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Optimizing Financial Feasibility and Resource Utilization in Binary Geothermal Systems: A Case Study from the Dieng Geothermal Field, Indonesia

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Abstract. This study evaluates the technical and financial feasibility of developing a binary geothermal power plant by utilizing residual brine from the Dieng geothermal field in Central Java, Indonesia. As one of the most geologically complex and active regions in Southeast Asia, the Dieng field represents significant untapped potential for secondary energy through binary cycle technology. By using data from reservoir simulation, brine chemistry analysis, and economic modeling, the study examines multiple development configurations across several scenarios. Technically, the study finds that several wells will have sufficient brine temperature and sustainability for the project, although there is a risk of silica content, which poses a scaling problem. Finally, the base scenario of the financial project is not viable under the current tariffs of USD 6.23 cents/kWh but becomes attractive when paired with optimized tariffs and resource integration from Dieng Unit-2. The findings support the pathway for enhanced geothermal utilization in Indonesia, emphasizing the importance of flexible development strategies, regulatory alignment, and technological optimization to ensure long-term project viability.

Keywords: *Binary System, Dieng, Silica Content, Residual Brine*

1 Introduction

As a country with the world's largest geothermal reserves, Indonesia presents significant potential for renewable energy development (worldbank.org, 2017. Its location along the geologically active "Ring of Fire" makes Indonesia one of the world's most substantial geothermal energy potentials (Purba et al, 2021). Rough estimates suggest that the country harbors 29.5 GW of geothermal resources, accounting for 40% of the world's geothermal power (InCorp, 2025). Despite this potential, only a fraction has been utilized, with around 2.3GW installed as of 2022, positioning Indonesia as the world's second-largest geothermal behind the USA (ANL geothermal, 2025).

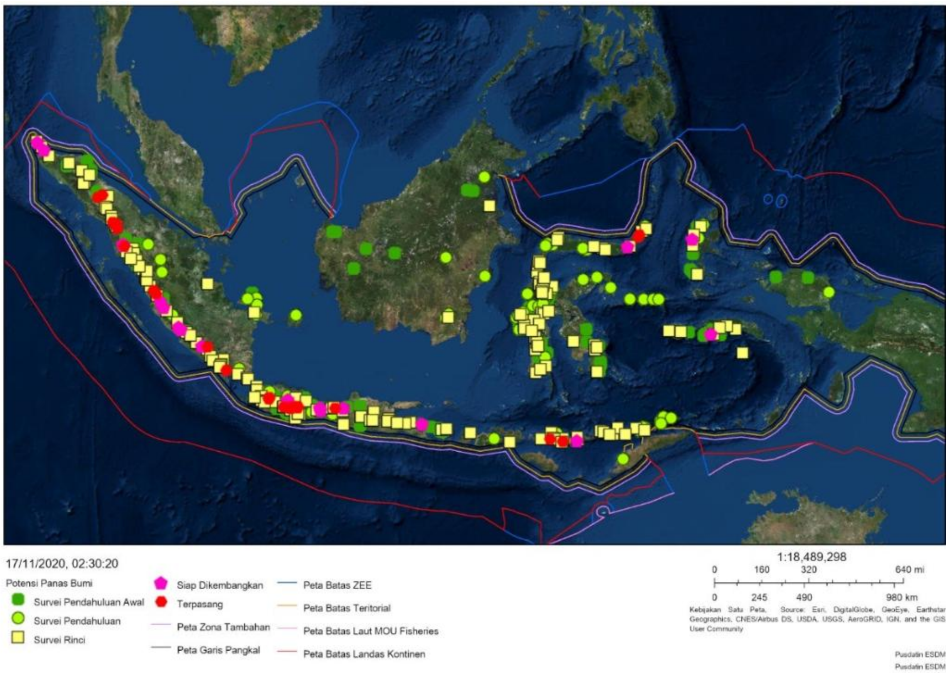

Figure 1 Maps of geothermal potential area in Indonesia (Pusdatim ESDM, 2020)

