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Advanced Financial and Risk Feasibility Assessment of Indonesia's Binary Geothermal Plant with Carbon Credit Integration

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ABSTRACT

Global warming is a pressing issue. NASA has predicted that 15 Southeast Asian islands will be submerged by 2100, as a result of a 0.77 cm increase in global sea levels from 2022 to 2023. Global temperatures were 1.48°C higher than pre-industrial levels in 2023. Indonesia must increase the use of renewable energy sources and energy efficiency. By 2030, energy consumption will rise by 3% and power demand by 8.5%, with fossil fuels meeting two-thirds of demand and CO_2 emissions rising 35%. This study evaluates the techno-economic feasibility of a 60 MW Indonesian Organic Rankine Cycle (ORC) geothermal power plant using carbon credits. Indonesia's geothermal potential is 40% of global resources, but high upfront costs, insufficient regulatory support, and technical obstacles limit development. Flexible and efficient ORC geothermal power generation provides steady baseload power for low to medium-temperature resources. This study applies RETScreen software for techno-economic analysis, sensitivity, and risk assessment to analyze project feasibility under multiple scenarios. Initial costs, operation and maintenance expenditures, energy generation, and GHG reductions are analyzed in detail. Net Present Value (NPV), Internal Rate of Return (IRR), and Levelized Cost of Energy (LCOE) were calculated for four scenarios: minimal incentives, increased carbon credit incentives, extended project lifespan with tax benefits, and optimized scenarios with high carbon credit prices. With a pre-tax equity IRR of 20.7% and an NPV of $97.52 million, the project is commercially viable at $2/ton CO_2 in Indonesia. Raising the carbon credit price to $18/ton CO_2 boosts IRR to 26.1% and NPV to $142.74 million. An equity payback period of 2.9 years and decreased LCOE is achieved by extending the project lifespan to 30 years and using a carbon credit price of $46/ton CO_2. These data show how carbon price affects geothermal investment profitability. Optimizing geothermal exploration and adopting innovative technologies can cut expenses and speed up progress. Inspired by the Philippines and Kenya, government incentives, tax cuts, and faster approvals can make geothermal projects financially viable, helping Indonesia reach its 2060 zero carbon emissions objective.

Keywords: Techno-economic Feasibility, Carbon Credits, Levelized Cost of Energy, GHG Emissions, RET Screen Software, Energy Transition
JEL Classifications: Q42, Q54, Q51, Q31

1. INTRODUCTION

Global warming has become an urgent issue to address. Data from NASA recorded a global sea level rise of 0.76 cm from 2022 to 2023 refer to (NASA, 2023). Based on SSP5-8.5 high carbon emissions, it is predicted that in 2100 will rise by about 0.77m (IPCC, 2023). Due to sea level rise and land subsidence, it is estimated that at least 15 islands in Southeast Asia's Indonesia will be submerged. In 2023, global temperatures were 1.48°C higher than the average temperature during the industrialization period (PAC, 2024). For the first time in history, EU monitoring data shows that global warming has surpassed the 1.5°C threshold (Guo et al., 2023).

According to the 2015 Paris Climate Agreement, global leaders committed to keeping temperatures below 1.5°C in the long term (PAC, 2024). Global warming is a complex issue, mainly driven by the continuous increase in greenhouse gas emissions, especially

CO_2. The accumulated impacts of human activities over decades, particularly the use and burning of fossil fuels since the Industrial Revolution (Zandalinas et al., 2021), have led to global warming, rising temperatures of the earth's surface and oceans, melting polar glaciers, etc.

The reliance on fossil fuels has caused significant environmental issues. Researchers are optimizing non-renewable fuel use (Cao et al., 2021). Indonesia's dependence on fossil fuels is a major weakness. The IEA recommends improving energy efficiency, developing renewables, and transitioning to low-emission fuels (Arens et al., 2024; Jollands et al., 2010). Indonesia, with a 5.05% growth rate (2022-2023) (UI, 2024), aims to reduce CO_2 emissions and fossil fuel imports per its Electricity Power Supply Business Plan 2021-2030 (PLN, 2021). Annual electricity demand is expected to increase by 6.2%, with 75% met by fossil fuels, raising CO_2 emissions by 29.2% (PLN, 2021).

Indonesia is located in the Pacific Ring of Fire (Pambudi, 2018) and has abundant geothermal resources, accounting for 40% of the global total (Mohammad et al., 2018). Geothermal power generation extracts steam and hot water through drilling (Rera et al., 2021). The country has around 300 geothermal fields with a total capacity of approximately 23.7 GW, but the current installed capacity is only 2.342 GW (Alhusni et al., 2023). Conventional plants in Indonesia underutilize medium and low enthalpy resources (110°C-160°C), with potential nearly 2000 MW (Febrianto et al., 2019).

The advantage of geothermal power generation is its ability to provide baseload power supply (Mohammad et al., 2018; Tambunan et al., 2020), running continuously 24 h a day except during maintenance, which is convenient and straightforward. Despite geothermal energy being recognized as a reliable and clean source of energy (Cerci, 2003), the development of geothermal power projects in Indonesia has been slow. The main challenges include high upfront investment costs, insufficient policy support, inadequate incentives and pricing mechanisms, high local content requirements, and limited capacity of Indonesian geothermal development agencies (Alhusni et al., 2023). The de-dieselization process may be slowed down by the limitations of tariffs and the absence of incentives (Paradongan et al., 2024), which pose obstacles to the project's viability from the perspective of independent power producers (IPPs).

Several studies have explored the feasibility of medium and low-temperature geothermal power plants outside Indonesia. (Prasad, 2022) analyzed various renewable technologies at Fuji, including tax holidays and carbon credit incentives, showing positive NPV. RETScreen has been used to assess large geothermal and photovoltaic plants (Alhassan et al., 2023; Baccay et al., 2020; Pan et al., 2017; Paradongan et al., 2024; Malik, 2021). Research also examined brine water and ORC plants at low temperatures (Prasad, 2022; Sveinbjornsson and Thorhallsson, 2012; Rera et al., 2021; Mohammad et al., 2018; Tang, 2023; Patihk et al., 2022; Ehyaei et al., 2024; Yousefi et al., 2018). Fathoni explored carbon credit incentives for Indonesian geothermal plants (Paradongan et al., 2024; Fathoni et al., 2014).

The novelty feature of this study is a comprehensive assessment of the technical, economic, environmental, and risk feasibility of the latest organic Rankine cycle (ORC) technologies for expanding power generation at low and medium temperature resources. The study is the first to examine the impact of incentives on net present value and production costs within the framework of current carbon credit policies with ORC geothermal power area in Indonesia, which are rarely covered in industry publications. In addition, this study explores the policy implications and barriers to geothermal power generation, and its findings will provide important references for Indonesia and other geothermally rich developing countries, providing key insights for investors and policymakers to understand the potential of geothermal energy and advocate for the diversification of renewable energy sources. It also promotes the development of sustainable geothermal energy by reusing abandoned Wells.

2. LITERATURE REVIEW

Geothermal power generation extracts underground steam and hot water through drilling to drive turbines (Rera et al., 2021). The Sorik Marapi geothermal power plant in North Sumatra has drilling depths of up to 2500 m. The main systems include dry steam, flash steam, and binary cycles. Dry steam single flash systems are efficient but have long development, while the binary Organic Rankine Cycle (ORC) is suitable for low- medium temperature heat sources (Cao et al., 2023), with short construction periods and low maintenance costs. The 50 MW Sorik Marapi project requires only 9-12 months for construction (Tang, 2023).

The convention-enthalpytional geothermal power plants need high enthalpy steam (Chamorro et al., 2012), but the latest binary ORC modular power plants can achieve a one-well-one-station layout, flexibly utilizing steam and brine resources (Tang, 2023). At the same time, ORC can have steam ORC and brine ORC, which means that well drilling resources can be fully utilized. It is reported that only the existing idle geothermal wells and the tailwater of geothermal power stations in geothermal fields in this country can produce an additional 2000 MW of geothermal power without newly drilling geothermal wells (Kumolosari et al., 2020), which will greatly shorten the development time and save development investment.

The Lahendong geothermal system in North Sulawesi has been operational since 2001, with four 20 MW plants and a 1100 t/h production rate from 10 wells (Mohammad et al., 2018). PT Pertamina successfully tested a 500 kW ORC plant in December 2022. Geo-Dipa's Sikidang proposal involves 28 wells (PT GeoDipa Energi 2023), previously Pertamina-operated, now showing potential for steam and brine use but remain inactive due to technological limitations. In New Zealand, the Kawerau plant has a 200 MW capacity from 31 wells at 1611 m and 310°C. Bay of Plenty Energy's 6.4 MW binary OEC unit achieves over 98% efficiency (Kaplan and Schochet, 2005). Trinidad and Tobago convert abandoned wells into geothermal systems with a 33,721 MW capacity, a 190% IRR, a $1.43 billion NPV, and $0.05 per kWh energy cost, reducing CO_2 by 50.0625 million tons over 25 years (Patihk et al., 2022).

