD. These findings underscore the importance of moderate financial incentives for achieving commercial viability of EGS deployment in South-Central South Dakota.

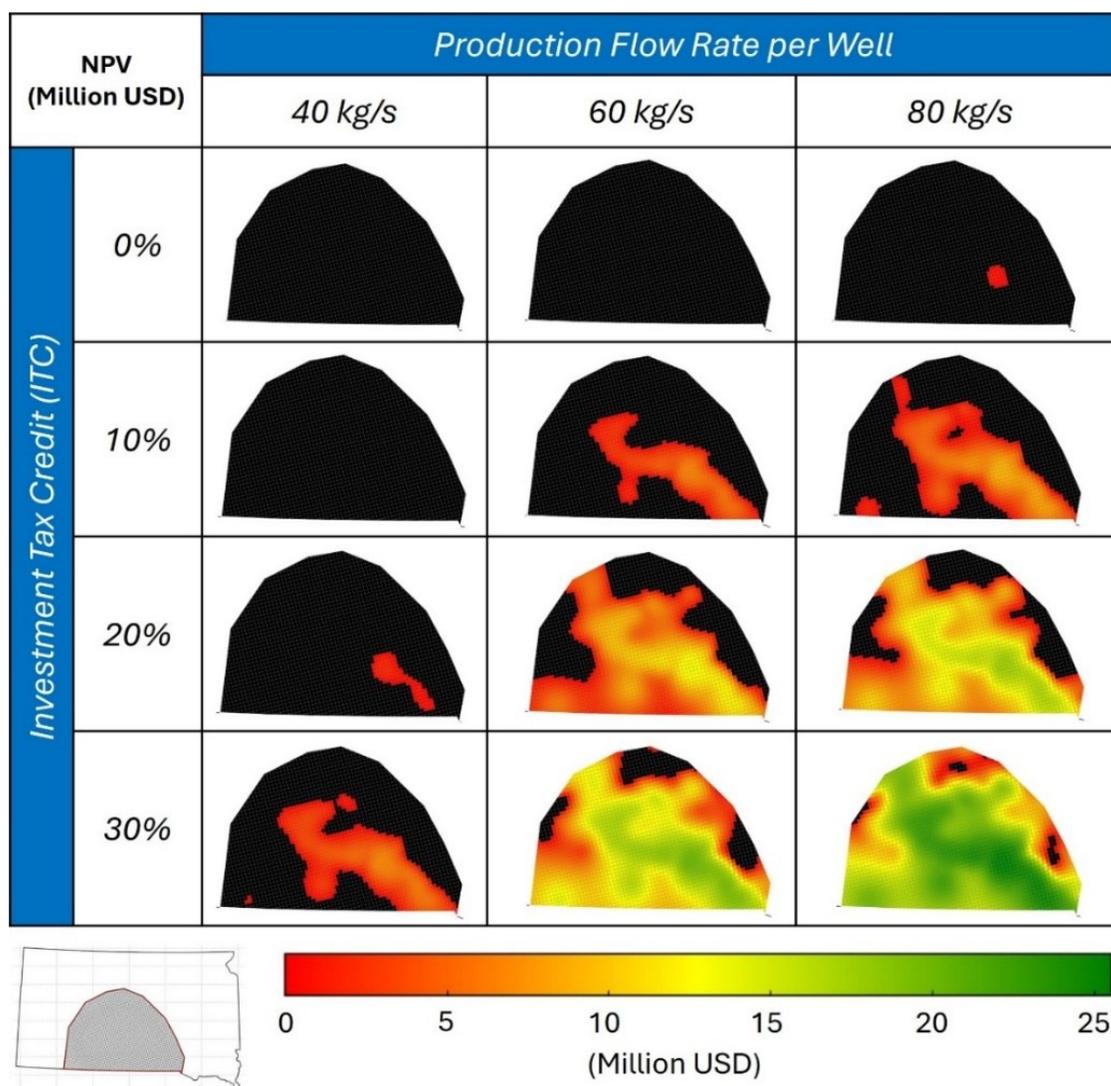


Figure 9: Net Present Value (NPV) maps showing the impact of production flow rate and Investment Tax Credit on economic feasibility. NPV is negative throughout the region at 0% ITC but becomes positive as tax incentives and flow rates increase, with maximum values reaching approximately 25 million USD. Dark-shaded areas represent non-profitable locations (negative NPV), indicating regions unsuitable for commercial EGS deployment under the specified operating and policy conditions.