The Dieng Power Plant is a geothermal field in Central Java, operated by Geo Dipa Energy (GDE), an active geothermal site characterized by high enthalpy and a history of energy production (Shalihin, et al, 2022). The Dieng Unit-1, managed by the company, produces a two-phase fluid that requires steam-water separation before energy conversion. The residual brine, typically discharged after separation, still contains considerable thermal energy that can be harnessed using binary cycle technology, suitable for fluid temperatures of 80-150 °C (DiPippo, 2005). GDE initiated the study in 2015 to explore the binary utilization of brine from the Dieng Unit-1, but the process was delayed until 2020 due to legal challenges. Interest emerged after the 2021 test using the HCE-7C well, which employs the combined flash-binary system. Although the combination style was falling through due to silica risk, the findings supported the investigation for the binary plant at Unit 1. This study investigates the technical and financial feasibility of developing a geothermal power plant using brine from Dieng Unit-1. From a geological perspective, the analysis focuses on brine temperature, fluid chemistry, wells sustainability, and scaling potential. Financially, it will expand upon capital and operational costs, loan structures, and tariff scenarios. The study is based on reservoir simulations, chemical analysis, and an economic model using real project data from the GDE 2023 study. It aims to support decision-making for future developments by identifying viable technical configurations and financial thresholds.

2 Geological And Technical Feasibility

2.1 Geological Setting

The Dieng geothermal field is situated within the Dieng volcanic complex in Central Java, characterized by a series of Quaternary volcanic formations, including stratovolcanoes, lava domes, and craters, resulting from a history of volcanic activity (Shalihin et al, 2022). The field encompasses several geothermal prospect areas, like Sileri, Sikidang, and Pakuwaja, with each having its own geological and geochemical characteristics (Kencana et al, 2024).

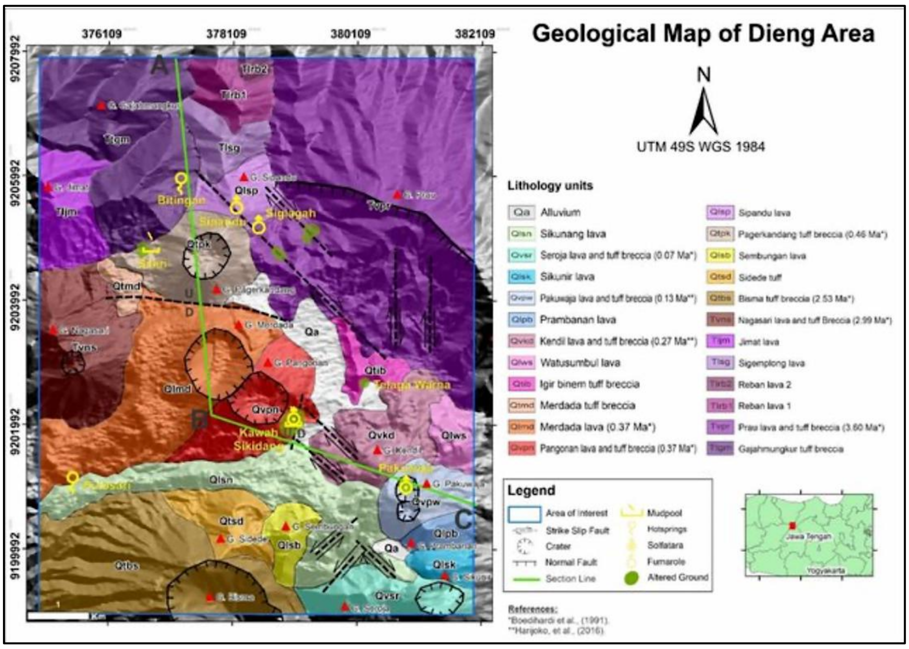

Figure 2 Geological maps of the Dieng area (Shalihin, et al, 2022)

The brine resources in the Dieng field are a byproduct of the geothermal energy extraction process, where steam is separated in power generation, leaving behind a hot mineral-rich liquid. This brine contains a significant concentration of dissolved minerals, including silica and lithium (Kencana et al, 2024). Understanding the geological frameworks of the Dieng geothermal fields is crucial for assessing the feasibility of binary power generation, as the fields have a complex volcanic history, structural geology, and hydrothermal characteristics that influence temperature chemistry and sustainability of brine resources, which is a crucial factor in the operation of the power plant.

2.2 Brine Chemistry and Scalling Risk

Geochemical analysis indicated that high Silica Saturation Index (SSI) values were observed across several wells, with values exceeding 2.5 at typical operating temperatures (90- 120 °C). High SSI possesses significant scaling risk, especially in heat exchangers and pipelines, wells such as HCE-/C, HCE-28A exhibit SSI values above 3.0 at 100 °C. There is an effort to implement sailing control measures like inhibitors or temperature adjustments, which are essential for operations.