In Indonesia, conventional geothermal power plants predominantly use single-flash steam turbines (Frick et al., 2019), which only utilize steam for electricity generation. This has led to the underutilization of medium and low enthalpy geothermal resources (between 110°C and 160°C), with an estimated potential of nearly 2000 MW (Febrianto et al., 2019), resulting in many "abandoned wells." The latest development of ORC expansion generator units utilizes the brane water from flash steam, enhancing the overall efficiency of high enthalpy geothermal fields. It also efficiently generates power from medium and low-enthalpy resources (Cao et al., 2021), making small-scale geothermal power plants feasible, and providing energy to remote small islands.

ENDE PT Sokoria Geothermal commissioned ORC expansion generator units with a total capacity of 10 MW from 2019 to 2023 (Tang, 2023), addressing the high-cost issue of fuel oil power generation in the area. The total investment was $212.85 million, with a PPA (Power Purchase Agreement) price of 120 cents and an annual revenue of $31.104 million. The Sorik Marapi project, through a binary modular power plant model, achieved 50 MW COD (Commercial Operation Date) operation within 12 months and reached 190 MW in 4 years (Rakit et al., 2022).

Renewable energy sources like wind, solar, and geothermal have no external dependencies. Although geothermal energy has high upfront costs, it can optimize the reuse of waste brine (Soltani et al., 2021). The binary ORC modular power plant and one-well-one-station model can enhance power generation, making them popular among investors and governments for their energy efficiency and environmental benefits.

Non-condensing geothermal steam turbines release exhaust gases into the atmosphere at temperatures exceeding 100°C, examined the method of generating CO_2 by utilizing non-condensing gas that is derived from a heat-carrying fluid that contains 96% CO_2 (Li et al., 2022). This wastes thermal energy and has a significant negative environmental impact. Geothermal brine from the steam/brine separator typically generates steam flow accounting for 10-30% of the total flow (Febrianto et al., 2019), resulting in large volumes of brine being reinjected into the reservoir or discharged to the surface. This brine, with temperatures between 110°C and 180°C, contains a substantial amount of undeveloped or wasted energy (Kaplan and Schochet, 2005). But remain underdeveloped due to obstacles such as engineering design, legal uncertainty, tariffs, weak demand, insufficient reservoir data, and social pressures. The lack of feasibility studies for medium and low-temperature systems has led to low investment interest, making it crucial to demonstrate their technical and economic viability.

Table 1 investigates and summarizes prior research conducted with RETScreen, categorizing them by country, energy type, power plant capacity, project lifecycle, electricity output price, initial investment, O&M costs, etc. The collection of this exhaustive historical data provides essential data sources for the following analyses: cost analysis, greenhouse gas (GHG) analysis, financial summary, sensitivity, and risk analysis. This enables comprehensive research and comparison.

The technical and economic feasibility of a dual geothermal power plant in Indonesia is a multifaceted topic that involves a detailed analysis of the technical and economic aspects of geothermal energy production, especially when carbon credits are considered. There are few such studies. The results show that location, technology choice, and financial incentives can significantly affect the levelized cost of energy (LCOE) of geothermal projects (Kabeyi and Olanrewaju, 2023; Energy Information Administration, 2022). For example, studies by Lazard and the National Renewable Energy Laboratory (NREL) (Stark et al., 2011) highlight the declining LCOE of renewables and their competitiveness with traditional fossil fuels.

Regarding initial costs, the study shows that geothermal plant construction costs range widely (Stefánsson, 2002). For example, IRENA (2017) estimates between $1,870 and $5,050 per kilowatt (IRENA, 2017; Prasad, 2022; Sveinbjornsson and Thorhallsson, 2012; Rera et al., 2021; Moya et al., 2018; Patihk et al., 2022; Tang, 2023), depending on location and technology choice. Operating and maintenance costs are usually low, between 1 and 3 cents/kilowatt-h. Due to their typical life span of 30-50 years (Basosi et al., 2020; Gutiérrez-Negrín, 2024), Geothermal projects have significant economic advantages throughout their life cycle. Key metrics used to evaluate the economics of geothermal projects include net present value (NPV) and internal rate of return (IRR). According to the findings, geothermal projects can achieve positive NPV with appropriate financial incentives, and IRR is typically between 10% and 20% (Zarrouk and Moon, 2014; Wirawan et al., 2020; Azhar and Suhartoyo, 2015). In addition, Indonesia's new renewable energy tariff policy also has a significant impact on LCOE (ASEAN, 2016). After accounting for carbon credits, geothermal power plants cost 5-8 cents/million h. In addition, related papers by Pan et al. (2018), and Fathoni et al. (2020) demonstrate the effectiveness of RETScreen in assessing the feasibility of renewable energy projects.

3. RESEARCH METHODOLOGY AND DATA COLLECTION

The author collected a substantial amount of data by doing thorough literature research and gaining practical expertise from participating in multiple significant geothermal projects. The key data sources for this study were complemented by data from reputable sources such as PLN, PGE, Geo-Dipa, and Bank Indonesia. This analysis will reveal critical insights into the project's viability, considering factors like carbon credit prices and project lifespan. Also considering various weather parameters such as ambient temperature, ground temperature, wind speed, and rainfall. These data assess the seasonal performance of the geothermal system. Climate data are collected by RETScreen from NASA satellites and used to create models for calculating power generation. The findings will provide valuable recommendations for stakeholders and decision-makers in the renewable energy sector to make informed decisions based on their specific needs.

Using the RETScreen program, we conduct a detailed feasibility analysis across four scenarios: Baseline, Carbon Credit Incentives

Table 1: Literature review studies on renewable energy sources power plant

No.	Title and Author	Location	Energy	Capacity (MW)	Initial cost (USD/kW)	Operation cost (USD/kW/Year)	Electricity tariffs (USD/kWh)	Project lifetime (Years)	Methodology
1	(Tomasini-Montenegro et al., 2017)	California and Larder Ello	Geothermal	206	Not specified	Not specified	Not specified	30	LCA
2	(Prasad, 2022)	Fiji	Geothermal binary cycle	10	3500	406.30	0.1621	20	RETScreen SAM
3	(Sveinbjornsson and Thorhallsson, 2012)	Ice Land, Hengill	Geothermal	Not specified	4000	Not specified	40~50% of the initial cost is assumed	Not specified	The Monte Carlo method
4	(Yousefi et al., 2018)	Iran	Geothermal Heat Pumps	80	Not specified	Not specified	Not specified	25	RETScreen
5	(Kaplan and Schochet, 2005)	Nevada, Nicaragua, Miravalles	Geothermal ORC	35	Not specified	Not specified	Not specified	10	RETScreen
6	(Rera et al., 2021)	Indonesia	Geothermal	20	2454	227.063	Not specified	30	POD
7	(Mohammad et al., 2018)	Indonesia	Geothermal	Not specified	Not specified	Not specified	Not specified	Not specified	Exergy Analysis
8	(Tang, 2023)	Indonesia	Geothermal ORC	240	2000(exclude Drilling)	105	0.081	30	RETScreen
9	(Moya et al., 2018)	Ecuador	Geothermal Binary Cycle	22	5195	25.36	0.132	Sc1:25 Sc2:15	RETScreen
10	(Tang, 2023)	Indonesia	Geothermal Binary Cycle	30	2000(exclude Drilling)	105	0.120	25	Not specified
11	(Patihk et al. 2022)	Trinidad and Tobago (TT)	Geothermal binary cycle abandoned well	3.37	3558.87	593.22	0.05	25	CMG Software
12	(Kaldellis et al., 2005)	Greece	Hydro Power	10	1650	Not specified	0.0606	20	RETScreen
13	(Paradongan et al., 2024)	Indonesia	Solar and Geothermal	26	999.04	13	0.057	25	RETScreen
14	(Alhassan et al., 2023)	Ghana.	Solar PV	420	1350	115.19	0.10	25	RETScreen
15	(Malik, 2021)	Canada	Solar	0.01	1896	9.48	0.1027	25	RETScreen
16	(Baccay et al., 2020)	Ethiopia	Solar	100	Not specified	Not specified	0.09	25	RETScreen
17	Paradongan et al.	Indonesia	Solar	Not specified	Not specified	4% of initial	Not specified	Not specified	RETScreen
18	(Pan et al., 2017)	China	Various renewable sources	800	1320	Not specified	0.52	25	RETScreen
19	R Zahedi, S Gitifar, A Ahmadi	Iran	Geothermal	10	Not specified	Not specified	0.17	30	RETScreen
20	MI Yuce, S Yuce	Turkey	Hydropower	Small-scale	Not specified	Not specified	Not specified	Not specified	RETScreen
21	(Ehyaei et al., 2024)	Iran	Geothermal	4.202	Not specified	3% of the initial capital costs.	0.22	25	RETScreen

with Tax Holiday, Lifetime Adjustment, and Proposed. The following scenarios were established.