3.3 Internal Rate of Return (IRR)

IRR distributions closely align with the trends observed in NPV, highlighting the role of flow rate and tax incentives in driving investment viability. At 0% ITC, IRR values across the region range from 0.7% to 8%, remaining below the typical investment threshold for geothermal projects. A 10% ITC marginally improves IRR, but most of the region still falls short of competitive levels. With 20% ITC, areas with higher flow rates (particularly 60–80 kg/s) begin to exceed the 8% benchmark, indicating improved investment potential. At 30% ITC, broad portions of the study area achieve IRRs in the 8–11.8% range, meeting or surpassing typical industry expectations. These findings underscore the importance of combining high flow rates with policy support to make EGS deployment in South Dakota financially attractive.

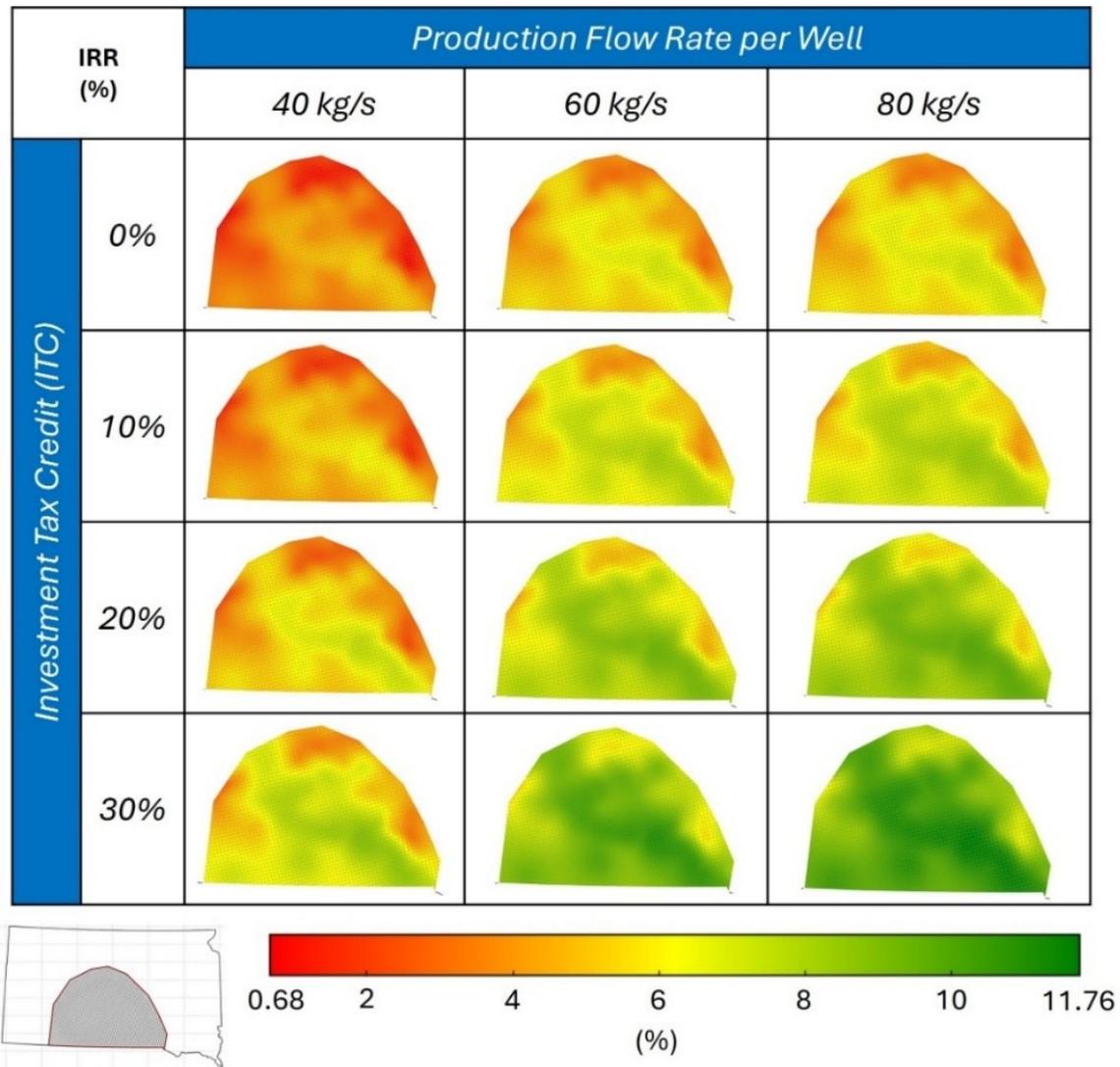


Figure 10: Internal Rate of Return (IRR) distributions representing the investment sensitivity of EGS projects in the region. IRR remains below attractive investment levels without tax incentives but rises above the competitive level when 20-30% ITC is applied, especially at higher flow rates.

4. DISCUSSIONS

The simulation results suggest that EGS in South-Central South Dakota are technically viable and hold considerable long-term potential, but their near-term economic success remains sensitive to reservoir performance (particularly, the production rate) and the presence of policy incentives. Importantly, the techno-economic outcomes presented in this study are based on current cost structures, particularly for drilling, surface infrastructure, and stimulation. As technology matures, such as continued reductions in drilling costs, improved stimulation methods, and more efficient surface systems, the economics of EGS are expected to improve significantly.

To better understand the implications, the following subsections (1) compare the modeled Levelized Cost of Electricity (LCOE) with existing geothermal and U.S. energy benchmarks, (2) examine spatial variability in local-scale geothermal potential, and (3) assess how operational strategies and financial incentives affect project feasibility. Together, the findings demonstrate that EGS has substantial potential in the south-central region of South Dakota, especially when future cost declines and supportive energy policies are taken into account.