Table 1 Dieng Unit-1 Chemical Data

Well	pH	SiO_2 (ppm)	Na^+ (ppm)	Cl^+ (ppm)	As (ppm)	Ca^{2+} (ppm)
HCE-7B	6.42	1.099	7.029	13.516	21.9	394
HCE-7C	6.46	881	9.1	18.2	59.3	713
HCE-28B	6.07	1.03	7.93	14.8	31.2	386
HCE-29	6.49	1.17	9.23	18	-	-
HCE-33	6.7	800	8.467	15.966	-	-
HCE-10A	4.5	769	5.842	11.188	45.3	389
HCE-31	6.47	868	10.7	20.8	56.5	886
HCE-28A	6.16	973	9.17	17.9	51.9	625
HCE-30	6.2	1.099	7.029	13.516	21.9	394

Table 2 SSI Values for each brine temperature

Well	120°C	110°C	100°C	90°C	80°C
HCE-7B	2.26	2.54	2.85	3.25	3.71
HCE-7C	2.49	2.8	3.15	3.59	4.1
HCE-29	2.35	2.64	2.98	3.39	3.87
HCE-33	2.75	3.09	3.48	3.97	4.54
HCE-10A	1.5	1.68	1.89	2.16	2.46
HCE-31	1.73	1.94	2.18	2.49	2.84
HCE-28A	1.95	2.19	2.47	2.82	3.22
HCE-30	2.17	2.44	2.75	3.14	3.58

Additional challenges included arsenic content and variable pH levels, which must be managed through appropriate material selection and water chemistry control (Ballantyne & Moore, 1988; Mathiesen, et al, 2021). Therefore, there is a suggestion to implement scale control measurements, inhibitors, and temperature adjustments for sustained operations.

A brine availability study used reservoir simulations based on 2019 model data and well testing results from 2021 and 2022. The results predicted a total decline in output from 903 tons/hour in 2023 to 118 tons/hour by 2056. However, certain wells, such as HCE-30 and HCE10A, demonstrate strong sustainability, with projected brine flow rates exceeding 180 tons/hour until at least 2045.

Table 3 Well evaluation of 9 existing production wells in Dieng Unit-1

Well	Well Status	Fluid Production	Brine Flow Rate (@2026)	Production Sustainability	Well History (Challenges & Issues)
HCE-7B	Production Dieng 1	Water Dominated	27 tph	Sustain until 2056 (Unstable Production)	Cannot be operated above SSI (SSI in 2022 at 22.2 barg) No stable production profile (fluctuated) with natural increase sometimes. WO: 2011, 2019, 2020

HCE-7C	Production Dieng 1	Water Dominated	104 tph	End production in 2044	Fish at 2,143 mMD in 2021 Potential rapid scaling in the near future WO: 2011, 2019, 2020
HCE-28A	Production Dieng 1	Steam Dominated	56 tph	Sustain until 2056	Wellbore clearance issue Production drop since 2022 by 32% from expected deliverability curve
HCE-28B	Production Dieng 1	Water Dominated	0 tph	End production in 2023	Stop Production in 2023 Potential casing leakage in between 344.6 and 335 mRKB (float shoe 7" and top 8-5/8") WO: 2005, 2020 Tie Back: 2020 Acidizing: 2021, 2022
HCE-29	Production Dieng 1	Water Dominated	30 tph	End production in 2046	Overpull during PT logging at 1,549 mMD Potential casing issue WO: 2010, 2019 Tie Back: 2019 Acidizing: 2020
HCE-30	Production Dieng 1	Water Dominated	232 tph	Sustain until 2056	Production drop since the end of October 2022 Potential condensate inflow Liner condition is not good
HCE-31	Production Dieng 1	Steam Dominated	31 tph	No brine flow rate starts 2039	Production casing issue, work over tagged at 40.8 mMD (2015)

HCE-10A	Production Dieng 1	Water Dominated	202 tph	Sustain until 2056	Wellbore clearance issue Potential casing issue
HCE-33	Production Dieng 1	Water Dominated	68 tph	End production in 2045	Logging tool cannot pass depth 2,178 mMD (most likely liner issue)

2.3 Well Evaluation and Technical Configuration

Nine production wells were evaluated based on fluid type, mass flow rate, and operational history (see Table 4). Wells HCE-30, HCE-10A, and HCE-7C ranked the highest due to their brine output, sustainability, and manageable operational issues. Table 4 summarizes the selections of several studied well sites.