Scenario 1: The geothermal power facility is funded by the investor, with no government assistance or subsidies. The cost of exporting electricity is \$0.094/kilowatt-hour (kWh). \$2 per metric ton of CO_2 is the sustainable production incentive for the sale of carbon emission quotas, as stipulated in Regulation No. 7 of 2021. The initiative is expected to last for 25 years (IRENA, 2017).

Scenario 2: Supplementary incentives are accessible. The initial incentive to produce renewable energy is contingent upon the presence of an emission trading system (ETS). No modifications are required. The price of electricity remains at \$0.094 per kilowatt-hour (kWh) (Asian World Bank, 2015).The financial inducement for sustainable energy generation is \$18 per metric ton of CO_2 emitted through the sale of carbon credits (Siagian, 2023).The endeavor is expected to last for 25 years.

Scenario 3: This scenario is identical to Scenario 2, but it incorporates additional incentives. The user did not submit any text. The initial motivation is the incentive to produce renewable energy, which is contingent upon the existence of an ETS (Emissions Trading Scheme). The user's text is devoid of any content. As per Siagian (2023), the emission trading rate is \$18 per ton. The user did not submit any text. A tax holiday incentive is offered for a period of 10 years (Kusumastuti and Fatin, 2023). The project's lifespan has been extended to 30 years.

Scenario 4: This scenario is identical to Scenario 2, but it includes additional incentives. The initial motivation is the incentive for the production of renewable energy during the first 25 years of power generation. It is assumed that the emission trading system exists. The internationally recognized benchmark for emission trading pricing is \$46 per ton (Biedenkopf et al., 2024). This strategy is anticipated to have a lifespan of 25 years.

RETScreen is used for the techno-economic and environmental analysis of the 60 MW binary ORC GPP at the Rajabasa Geothermal Power Plant. It is a clean energy management tool suitable for benchmark studies, feasibility studies, economic analysis, and risk assessments. RETScreen can analyze projects from multiple dimensions, including technical, financial, and environmental aspects, and verify the sustainability of clean energy projects. Its software model follows a five-step standard project analysis, including an energy model, greenhouse gas (GHG) emission analysis, financial analysis model (FAM), sensitivity, and risk analysis, as detailed in Figure 1.

First, the energy data is entered into the Energy Model worksheet, including project location, system type, load and renewable energy resources, capacity factor, operating pressure, steam temperature, back pressure, and steam turbine (ST) efficiency, to calculate the annual energy output. Next is the cost analysis in the RETScreen feasibility study, where the Cost worksheet shows the cost breakdown of the project, including initial costs and annual expenses. For this study, initial costs and operation and maintenance (O&M) costs will be gathered from similar literature. The GHG analysis worksheet calculates the annual reduction in GHG emissions. By inputting the GHG emission factors of the regional power system and fuel, it compares the emissions of the baseline scenario with the proposed scenario and converts them into units such as liters of gasoline and barrels of crude oil. This helps to understand the project's impact on emissions. Relevant cost data will be collected from similar literature.

By running RETScreen, results such as LCOE, debt service coverage ratio, internal rate of return, and net present value (NPV) are obtained. Users can specify the inflation rate and discount rate in the Financial Summary worksheet to calculate the NPV. The Sensitivity and Risk Analysis worksheet helps identify uncertainties in key parameters, assisting decision-makers in evaluating the project. The final step of the feasibility analysis is the risk analysis, allowing users to perform sensitivity analysis on various factors.

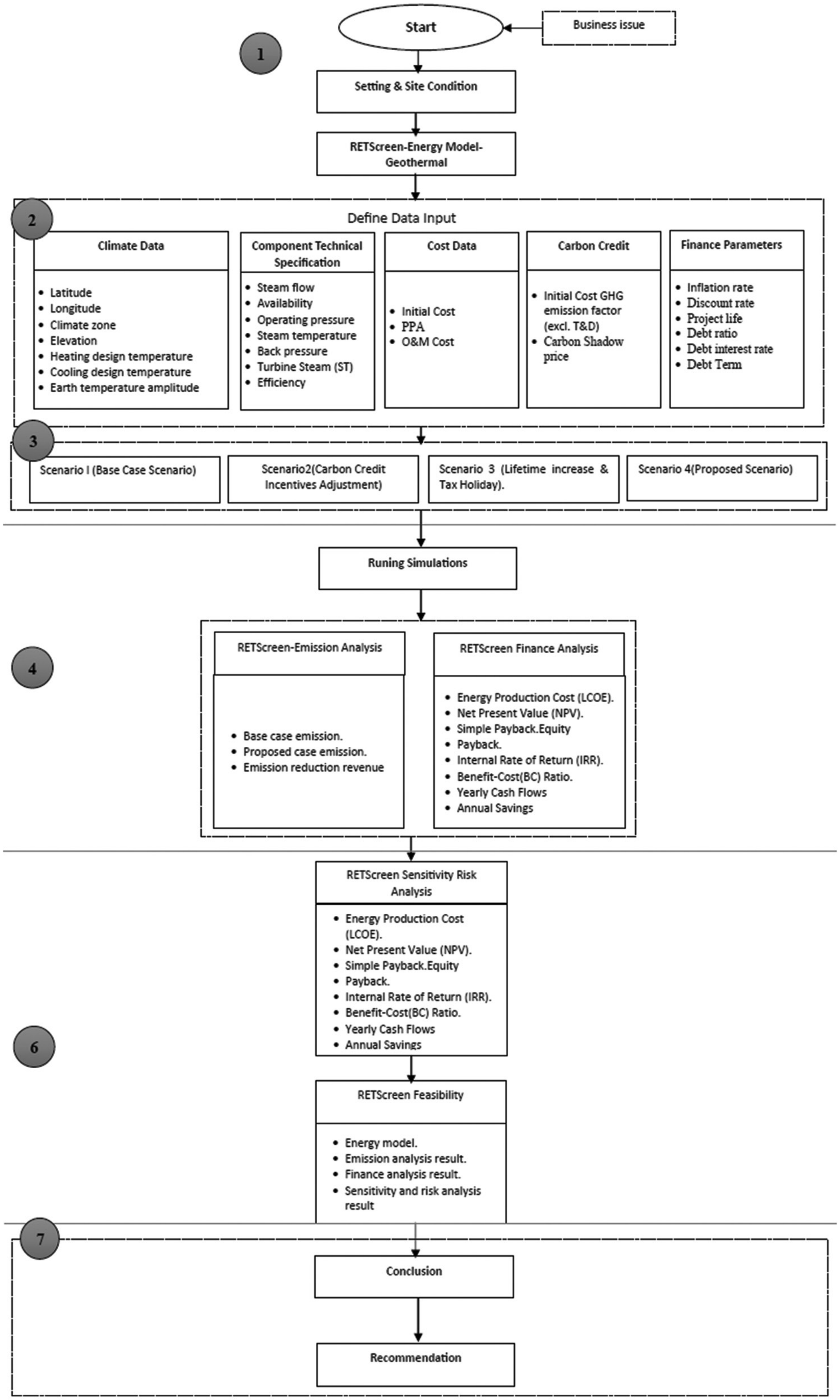
The ADB geothermal project report indicates that the drilling costs of geothermal wells in Indonesia vary due to well depth and geological conditions. The drilling cost of geothermal wells in Indonesia ranges from \$1,200 to \$1,500/m, with typical well depths between 1500 and 2500 m, resulting in a total cost of \$1.8-\$3.75 million. Indonesia has 711 wells (Purwanto et al., 2018). The report does not clarify whether geothermal exploration costs are included in the capital costs and notes that the lifespan of geothermal power plants is 30 years. According to the ASEAN Center for Energy (ACE), the installation cost of geothermal power plants in Indonesia ranges from \$6,251 to \$12,075 per kilowatt, with an average of \$8,593.

High initial investments in drilling, road construction, and facility development significantly raise the costs. The financial feasibility study for a 60 MW geothermal project divides the initial costs into drilling and power plant construction costs, with capital costs at \$6,000/kilowatt (Purwanto et al., 2018) and operation and maintenance costs at \$105.12/kilowatt per year, based on data from the PT Sorik Marapi geothermal project, with more detail refer to Table 2. Assuming an inflation rate of 5% and a discount rate of 10% (Prasad, 2022; Irawan and Smith, 2023). The Indonesian Ministry of Energy, an autonomous regulatory entity responsible for establishing the minimum energy export pricing, has set the power export price at USD 0.094/kWh.

