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Investment Analysis And Economic Benefits Of Depressurisation Strategies For Enhanced Slope Stability And Optimization Of Coal Mine Slopes

Reynara Davin Chen [1]; Oktofa Yudha Sudrajad [2]
[1]Study Program of Master of Business Administration, Institut Teknologi Bandung, Indonesia
[2] Department of Business Administration, Faculty Of Business and Management, Institut Teknologi Bandung, Indonesia
Email: [1] rdavinchen@gmail.com ;[2] oktofayudha@itb.ac.id

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ABSTRACT

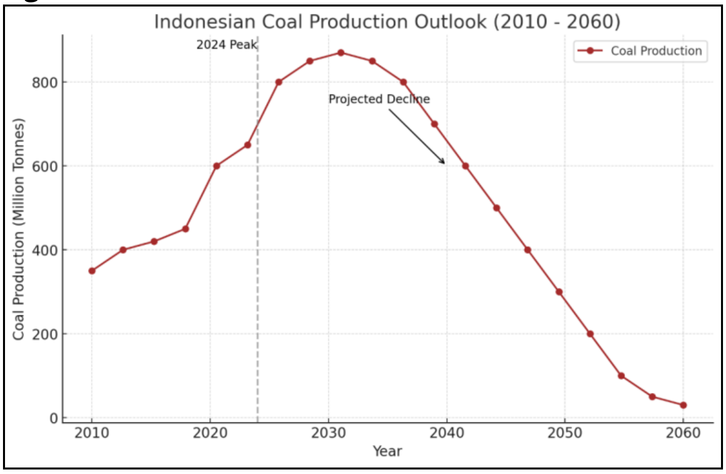
PT OPQ aims to increase its coal production target from 50 million tons in 2025 to 100 million tons in 2030 to meet both domestic and export market demand which aligns to the strategic direction from management. However, because of the geological and hydrogeological constraints and land limitations in Pit BU, there are only so many optimizations that can be done with just technical evaluations. It is necessary to conduct a thorough economic feasibility assessment to identify if the chosen operational approach can be executed profitably within the framework of the company's long term business goals. Given the constraints that PT OPQ faces in PIT BU, the consideration of investment feasibility, driven through technical data in assessment of slope depressurization hipothetical scenarios, from a geological, hydrogeological and mine planning perspective, is paramount. Equally, having such a complex technical assessment requires a financial counterpart. This is the purpose of the study, to construct a financial model based on Discounted Cash Flow, with the Payback Period, Discounted Payback Period, Net Present Value (NPV), Internal Rate of Return (IRR), and Profitability Index (PI) as the key decision parameters. To understand the effect of market fluctuations and operational risk with respect to the investment's feasibility, sensitivity analysis and Monte Carlo simulation were conducted. Analyzing the financial risk from the NPV also indicates the least risk to the finances of the business from the base case scenario. Therefore, the choice of depressurization (Option 2) compared to continued operation without depressurization (Option 1) illustrates that there is greater financial potential. In the worst case, there is still a minor loss of financial potential for a scenario exhibiting the dependence on the price of coal. Thus, the approach for depressurization is the best for the medium term, though there needs to be a reconsideration of the cost of the coal, the coal from the closed mine, the loss of volatility of the coal, and the mining of coal.

INTRODUCTION

Coal production is crucial to the global energy supply, The coal industry supports and sustains the economic growth. However, achieving sustainability in the coal mining industry presents complex challenges in PT OPQ, particularly in balancing operational efficiency and profitability. The energy commodity is notably significant. The world's leading export of thermal coal is Indonesia; thus makes coal economically important. In the coal industry, Indonesia's mining sector in 2023, reported non-tax revenue of 5.7 billion USD. 80 percent of this revenue is generated from the coal industry. The coal mining sector directly employs 150,000 workers. The economically important coal industry is especially significant to the coal mining regions of South Sumatra and East Kalimantan.

Coal production domestically is predicted to plateau at 700 million tonnes (Mt) from 2024 to 2035 before tapering off to over 250 Mt by 2060 (Figure 1). This is consistent with predictions from the International Energy Agency (IEA) and the Australian government who also predict a rapid decrease in the global appetite for coal. Although in their predictions this decrease in demand seems to be a foregone conclusion.