Table 4 Well ranking based on technical parameters

Well	Brine Flow Rate (Point)	Sustainability (Point)	Manageable Issue (Point)	Total	Ranking
HCE-30	9	9	9	27	1
HCE-10A	8	8	8	24	2
HCE-7C	7	5	7	18	3
HCE-29	3	7	5	15	4
HCE-28A	5	6	4	15	5
HCE-33	6	4	3	13	6
HCE-7B	2	3	5	9	7
HCE-31	4	2	2	7	8
HCE-28B	1	1	1	3	9

The proposed plan design included a centralized internal power system using isopentane as the working fluid. The base configuration targets 5- 10 MW, utilizing up to 60% of the available brine. Multiple layouts, 7 central and 6 clustering configurations, were explored to optimize the resource use and minimize pipeline losses. Specific brine consumption (SBC) is estimated at 54.45 tons/hr per MS. Align with typical values in similar geothermal applications. The wells (see table 4) will supply the power plan Well Pad 30, Well Pad 28, Well Pad 31, Well Pad 7, Well Pad 29, Well Pad 33, and Well Pad 10.

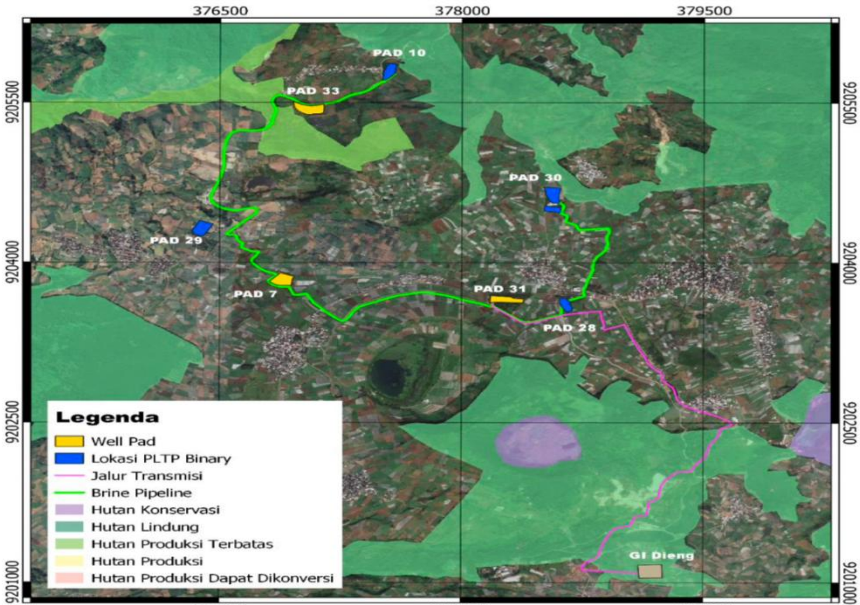

Figure 3 The map outlines the overall development plan for the wells; the blue mark indicates the location of the power plant, yellow identifies the well pad location, the purple line represents the transmission line, and the green shows the brine pipeline

3 Financial Feasibility

3.1 Capital and Operational Cost

The financial sustainability of the Dieng Binary Geothermal Power Plant is closely tied to its capital structure and long-term cost dynamics, which are shaped by the sequential, capital-intensive nature of geothermal development. Cost drivers include site conditions, reservoir characteristics, plant design and capacity, and macroeconomic factors such as interest rates and capital accessibility (Hance & Gawell, 2005). Geothermal projects are commonly financed through a mix of 25% - 30% equity targeting an IRR of around 18% and 70% - 75% debt with interest rates averaging 7%. While equity offers flexibility, lenders typically require a minimum 25% equity share to mitigate risk and ensure financial discipline. This financing structure aligns with international best practices for renewable infrastructure investment (Hance & Gawell, 2005; Owens, 2002). Several base scenarios have been introduced for estimation, with base scenario 3, which employs main production wells (HCE-30, HCE7C, and HCE10A), having a CAPEX of USD 35.2 million. Operational costs (OPEX) include general operations and maintenance, chemical handling (for inhibitors), and major overhauls every four years. The average cost is 1.25 cents/kWh, while chemical treatment and brine management add an annual cost of USD 392.000 for 300 tons/hour of brine. These figures are benchmarked from Dieng Unit 1's historical performance and market surveys conducted with technology providers. Table 4 provides the assumptions used for technical optimization scenarios.