The Rajabasa Geothermal Power Plant is a 220 MW project developed by Supreme Energy, comprising 22 wells. It is expected to generate 1, 7 GWh annually, offsetting 1.1 million tons of CO_2. The project includes two turbines, each with a capacity of 110 MW. To validate the feasibility of the 60 MW ORC geothermal power plant in Sumatra refer Table 3, this study assumes a parasitic load of 10% and transmission losses of 2%, based on (Moya et al., 2018).

The choice of a 60 MW power plant is based on the site's brine and well evaluations, indicating a geothermal potential of 40 MW-220 MW, as per Table 4 data. RETScreen software assesses technical, environmental, and financial aspects, including sensitivity analysis. It's widely used to validate the techno-economic and environmental sustainability of clean energy projects. Comparing RETScreen simulation results effectively refines project feasibility studies.

Figure 1: Conceptual framework



4. RESULTS AND DISCUSSION

4.1. Scenario 1: Basic Scenario Analysis

In this scenario, geothermal electricity is priced at USD 0.094/kWh, with a carbon credit incentive of USD 2/ton CO_2. Figure 2 shows an equity payback period of 5.2 years, resulting in a cumulative cash flow of USD 538.53 million. The pre-tax equity IRR is 20.7%, exceeding the 10% discount rate, and the pre-tax asset IRR is 5.8%. The simple payback period is 8.5 years, with an NPV of USD 97.52 million. The cost to reduce GHG emissions is −18.76 USD/ton CO_2, with a benefit-cost ratio of 2.2 and an LCOE of USD 0.087/kWh.

Table 2: Financial analysis initial data

Parameter	Value	Unit	References
Installed initial cost	6000	USD/kW	(Hafner and Luciani, 2022)
O&M cost	105.12	USD/kW	(SMGP, 2023)
Discount Rate	10	%	(Prasad and Raturi, 2022)
Inflation rate	5	%	(Irawan and Smith, 2023)
Debt ratio	70	%	Assumption

Table 3: Rajabasa energy model initial data

Input parameter	Value	Unit	References
Installed capacity	Up to 60	MW	(Yan, 2023)
Capacity factor	90	%	(Goldstein et al., 2015)
Steam Flow	272,000×2	Kg/h	(Yan, 2023)
Operating pressure	7.6	Bars	(Yan, 2023)
Steam temperature	168.3	Celsius	(Yan, 2023)
Back pressure	3.95	Bars (ORC)	(Moya et al., 2018)
Steam turbine efficiency	88	%	(Prasad, 2022)

Table 4: Design condition (Yan, 2023)

Geothermal parameter	Value
Steam mass flow (t/h)	270
Steam pressure at the plant inlet (barA)	7.6
Steam temperature at the plant inlet (°C) - saturated	168.3
NCG content in the steam by weight (%)	3
Brine mass flow (t/h)	767
Brine pressure at the plant inlet (barA)	11.1
Brine temperature at the plant inlet (°C)	169
Brine outlet temperature (°C)	80
The site elevation (m)	793
The atmosphere pressure (barA)	0.922
Design dry bulb temperature (°C)	26
Design wet bulb temperature (°C)	24

Figure 2: Cash flow of base case scenario

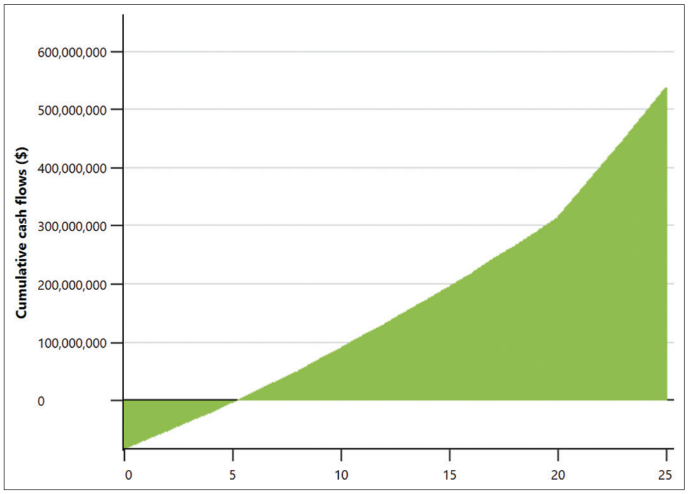


Figure 3 highlights that the electricity export rate is the primary factor influencing the net present value (NPV). Next in sensitivity is the amount of power exported to the grid, followed by initial costs, operation and maintenance (O&M) costs, interest rates, debt ratio, loan term, GHG reduction credit rates, and net GHG reduction. Higher electricity export rates boost project profitability, while lower rates decrease it. Sensitivity analysis stresses optimizing export rates and managing costs to maximize NPV. Favorable loan terms, such as low interest rates and optimal debt ratios, also significantly affect financial viability. High GHG reduction credits further enhance economic performance.

Figure 4 shows that the probability of NPV < 0 is minimal, indicating the project is generally profitable under the base case scenario. From 1,000 Monte Carlo simulations, the NPV ranges from \$29.6M to \$163.1M, with most values clustering around the central range. This suggests that while there is some risk of lower NPV, nearly all simulations yield positive outcomes, highlighting the project's robustness and overall financial viability despite uncertainties.

4.2. Scenario 2: Carbon Credits Case Scenario Analysis

In this scenario, the electricity price for geothermal power is assumed to be USD 0.094/kWh, and the clean production incentive for selling carbon credits is set at USD 18/tCO_2. As shown in Figure 5, the equity payback period is 4.1 years, indicating that positive cash flow will be achieved after this timeframe, with a cumulative total cash flow of USD 663,069,041. According to the result, the pre-tax equity internal rate of return (IRR) is 26.1%, exceeding the 10% discount rate. The pre-tax asset IRR is 7.7%, the simple payback period is 7.4 years, the NPV is USD 142,741,751, the cost of GHG reduction is -USD 18.76/tCO_2, the benefit-cost ratio is 2.7, and the levelized cost of energy (LCOE) is USD 0.098/kWh.

In Figure 6, the chart illustrates that the primary factor affecting NPV is the rate of power output. The second most significant factor is the amount of power exported to the grid, followed by initial costs, operation and maintenance (O&M), debt interest rate, net GHG reduction amount, GHG reduction credit rate, debt ratio, and finally, debt term. Essentially, the higher the power export rate, the more profitable the project becomes, whereas a lower rate results in decreased project profitability.

Figure 7 shows that the project's NPV, under the base case, ranges from \$74.9M to \$208.4M based on 1000 Monte Carlo simulations. The likelihood of NPV being less than zero is minimal, indicating profitability. Most common NPV values are around \$178.2M. The distribution is biased towards positive NPVs, highlighting the project's financial strength and the significant positive impact of carbon credit incentives.

According to Figure 8, the characteristic that has the greatest impact on the Levelized Cost of Electricity (LCOE) is the quantity of power that is sent to the grid. The initial cost is the second most influential factor, followed by operation and maintenance (O&M) costs, debt interest rate, debt ratio, debt term, GHG reduction credit rate, power export rate, and finally, the net GHG reduction amount. The findings suggest that a higher amount of power exported to the grid contributes to the enhancement of project profitability, but a lower amount of power exported raises the probability of the project being unprofitable.