4.1 LCOE Comparison with Other EGS and U.S. Energy Technologies.

The levelized cost of electricity (LCOE) modeled in this study is compared with prior U.S. EGS assessments and other mainstream electricity generation technologies (Figure 11). The modeled LCOE decreases with increasing Investment Tax Credit (ITC) level, ranging from 7.5-9.0 cents/kWh (75-90 \$/MWh) at 0% ITC, 6.0-7.5 cents/kWh (60-75 \$/MWh) at 10% ITC, 4.5-6.0 cents/kWh (45-60 \$/MWh) at 20 percent ITC, and 3.3-4.8 cents/kWh (33-48 \$/MWh) at 30% ITC. Even without ITC support, the estimated LCOE for the South Dakota project is comparable to published U.S. EGS techno-economic assessments.

For comparison, the DOE GeoVision analysis (U.S. Department of Energy, 2019) anticipates long-term geothermal electricity costs of 4-8 cents/kWh (40-80 \$/MWh), while the MIT EGS study (Panel, 2006) reports LCOE ranges of 3.6-9.2 cents/kWh (36-92 \$/MWh) across six U.S. locations. Similarly, NREL GETEM-based models show a broader range of ~4.1-10 cents/kWh (41-100 \$/MWh). The overlap between these benchmarks and the South Dakota results indicates that geothermal power from this region, though located outside traditional western geothermal zones, can be economically competitive under favorable development conditions.

Incentivized scenarios (20-30% ITC) yield LCOE values between 4 and 6 cents/kWh (40-60 \$/MWh), positioning EGS in South Dakota close to or within the cost range of other U.S. energy technologies. As reported by the U.S. Energy Information Administration (2025), typical LCOEs are ~4-7 cents/kWh (40-70 \$/MWh) for natural gas combined-cycle, 3-4 cents/kWh (30-40 \$/MWh) for utility-scale solar PV, and 3-5 cents/kWh (30-50 \$/MWh) for onshore wind. The fact that modeled geothermal LCOEs under moderate policy support approach or match these values illustrates the potential for EGS to serve as a viable dispatchable resource.