Table 5 Technical optimizations simulated in the analysis for cost estimation

Changes	Unit	Base Scenario 3	Usage of chemical treatment (Inhibitor)	Integration with Mineral Extraction	Additional Brine from Dieng Unit-2
COD Date	Date	2026	2026	2026	2027
Net Power plant capacity	MW	10	11	13	24
Make up well schedule	Year	2x2033, 2x2041, 2x2049	2x2033, 2x2040, 2x2049	2x2030, 2x2040, 2x2048	2x2033, 2x2040, 2x2038, 3x2045, 4x2049
Capex	000 USD	35,204	38,272	44,408	79,405
Preparation	000 USD	187	187	187	187
ISBL	000 USD	29,481	32,429	38,325	71,886
OSBL	000 USD	1,806	1,806	1,806	1,835
Land & Infrastructure	000 USD	329	329	329	334
Additional cost	000 USD	2,077	2,077	2,077	2,110
IDC	000 USD	1,325	1,455	1,685	3,052
Brine cost/ brine management fee	$c/kWh	1.98	1.98	1.98	1.55
PLN electricity purchase price	$c/kWh	6.23	6.23	6.23	6.23
Dieng Binary Power Plant rent price	$c/kWh	3.6	3.6	3.6	3.97

3.2 Tariff and Optimization Scenarios

As electricity tariffs play a critical role in the project, the base case utilizes a tariff of US$ 6.23 cents/kWh based on the existing power purchase agreement (PPA) with PLN. However, the study found that a minimum tariff of USD 7.14 /kWh is required to meet the margin target. A higher tariff of USD 8.28 /kWh currently applied to the Dieng geothermal ESC significantly improves project performance, pushing the IRR (internal rate of return) above 25%. To evaluate the project's financial viability, the Weighted Average Cost of Capital (WACC) is calculated based on a typical project finance structure. The cost of equity is assumed at 12.13%, reflecting current returns for investors, and a 5% cost of debt loans from institutions like ADB. WACC represents the average cost of financing the project and is calculated using the formula:

$$WACC = (W_E \ x \ K_e \ x) + (w_d \ x \ K_d) \ x \ (1 - T) \qquad (1)$$

Where:
Weight of equity portion in the capital structure (Er) : 15%
Cost of Equity (CoE) : 12.13%
Weight of debt portion in the capital structure (Dr) : 85%
Cost of Debt (CoD) : 5%
Income tax rate (T) : (i) 22% (ii) 34%
Weighted Average Cost of Capital (WACC) : (i) 5.17% (ii) 4.78%

To understand the values of tariff optimization, Table 5 presents the analysis conducted to determine the tariff at which the Dieng Binary power plant should achieve the target IRR.

Table 6 Base tariff based on different scenarios

	Base Tariff	**Dieng Binary Power Plant rent price**	**Project IRR**	**WACC + margin**	**Margin / Risk Premium**	**Equity IRR**	**Cost of Equity**	**Margin/ Risk Premium**
HOA electricity price	\$6.23 c/kWh	\$3.97 c/kWh	4.22%	7.17%	-2.95%	2.64%	12.13%	-9.49%
Dieng Geothermal ESC electricity price	\$8.28 c/kWh	\$5.73 c/kWh	10.28%	7.17%	3.11%	25.70%	12.13%	13.57%
Cost of equity as target	\$7.33 c/kWh	\$4.92 c/kWh	7.74%	7.17%	0.57%	12.13%	12.13%	-
WACC+margin as target	\$7.14 c/kWh	\$4.75 c/kWh	7.17%	7.17%	-	10.13%	12.13%	-2.00%

4 Risk Assessment

4.1 Technical Risk

The scaling from a high silica saturation index (SSI) in the brine, particularly at lower temperatures, is typical for a binary system. Wells such as HCE-7C and HCE-33 exhibit SSI values above 3.0% at 100 °C, significantly increasing silica deposition in pipelines. This can lead to efficiency loss, unplanned downtime, and equipment damage. However, using chemical inhibitors, along with regular maintenance cycles and adjusting brine reinjection temperatures, will help to avoid the problem. Another technical concern is the decline in brine flow rate over time, as reservoir pressure naturally decreases. Predictions indicate reductions from 903 tons/hr in 2023 to 118 tons/hr in 2056. Additionally, prioritizing wells with sustainable output, such as HCE-30 and HCE-10A, along with scheduling make-up wells approximately every 8-10 years, can help maintain capacity.