Figure 3: Sensitivity analysis of scenario 1: Base case scenario – NPV

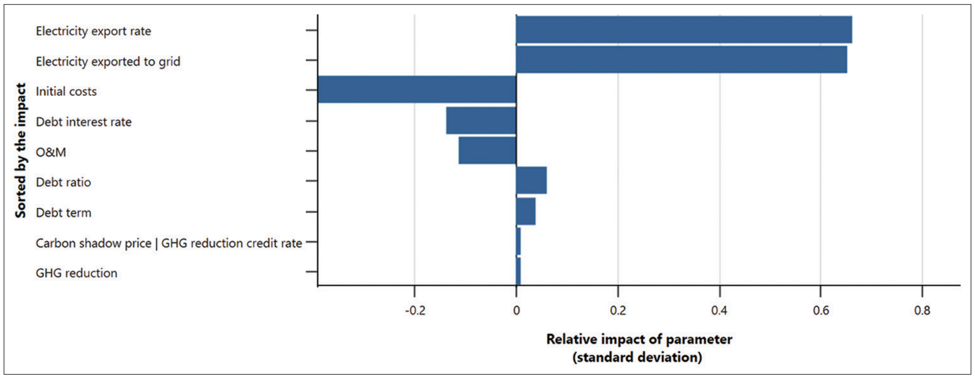


Figure 4: Distribution of scenario 1: Base case – NPV

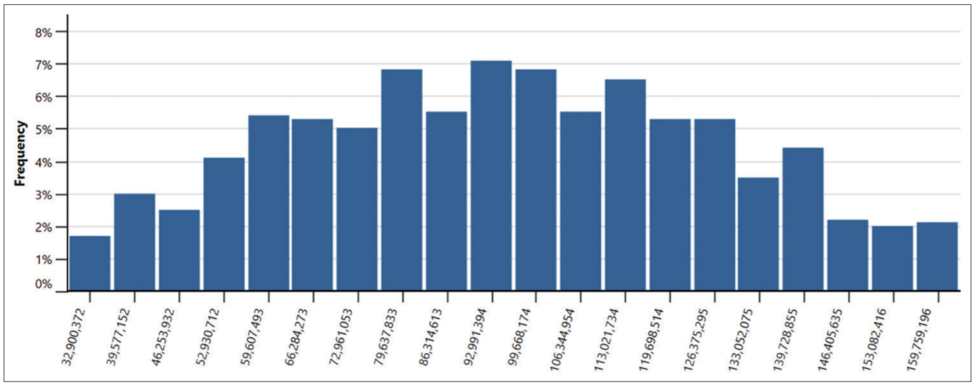
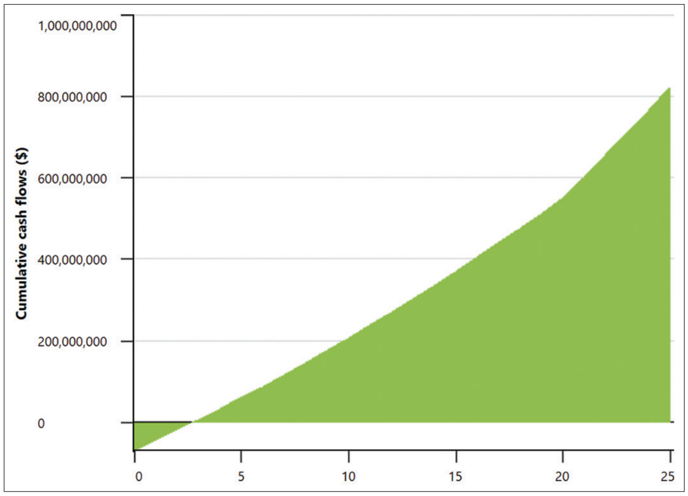


Figure 5: Cash flow of scenario 2: Carbon credit incentives scenario



4.3. Scenario 3: Lifetime and Tax Holiday Case Scenario Analysis

Under the baseline scenario, the cost of geothermal power is \$0.094/kWh, with a 30-year project lifespan and an \$18/ton CO_2 carbon credit incentive. Scenario 3 shows a 4.1-year equity payback and a total cumulative cash flow of \$709M as shown in Figure 9.. The pre-tax IRR on equity is 26.2%, and the post-tax IRR is 25.2%, both exceeding the 10% discount rate. The asset's pre-tax IRR is 8.6%, with a 7.4-year payback and an NPV of \$129M. The GHG emission reduction cost is -\$23.55/ton CO_2, with a benefit-cost ratio of 2.5. Excluding debt repayment, the LCOE is \$0.0359/kWh, and \$0.0426/kWh considering post-tax cash flows.

Figure 10 illustrates that the power export rate is the main determinant of NPV. The subsequent most notable elements are the amount of electricity supplied to the grid, subsequent to that are the costs associated with operation and maintenance, starting costs, net reduction in greenhouse gas emissions, the rate at which greenhouse gas credits are earned, the interest rate on loan, the ratio of debt, and lastly, the duration of the debt. Furthermore, it is evident that the long-term effect of the tax vacation on net present value (NPV) is negligible and is not depicted in Figure 14. In essence, the project's profitability is directly proportional to the power export rate. A higher rate results in greater profit, whereas a lower rate leads to less profitability.

Figure 11 demonstrates the critical impact of variations in initial and O&M (Operation and Maintenance) expenses on the project's Net Present Value (NPV). Major deviations from expected costs can significantly influence profitability. Changes in power generation capacity and energy export rates are also pivotal. If actual power generation or energy prices fall short of expectations, NPV will notably decrease. Additionally, reductions in greenhouse gas emissions and higher carbon prices positively affect NPV. Even in the worst-case scenario, the project retains a positive NPV, with potential peaks around USD 200,000,000 in the best-case scenario. Based on 1000 Monte Carlo simulations, the base scenario's NPV ranges from USD 64,139,614 to USD 192,265,587, guaranteeing profitability.

Figure 12 highlights that power delivered to the grid is the key factor affecting the Levelized Cost of Energy (LCOE). Higher power output significantly lowers energy production costs. Initial

Figure 6: Sensitivity analysis of scenario 2: Carbon credit incentives scenario – NPV

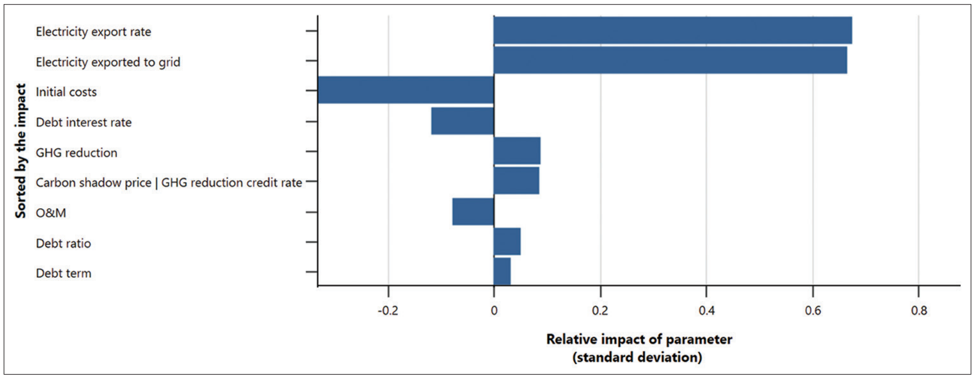


Figure 7: Distribution of scenario 2: Carbon credit incentives scenario – NPV

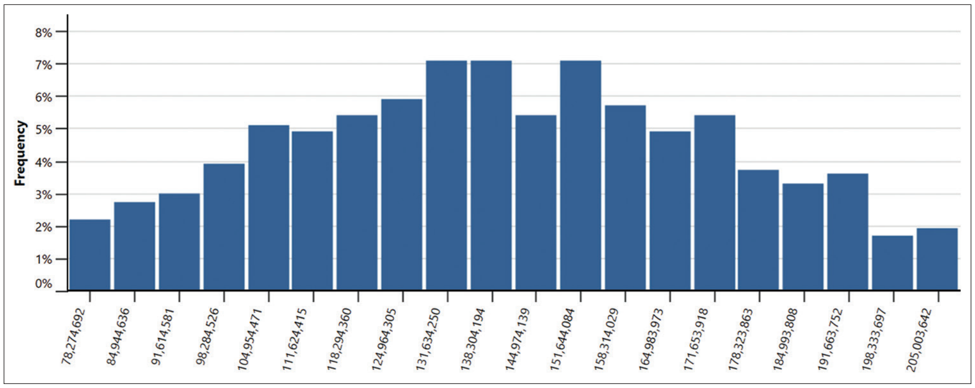
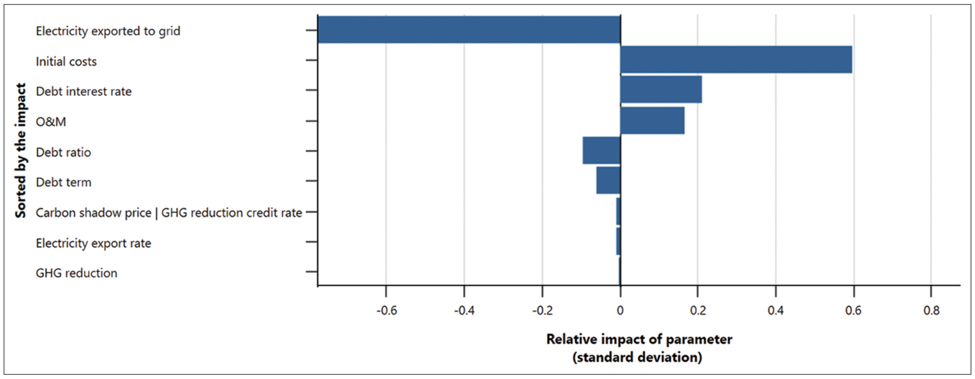


Figure 8: Sensitivity analysis of scenario 2: Carbon credit incentives scenario – LCOE



capital expenditure, followed by O&M costs, debt interest rate, debt ratio, debt duration, GHG reduction credits, power export rate, and net GHG reduction also impact LCOE. Increased power transmission boosts profitability, while decreased transmission raises the risk of unprofitability. Consistent electricity export rates lead to higher revenue.