These results suggest that with tax incentives and continued advancements in drilling and stimulation technology, enhanced geothermal systems could offer competitive, firm power in a broader geographic footprint, contributing to energy diversification and long-term grid reliability.

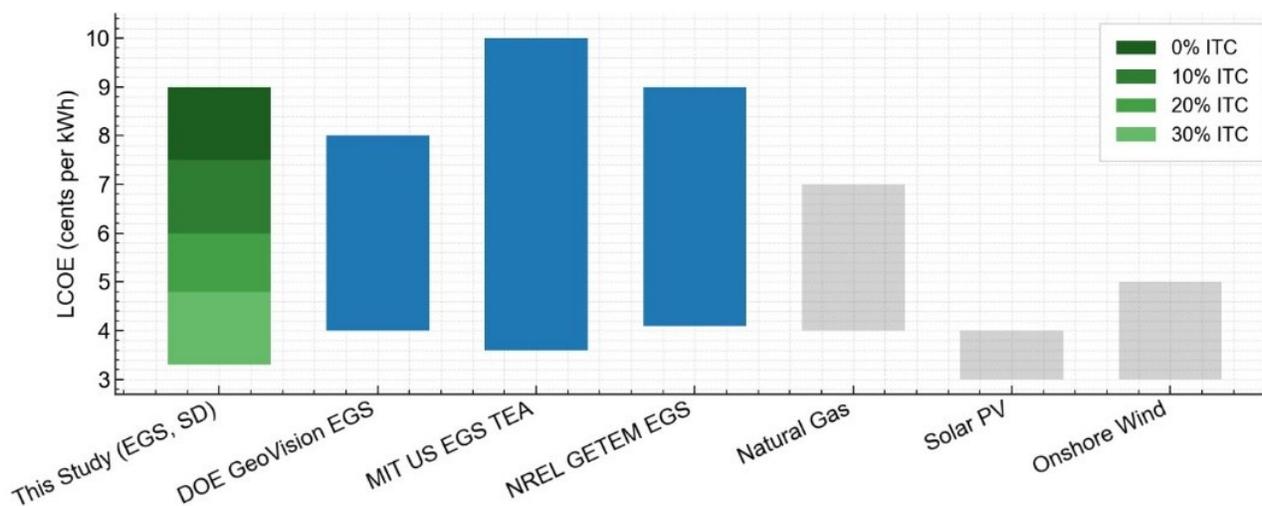


Figure 11: Comparison of the levelized cost of electricity (LCOE) for this study under different Investment Tax Credit (ITC) levels with U.S. EGS assessments and other electricity generation technologies.

4.2 EGS Potential at South-Central South Dakota

At a production rate of 80 kg/s, South-Central South Dakota displays strong potential for economically competitive EGS (Figure 12), with performance varying across county boundaries. In Lyman County, the southern and eastern portions consistently show favorable LCOE values, reaching 3.42-4.31 cents/kWh (34-43 \$/MWh) at a 30% ITC. This area also contains the highest concentrations of positive NPV. Tripp County exhibits broad improvement as tax incentives increase, with the northern zones profitable even when no ITC is applied, although NPV remains low, and becoming highly profitable at 20-30% ITC, supported by strong thermal gradients at depth. In Gregory County, positive outcomes are concentrated in the western and northwestern areas, where increased reservoir temperature and permeability support favorable economic performance, then extend to the eastern areas where higher ITC is applied.