4.2 Financial And Market Risks

The project faces low IRR across all base scenarios, with values ranging from 0.29% to 1.6% (see Table 6), well below the required WACC + margin of 7.17%. The projects remain financially unattractive to investors without tariff adjustments or capacity scaling. This issue can be addressed by optimizing the electricity tariff through the application of the current Dieng geothermal Energy Sales Contract (ESC) tariff of USD 8.28 cents/kWh. This tariff level yields the most favorable financial outcome, with a Project Internal Rate of Return (IRR) of 10.28% and an Equity IRR of 25.7% (see Figure 4).

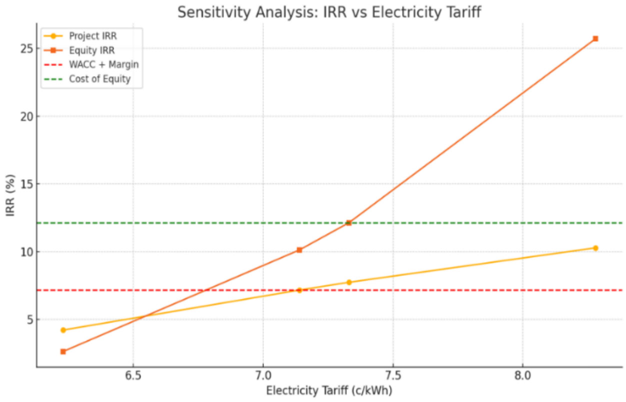

Figure 4 Sensitivity analysis illustrating the correlation between electricity tariffs (USD cents/kWh) and key financial Project IRR and Equity IRR for the Dieng Binary Geothermal Power Plant.

Moreover, concessional loans from institutions that offer lower interest rates and long grace periods can also help reduce financial pressures. Several options in partnership are also brought into the topic. Such as a self-development partnership scheme where GDE develops the binary plant independently, with two technical options: (i) Fully owned and operated by GDE, (ii) owned by GDE -formed Opco without external partners.

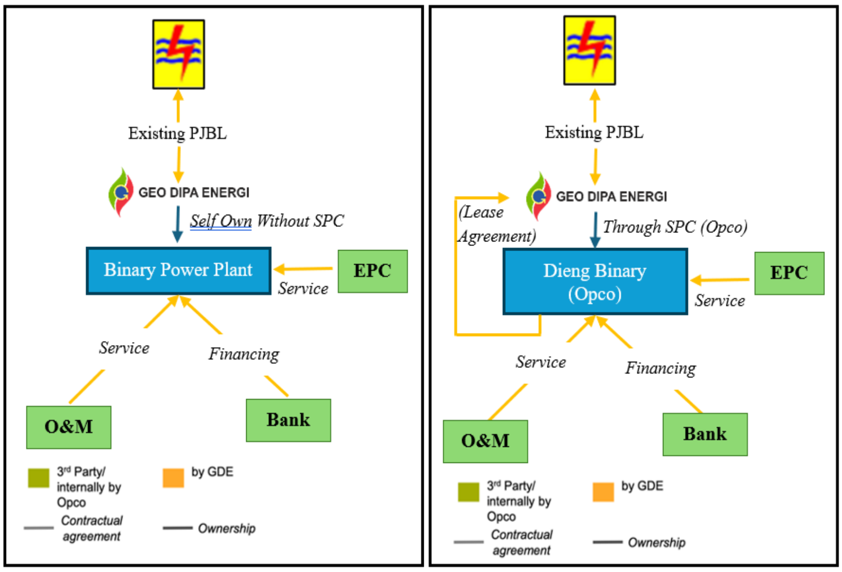

Figure 5 The scheme outlines two development options for GDE to build and operate the Dieng binary power plant without external partners

However, this full development risk-borne capital burden has advantages and disadvantages. Advantages: (i) higher operational and financial control, (ii) tariff flexibility under the current Dieng area agreement. While disadvantages are : (i) required higher equity investment or full debt exposure, (ii) potential limitations in access to project finance without PLN involvement.

5 Conclusion

This study assessed the technical and financial feasibility of developing a binary geothermal power plant using residual brine from the Dieng geothermal field in Central Java. From a technical perspective, the project demonstrated promising resource potential, with a sufficient temperature range of 90-130 °C. However, the high silica content poses a risk and must be managed with innovative technologies to ensure the expected long-term performance of the plant.

Financially, the base scenarios show limited attractiveness under the current tariffs of USD 6.23 cents/kWh, but with optimization, improvements in feasibility can be achieved through tariff adjustments up to USD 8.28 cents/kWh and a partnership scheme. These enhancements significantly improve the IRR and compliance.

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