According to Figure 13, the Levelized Cost of Energy (LCOE) for the project is mostly below 90 USD/MWh, and there is a greater chance that the LCOE will be <90 USD/MWh. This suggests a higher probability of the project's energy production costs being below 90 USD/MWh. Scenario 3 indicates that the project's Levelized Cost of Electricity (LCOE) is often lower than the average cost of generating electricity on Sumatra Island. After conducting 1000 Monte Carlo simulations, the project's Levelized Cost of Electricity (LCOE) varies between 78.20 USD/MWh and 103 USD/MWh. There is a 58% chance that the LCOE will be below 90 USD/MWh.

4.4. Scenario 4: Suggestive Case Study

In this scenario, the cost of generating geothermal power is $0.094 per kWh. The international carbon credit price fluctuates, with the EU price projected to reach $76 per ton by 2024 and $160 per ton by 2030. California's carbon price is around $42 per ton in 2024, expected to rise to $46 per ton by 2025. Using California's carbon price of $46 per ton over 30 years, similar to Scenario 3, Figure 14 shows Scenario 4 has an equity payback period of 2.9 years and a cumulative cash flow of $1,111,438,451.03. The pre-tax internal rate of return (IRR) for equity is 35.7%, indicating strong financial performance even with a discount rate above 10%. The project has a robust net present value (NPV) of $237,973,456.03 and a benefit-cost ratio of 3.8. The pre-tax IRR on assets is 11.5%, with a 6-year payback period for the initial investment. The cost of reducing greenhouse gas emissions is -$23.55 per metric ton of CO_2, and the LCOE is $0.087 per kWh. These metrics demonstrate substantial financial appeal and strong economic viability for the project.

Figure 15 highlights that the primary factor influencing the Net Present Value (NPV) is the power export rate. This is followed by the power delivered to the grid, operations and maintenance (O&M) costs, initial costs, net greenhouse gas (GHG) reduction, GHG reduction credit rate, debt interest rate, debt ratio, and lastly, the debt term. Additionally, it can be observed that the tax holiday has a negligible impact on the NPV over time and is therefore not shown in Figure 15. Essentially, the higher the power export rate, the greater the profitability of the project. Conversely, lower rates diminish the project's financial viability.

Figure 9: Cash flows for scenario 3: lifespan and tax holiday adjustment

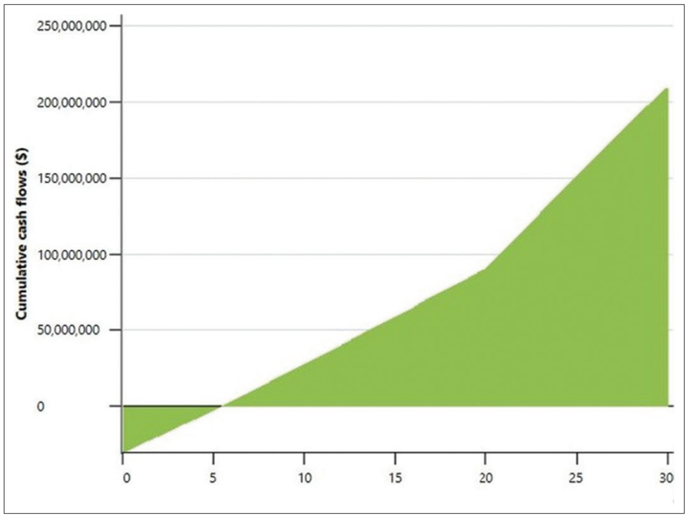


Figure 16 shows that fluctuations in startup costs, operational expenses, power output, and electricity rates significantly impact the project's net present value (NPV). Deviations in these factors could affect profitability. The project's revenue is also influenced by greenhouse gas (GHG) emission reductions and carbon prices; higher-than-expected reductions or prices would increase NPV.

The median NPV is $234,220,841, indicating strong financial success. There is a 100% certainty that the NPV will not drop below zero, ensuring profitability. Monte Carlo simulations (1000 runs) show a 90% likelihood that NPV will range between $164,199,978 and $307,153,286, with the most frequent values between $224,947,592 and $232,093,750. This highlights the NPV's stability and potential for high returns.

Figure 17 indicates that the quantity of power supplied to the grid is the most influential factor in determining the Levelized Cost of Energy (LCOE). The cost of energy production is mostly influenced by this parameter, suggesting that increasing power

Figure 10: Sensitivity analysis of option 3: Life span and tax holiday adjustment-NPV

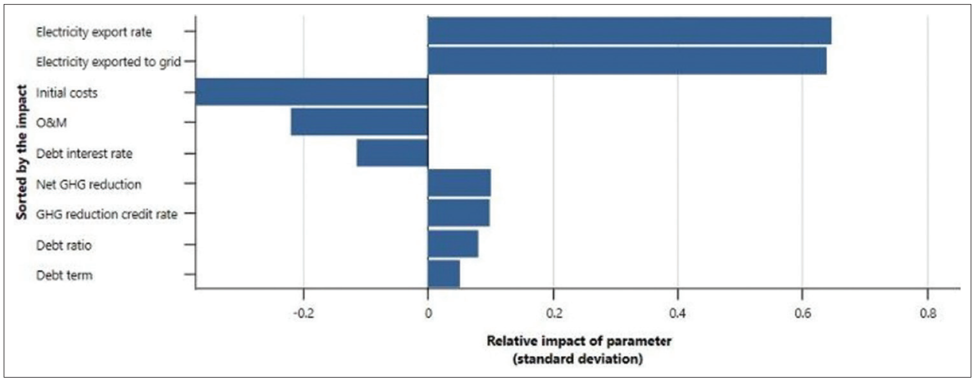


Figure 11: Distribution of scenario 3: Adjustment of life cycle and tax holiday - net present value

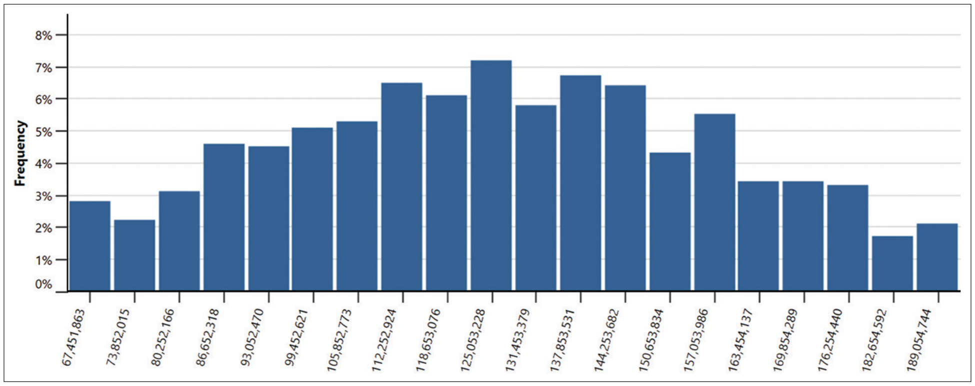


Figure 12: Sensitivity analysis of option 3: Life adjustment and tax holiday increase - LCOE

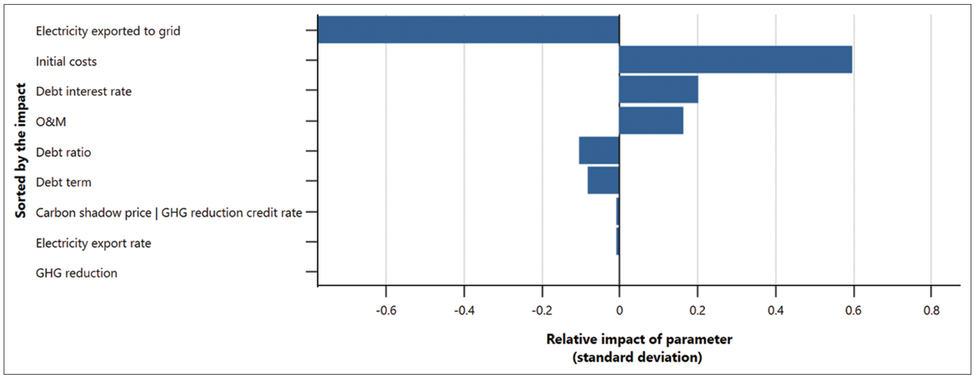


Figure 13: Distribution analysis of option 3: life adjustment and tax holiday increase - LCOE