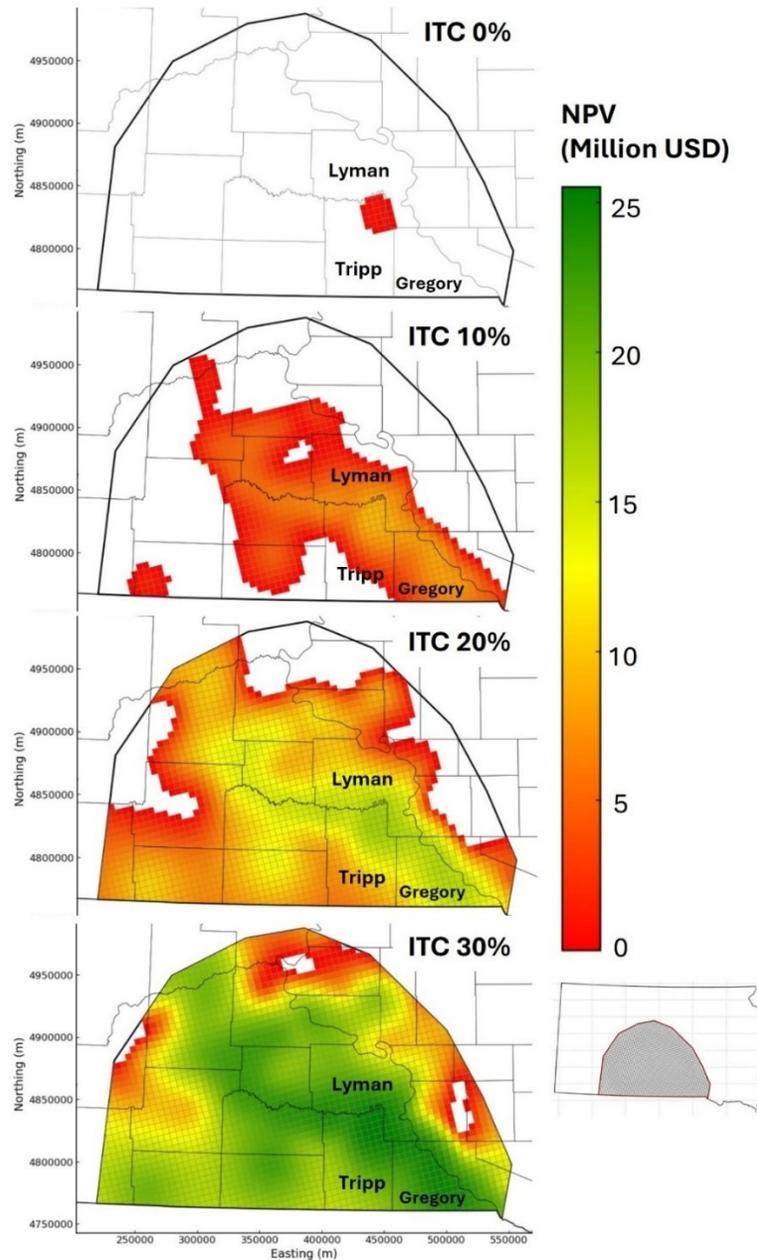


Figure 12: Economic potential for high-flow EGS (80 kg/s) in South-Central South Dakota across different Investment Tax Credit levels. Increasing ITC from 0% to 30% directly enhances NPV values and expands areas of commercial viability across Lyman, Tripp, and Gregory counties, with widespread feasibility observed at 30% ITC.

4.3 Economic Influence of Operation Strategy and Investment Incentives

The comparison of flow scenarios shows that both reservoir productivity and federal incentives strongly affect EGS feasibility in South-Central South Dakota (Figure 13). At a lower flow rate of 40 kg/s, the region remains unprofitable without ITC, and even with a 30% tax credit, the financial gains are limited. At the higher flow rate of 80 kg/s, profitability improves but remains marginal with 0% ITC, where only small regions, the lowest depth from surface, show positive NPV. This indicates that increased flow alone does not ensure commercial viability.

Applying 30% ITC to the 80 kg/s scenario significantly improves economic performance, producing widespread positive NPV values up to 15-25 million USD across Lyman, Tripp, and Gregory counties. The 3D reservoir model supports this trend, showing that shallower hot dry rock targets in northern Tripp County (≈ 3 km depth) align with the highest profitability due to reduced drilling costs and the highest heat delivery. Overall, commercial-scale EGS development in this region requires a combination of high production flow rates, favorable reservoir depth, and federal tax incentives.