Figure 1. Indonesia Coal Production Outlook 2025-2060

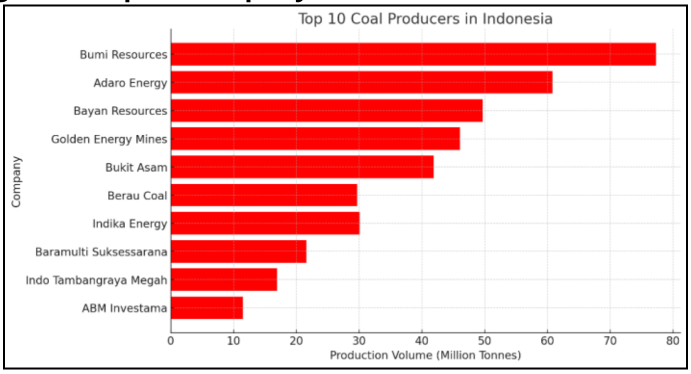


Source: Indonesian Ministry of Energy and Mineral Resources

PT OPQ, as Indonesian state-owned coal mining enterprise that operates in Tanjung Enim. In alignment with its strategic objectives, PT OPQ is committed to fulfilling domestic market demands through synergy with state-owned electricity providers while simultaneously catering to export market requirements. Based on Top 10 Coal Producers in Indonesia (Figure 2) among the other coal mining company, PT OPQ is in fifth position, with the highest production by volume is Bumi Resources (BUMI) To enhance its competitiveness within the coal mining industry, PT OPQ strives to increase its coal production capacity.

The increasing frequency of slope failure from 2021 to 2024, particularly in the coal excavation areas of the union of Pit BU and South as the highest coal production volume, has become a major challenge in mining operational activities. Field investigations indicate that the majority of slope failure are caused by unfavorable geological conditions.

Figure 2. Top 10 Company of Coal Producers in Indonesia



source: Ember, & Publish What You Pay, 2024

Geologically, the study area is composed of sedimentary rocks classified as weak rocks, wich also consists of two medium to high aquifer in terms of groundwater condition, where hydrogeologically plays a crucial role in the design and implementation of mining plans (Martin and Stacey, 2018). Groundwater conditions significantly influence the strength and cohesion of materials. As ground water levels increase, the strength and cohesion of the material decrease, subsequently reduces the slope stability of the coal mine, which in turn restricts the pit geometry and reduces accessible coal reserves ultimately affecting production capacity and long-term economic performance

From the combination of the technical and economic problems, the need of geotechnical intervention for slope depressurisation become critical to fullfil the current increasing production target. The integration of these approaches would ensure the profitability and the maintenance of operational sustainability for the long term plan of the Pit BU. The volume of production for the coal to accomplish the coal mines operational lifespan together with the the projection of the profitability of the company and the integration of the economy and the geotechnical engineering is the basis of this research.

LITERATURE REVIEW

Financial Modelling

Financial modelling is a structured process of representing real-world financial systems using numerical and mathematical formulations to support planning, forecasting, valuation, and decision-making. Rees (2018) emphasizes that financial models serve as simplified representations of reality that balance accuracy and usability through stages of specification, implementation, and decision support. The modelling process is iterative and bi-directional, involving backward thinking from outputs such as cash flows and forward calculations from input assumptions, while acknowledging trade-offs between complexity and practicality. Skipping formal specification, as often occurs in practice, may reduce robustness and transparency, highlighting the importance of sensitivity-based design and best practices to improve model reliability (Rees, 2018; Gitman et al., 2015).

Cost of Capital

The cost of capital represents the minimum required rate of return that an investment must generate to increase firm value and reflects the opportunity cost of using capital resources. Gitman et al. (2015) explain that it incorporates both debt and equity financing and serves as a benchmark for evaluating investment profitability. In practice, firms use the Weighted Average Cost of Capital (WACC), which accounts for the proportional costs of each capital component across the firm's capital structure. Maintaining an optimal balance between debt and equity is essential, as projects yielding returns above the cost of capital create value, whereas those below it erode shareholder wealth (Gitman et al., 2015; Warren & Jack, 2018).