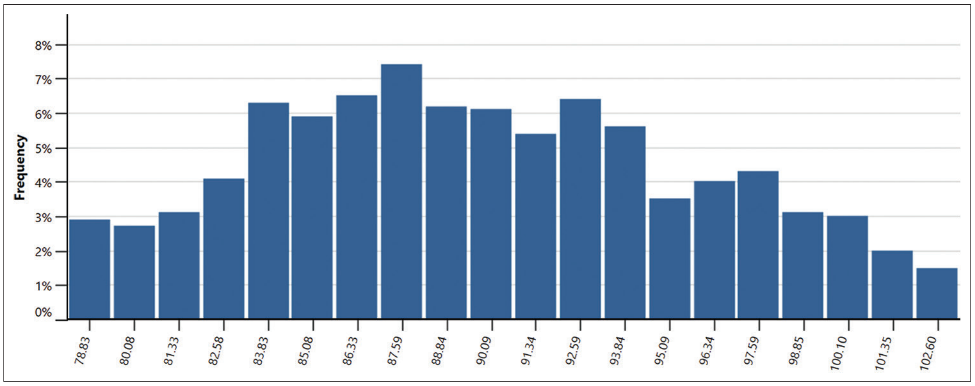
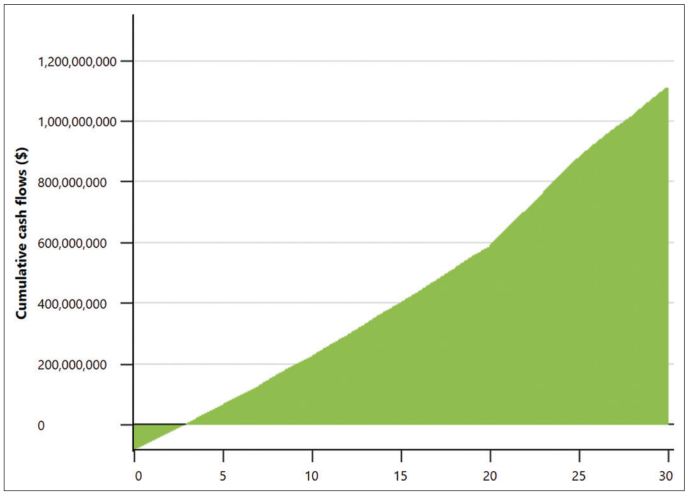


Figure 14: Scenario 4 cash flow: Proposed case



output will significantly decrease energy production costs. The subsequent characteristic with the most significant impact is the initial cost, followed by the operational and maintenance costs, the interest rate on loan, the debt ratio, the debt term, the rate of greenhouse gas reduction credits, the rate of power export, and ultimately, the net reduction in greenhouse gas emissions.

The results indicate that supplying more electricity to the grid improves the profitability of the project, while supplying less electricity increases the chances of the project becoming unprofitable. If the power export rate remains constant, additional electricity sales will instantly result in greater revenue.

Figure 18 shows that Scenario 4's Levelized Cost of Energy (LCOE) for the project is lower than the average cost of power production in Sumatra, providing a competitive advantage. Monte Carlo simulations indicate the LCOE is mostly between 80.43 and 85.20 USD/MWh. There is a 50% chance the LCOE will be below 85.81 USD/MWh, enhancing the project's economic viability and investment appeal. The LCOE ranges from 75.06 to 105 USD/MWh, suggesting costs remain acceptable even in unfavorable conditions and highly competitive in favorable ones. Overall, 1000 Monte Carlo simulations show stable and economically advantageous LCOE, making the geothermal power project financially attractive.

4.5. GHG Emission Analysis

The RETScreen software calculated the fundamental scenario of GHG emissions reduction for a diesel power plant as shown in Figure 19. According to the IEA and UNFCCC, the emission factor for oil-fired power generation varies between 0.8 and 1.0 tCO_2/MWh, depending on oil type, combustion efficiency, and technical conditions. For heavy fuel oil (HFO), the emission factor is around 0.9-1.0 tCO_2/MWh, according to ESSD Copernicus. Indonesia's power sector, heavily reliant on oil, has a GHG emission factor of 1.427 tCO_2. Transmission and distribution losses contribute 0.833 tCO_2 per unit, accounting for 9% (PLN, 2021) of total losses. A proposed 50 MW geothermal power project could reduce annual CO_2 emissions by 29,177,736.58 tons, equivalent to avoiding the consumption of 106,878 liters of gasoline each year. Using a carbon shadow price of 50 USD/tCO_2, this translates to an annual benefit of up to 29,177,736.58 USD.