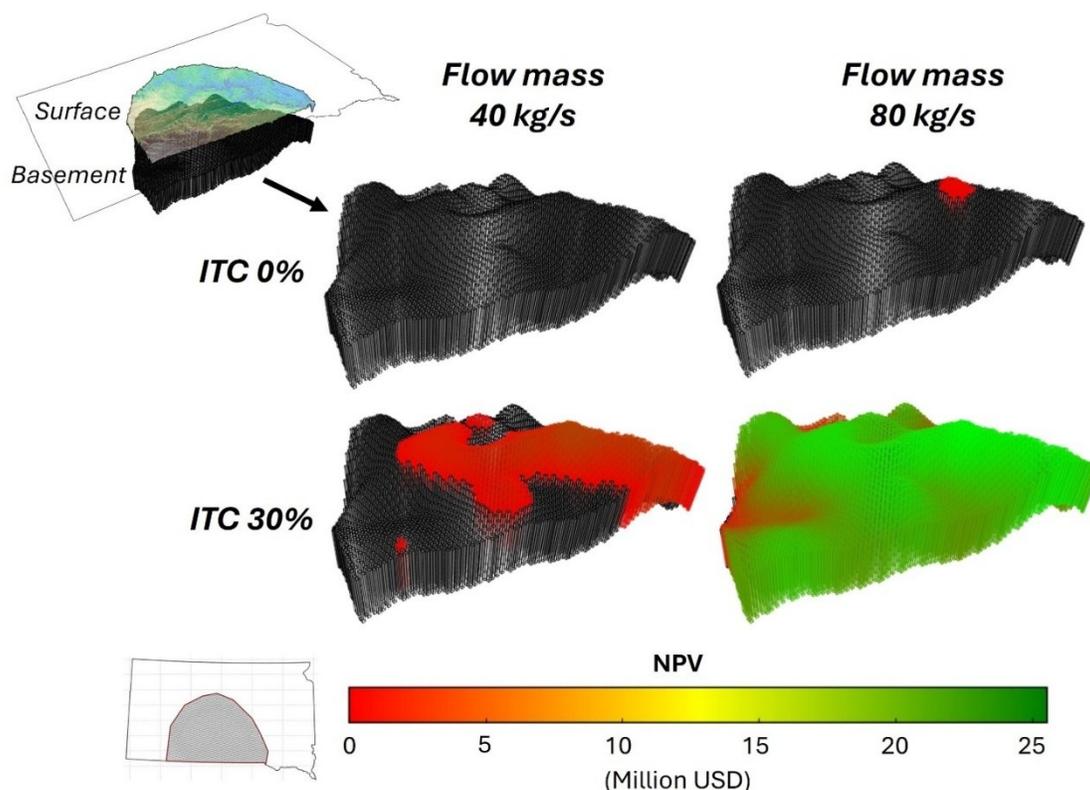


Figure 13: Comparison of economic performance (NPV) for low-flow (40 kg/s) and high-flow (80 kg/s) EGS scenarios under 0% and 30% Investment Tax Credit (ITC) in South-Central South Dakota. The 3D reservoir model illustrates the hot dry rock target, with shallower depths in northern Tripp County corresponding to higher profitability under the 80 kg/s and 30% ITC scenario.

5. CONCLUSION

This study demonstrates that enhanced geothermal systems (EGS) in South-Central South Dakota are technically feasible. Thermal transportation analysis shows that a doublet configuration with approximately 100 m well spacing is sufficient for effective heat extraction, with simulated fracture apertures enabling rapid fluid heating within a short distance from the injection point. These results confirm that the crystalline basement underlying the Kennedy and southern Williston basins can support sustained thermal energy production. From an economic perspective, commercial viability is strongly controlled by production flow rate, drilling depth, and federal investment incentives. Low-flow scenarios (40 kg/s) remain largely uneconomic despite technical feasibility, while higher flow rates (80 kg/s) significantly improve performance but still yield limited profitability without policy support. The application of 20-30% Investment Tax Credits (ITC) reduces LCOE to approximately 3.3-6.0 cents/kWh (33-60 \$/MWh), comparable to published U.S. EGS benchmarks and competitive with other low-carbon electricity technologies, while representing positive NPV and acceptable IRR values across much of the region. These findings indicate that economically viable EGS development in South-Central South Dakota requires a combined strategy of high mass flow, favorable drilling depth, and sustained federal incentives, with ITC play as the key factor that shifts the region from technically feasible to commercially competitive.

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