Capital Budgeting

Capital budgeting is the process of evaluating and selecting long-term investments that align with a firm's objective of maximizing shareholder wealth. According to Warren and Jack (2018), it involves forecasting future cash flows and allocating capital to projects with the highest value-creation potential, often using long-term government bond yields as a proxy for the risk-free rate. Strategic capital investments, such as capacity expansion or technological adoption, typically involve high risk and long-term impact, making rigorous evaluation essential (Alkaraan & Northcott, 2006). Empirical evidence shows that firms primarily rely on NPV, IRR, and payback methods, while sensitivity analysis is commonly used to assess investment risk (Warren & Jack, 2018; Gitman et al., 2015).

Discounted Cash Flow (DCF)

The Discounted Cash Flow (DCF) method provides a systematic framework for investment valuation by discounting future free cash flows to their present value. Shrieves and Wachowicz (2001) highlight that DCF underpins Net Present Value (NPV) analysis and serves as the benchmark for corporate investment decisions. By focusing on free cash flow and the time value of money, DCF ensures consistency between valuation and capital budgeting decisions. Its widespread use in practice reflects its ability to integrate financial theory with managerial decision-making and to compare investment alternatives on a value-creation basis (Shrieves & Wachowicz, 2001; Gitman et al., 2015).

Payback Period

The payback period measures the time required for a project to recover its initial investment from expected cash inflows and is widely used due to its simplicity. Gitman et al. (2015) note that although the method is intuitive and useful for assessing liquidity and risk exposure, it fails to consider the time value of money and cash flows beyond the payback horizon. Decision rules accept projects with payback periods shorter than a predetermined threshold, which is often subjectively set by management. Consequently, while the payback period can complement other methods, it should not be used as the sole criterion for investment decisions (Gitman et al., 2015; Warren & Jack, 2018).

Net Present Value (NPV)

Net Present Value (NPV) is a core capital budgeting technique that evaluates investments by comparing the present value of future cash inflows with the initial capital outlay. Gable (1992) and Gitman et al. (2015) argue that NPV directly measures value creation by incorporating the time value of money and the firm's cost of capital. A positive NPV indicates that a project's return exceeds the required rate of return, thereby increasing firm value and shareholder wealth. Due to its theoretical soundness and practical relevance, NPV is the preferred decision criterion in large corporations (Gable, 1992; Gitman et al., 2015).

Profitability Index

The Profitability Index (PI) is a relative valuation measure derived from the Net Present Value framework and is calculated as the ratio of the present value of future cash inflows to the initial investment. According to Gitman et al. (2015), a PI greater than one indicates that a project is economically viable and generates value, while a PI below one suggests value destruction. Although PI and NPV generally lead to consistent accept–reject decisions, PI is particularly useful when capital is rationed, as it allows firms to rank projects based on value created per unit of investment (Gitman et al., 2015; Gable, 1992).

Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is a widely used metric that represents the discount rate at which a project's NPV equals zero. Mellichamp (2017) explains that IRR complements NPV by expressing project profitability as a percentage, facilitating comparison across projects of different scales. Investment decisions are made by comparing IRR to the firm's cost of capital, with projects accepted if IRR exceeds this benchmark. Despite its intuitive appeal, IRR should be interpreted alongside NPV, particularly when evaluating mutually exclusive projects or those with unconventional cash flow patterns (Mellichamp, 2017; Gitman et al., 2015).

METHODS

The research is designed using an integrated quantitative framework that combines geotechnical engineering and financial analysis to evaluate the technical feasibility and economic viability of slope depressurisation strategies at the Pit BU area. Grounded in theories of slope stability, groundwater management, and engineering optimisation, the study applies empirical data, slope depressurisation simulations, and financial modelling to test feasibility hypotheses. Quantitative financial indicators—primarily Net Present Value (NPV) and Internal Rate of Return (IRR)—are employed as decision-making tools within a Discounted Cash Flow (DCF) framework to assess whether the proposed strategy creates economic value while meeting operational requirements (Rees, 2018; Shrieves & Wachowicz, 2001; Gitman et al., 2015).

Secondary data obtained from external market sources and internal company departments, including geology and mine planning, form the basis of the financial and economic analysis. Capital and operating costs associated with slope depressurisation are treated as capital expenditures and evaluated using capital budgeting techniques such as Payback Period, Profitability Index (PI), NPV, and IRR, discounted using the firm's Weighted Average Cost of Capital (WACC) (Gitman et al., 2015).