Figure 15: Sensitivity analysis of scenario 4: Proposed case – NPV

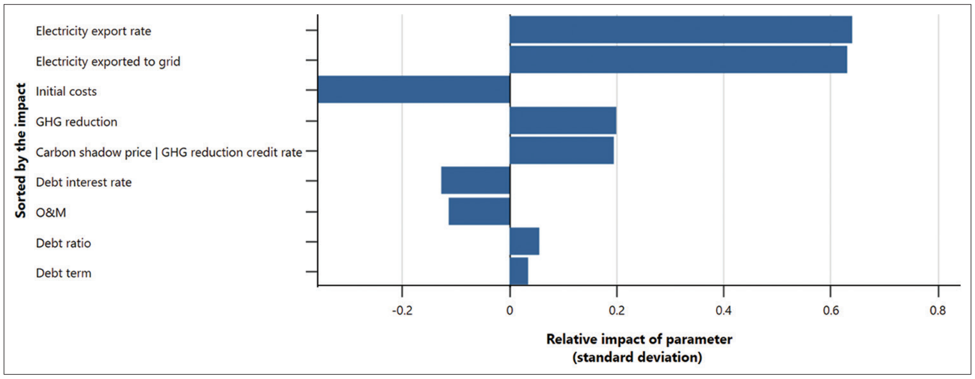


Figure 16: Distribution of scenario 4: Proposed case - net present value

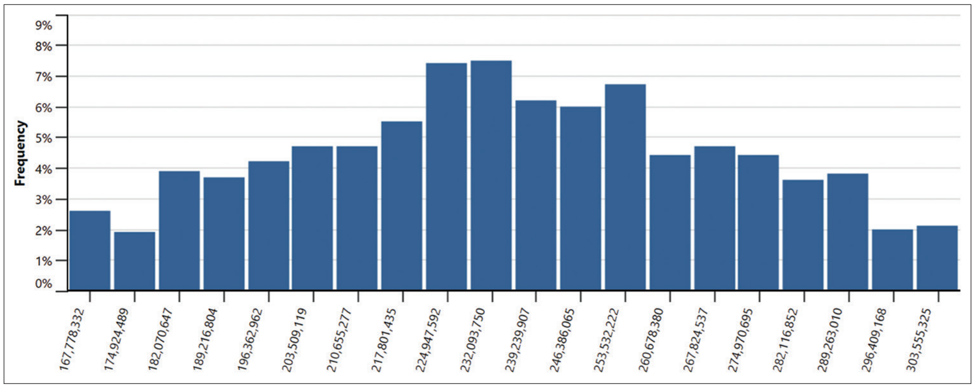


Figure 17: Sensitivity analysis for scenario 4: Proposed case – LCOE

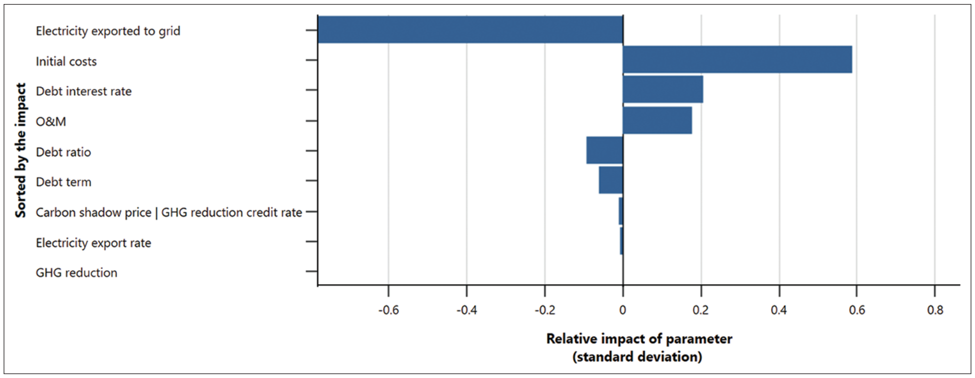


Figure 18: Distribution Analysis of Scenario 4: Proposed Case – LCOE

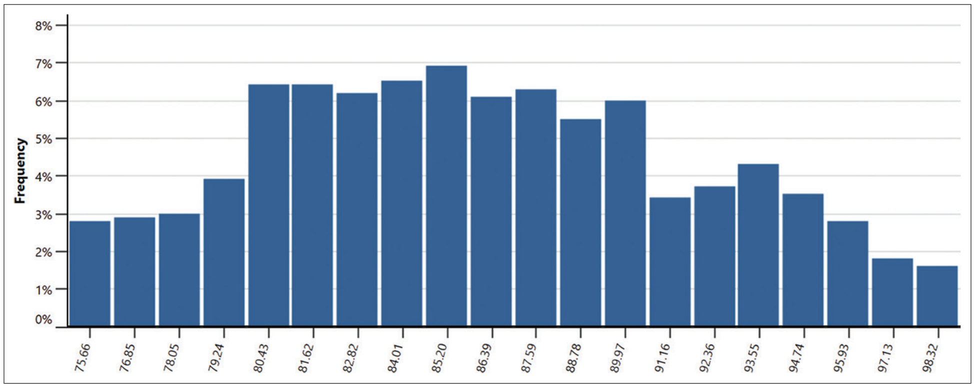


Figure 19: Annual GHG emission reductions - oil

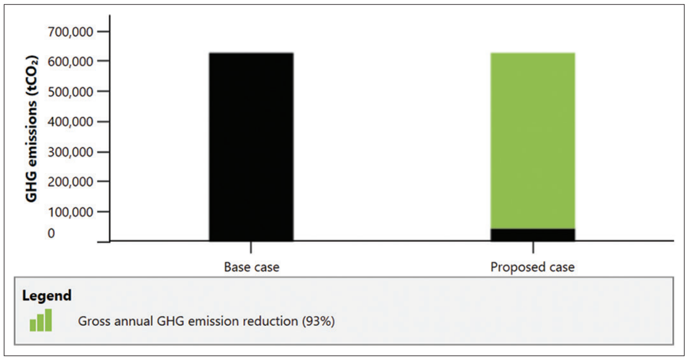


Figure 20: Annual GHG emission reduction – coal

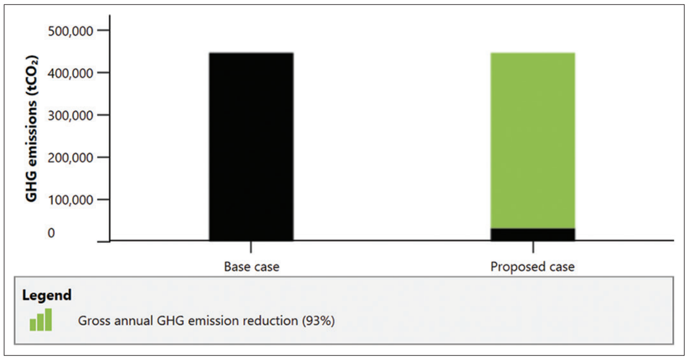
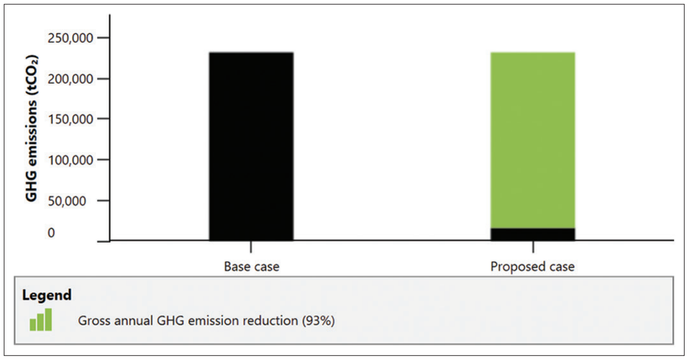


Figure 21: Annual GHG emission reduction - natural gas



RETScreen research shows Indonesia's coal-based power system emits 1.170 tCO_2 per MWh, accounting for a 9% transmission loss. Based on figure 20, a 54 MW geothermal plant can reduce CO_2 emissions by 416,614 tons annually, saving 76,303 L of fuel and yielding 20,830,724 USD in annual benefits with a carbon price of 50 USD/ton.

The RETScreen analysis shows Indonesia's coal-based power system emits 0.571 tCO_2 per MWh after accounting for a 9% transmission loss. According to the figure 21, a 21 MW geothermal plant could cut annual CO_2 emissions by 10,764,006 tons, equal to saving 39,429 L of gasoline, with a yearly benefit of 10,764,000 USD at 50 USD per ton of CO_2.

5. CONCLUSION AND RECOMMENDATION

The feasibility analysis for the Rajabasa Geothermal Power Plant in Sumatra indicates that a distributed geothermal power station system can achieve a total output of 60 MW. This system utilizes advanced technologies, including two steam screw expanders and multiple Organic Rankine Cycle (ORC) units. The project is projected to deliver 400,171,818 kWh of electricity to the grid. Financial analysis under different scenarios highlights the impact of carbon pricing on the project's viability. At the current Indonesian carbon price of \$2/ton CO_2, the project is financially feasible with a pre-tax IRR of 20.07%, NPV of \$97,524,087, and LCOE of \$0.087/kWh. However, raising the carbon credit price to \$18/ton CO_2 boosts financial returns to 26.1% and \$142,741,751. According to the International Energy Agency (IEA), extending the project life to 30 years and using a carbon credit price of \$46/ton CO_2 will yield a highly favorable return with an ultra-short equity payback period of 2.9 years and a reduced LCOE. Indonesia has lower energy pricing than other countries, but higher operating and maintenance costs limit its financial attraction to investors. Policy changes to match worldwide benchmarks are needed to make geothermal investments profitable and attractive due to the country's low carbon pricing.

Appendix A compares the viability of geothermal power projects, following on capacity, electricity price, initial cost, operation and maintenance cost, net present value (NPV), internal rate of return (IRR), and levelized cost of energy (LCOE). The SMGP (240 MW) has the lowest LCOE at \$0.00846/kWh, an NPV of \$537M, and an IRR of 11.3%. Rajabasa Project (60 MW) can achieve an IRR up to 35.7% and an NPV up to \$237M under different carbon pricing scenarios. The Fiji project (10 MW) has an LCOE of \$0.014/kWh and an NPV of \$17.3M. The Sarulla project (330 MW) has an LCOE between \$0.078 and \$0.082, with an IRR of 14-16%, showing regional and carbon price policy variations in financial returns.

Several recommendations are suggested to enhance the financial feasibility and investment attractiveness of the Rajabasa Geothermal Power Plant and similar projects in Indonesia. Initially, the IEA's recommendation to raise the carbon credit price to \$46/ton CO_2 will increase profitability and attract investment by providing superior returns through carbon credit sales. This modification will reduce the high initial investment costs, particularly for reconnaissance and early-stage well development. Subsequently, the implementation of sophisticated geothermal technologies, like organic Rankine cycle (ORC) technologies and optimize exploration and drilling processes to reduce costs and timelines. Make full use of idle and low-temperature geothermal resources. and the optimization of exploration and drilling processes can result in cost savings and a reduction in project duration. In the 240 MW SMGP project, technologies such as directional drilling have demonstrated effectiveness in reducing costs and accelerating returns. Furthermore, in order to mitigate investment risks and motivate both domestic and international investors, the Indonesian government should implement supportive policies, such as tax exemptions, financial incentives, and expedited approval processes. Indonesia can improve its pricing policies to better support geothermal development by incorporating lessons from countries with higher PPA prices, such as the Philippines and Kenya. Indonesia's zero-carbon emissions objective by 2060 will be furthered by these measures, which will also improve the financial sustainability of its geothermal initiatives.

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APPENDIX

Appendix A: Project valuation results comparison with previous studies

Project	Author	Region	Scenario	Capacity (MW)	Electricity Tariffs (USD/kWh)	Initial Costs (USD/kW)	O&M Costs (USD/kW/y)	NPV (M USD)	Simple payback period (Years)	Equity payback period (Years)	IRR (%)	LCOE (USD/kWh)
1	(KSORKA, 2023)	Mandailing Natal, Indonesia	ORC	240	0.081	2000	105	537	3.7	4.45	11.3	0.00846
2	Rajabasa Current Research	Bandar Lampung Indonesia	Scenario 1: 2 USD/tCO$_2$, 25 years	60	0.094	6000	156	97.5	8.5	5.2	20.7	0.087
			Scenario 2: 18/tCO$_2$, 25 years	--	--	--	--	142	7.4	4.1	26.1	0.091
			Scenario 3: 18 tCO$_2$, 30 years	--	--	--	--	129	7.4	4.1	19,4	0.088
			Scenario 4: 46 tCO$_2$, 30 years	--	--	--	--	237	6	2.9	35.7	0.088
3	(Prasad, 2022)	Fiji	ORC	10	0.1621	6000	406.3	17.3	6.9	4	N/A	0.014
			Additional Incentives	--	--	--	--	81	3.7	1.3		0.0136
			Electricity not exp. to grid	--	--	--	--	−40	20.5	None		0.0136
4	(Moya et al., 2018)	Ecuador	Scenario I (25 years, 3 MUSD)	22	0.132	5181	94.80	63	4.9	3.2	32.6	0.0032
			Scenario II (15 years, 3 MUSD)	--	--	--	--	36	4.9	3.7	27.8	0.0041
			Scenario III (A) (25 years, 3 MUSD)	--	--	--	--	−24	15.6	16	4.5	0.0032
			Scenario III (B) (25 years, 20 MUSD)	--	--	--	--	7	9.3	5,6	18.3	0.0018
5	(Rakhmadi and Sutiyono, 2015)	SARULLA Indonesia	First Scenario	330	0.078	5000	155.56	N/A	N/A	9	14-16	0.078-0.082