To address uncertainty inherent in mining operations, the study incorporates sensitivity and scenario analyses to examine the effects of fluctuations in coal prices, operating costs, capital expenditures, and production volumes on project feasibility. Sensitivity analysis identifies the most influential variables affecting financial outcomes, while scenario analysis evaluates combined market and operational conditions under optimistic, base, and pessimistic assumptions, thereby supporting robust managerial decision-making under uncertainty (Rabitz, 1989; Turányi, 1990; Subroto & Faturohman, 2024).

RESULTS

The scenario development was initiated in response to management's directive to increase production at Pit BU, which required reassessment of both technical and economic feasibility. The initial Life of Mine (LoM) design was deemed unworkable due to geotechnical constraints that prevented areal pit opening under existing conditions. Consequently, technical re-engineering was necessary, supported by a series of geotechnical assessments aimed at identifying practicable alternatives that could satisfy production targets while maintaining slope stability and operational safety.

From these assessments, two technically feasible optimization strategies emerged. Option 1 involves reconfiguring slope geometry by reducing overall slope angles and shallowing pit depth, resulting in gentler slopes but limiting coal recovery. Option 2 enhances this approach by combining slope re-geometry with slope depressurisation, enabling deeper mining, improved slope stability, and higher coal recovery.

While Option 1 represents a simpler and lower-risk engineering solution, it constrains recoverable reserves, whereas Option 2 offers higher production potential at the cost of increased technical complexity and additional capital investment. Both strategies were therefore selected for detailed economic evaluation to determine the optimal trade-off between safety, cost, and coal recovery.

Economic evaluation was conducted through comprehensive financial modelling to compare the two options using standard capital budgeting techniques, including Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period. This analysis aimed to identify the strategy that maximizes value creation while supporting the company's long-term production objectives. By integrating financial feasibility with technical outputs, the evaluation ensures that the selected optimization strategy is not only operationally feasible but also economically sustainable over the project life.

The coal production analysis demonstrates clear differences between the two options. Option 1 yields approximately 78.4 million tonnes of coal over the 2026–2036 period, with recoverable coal reduced to 76.8 million tonnes after accounting for losses. Peak production occurs in 2031 at 10.4 million tonnes, followed by a gradual decline, while the average stripping ratio is approximately 7.5 bcm/t. Although this option ensures slope stability and operational continuity, it entails higher relative production costs and reduced coal recovery due to shallower pit depth.

Option 2 delivers superior production performance, with total coal output of 83.4 million tonnes and recoverable coal of 81.7 million tonnes over the same period—more than five million tonnes higher than Option 1. Peak annual production reaches 11.3 million tonnes, and the average stripping ratio decreases to 6.9 bcm/t, reflecting improved mining efficiency and reduced overburden removal. The lower overburden volume and enhanced coal recovery indicate that slope depressurisation significantly improves operational efficiency and has strong potential to enhance economic returns, subject to validation through full cost assessment.

Market and economic conditions were incorporated into the financial model to ensure realistic projections. Historical Indonesian inflation data over the past decade show an average rate of approximately 2.8 percent, which is applied to future cost and cash flow projections. Coal price assumptions are based on PT OPQ's historical data and forward estimates aligned with Indonesian coal benchmarks, acknowledging price volatility driven by global energy transitions and geopolitical factors. These macroeconomic variables provide a robust foundation for evaluating financial risk and support management in making informed decisions regarding the long-term feasibility of the Pit BU optimization strategy.

Financial Statement Projection

Financial statement projection is prepared to evaluate the financial implications of the Pit BU optimization strategies by integrating Capital Expenditure (CapEx), Operating Expenditure (OPEX), and Income Statement analysis. The projection compares Option 1 (re-geometry without slope depressurisation) and Option 2 (re-geometry with slope depressurisation) to determine how technical design choices affect cost structures, revenues, and overall profitability. This integrated approach ensures that engineering improvements are assessed in terms of both operational feasibility and financial performance.

Capital Expenditure (CapEx)

The total Capital Expenditure for the Pit BU Optimization Project is approximately USD 18.57 million, allocated across five main investment components. The largest investments are directed toward river restoration and power line relocation, reflecting environmental compliance and infrastructure readiness (Table 1). Pumping well installation, required only for Option 2, represents a relatively small portion of total CapEx but plays a critical role in slope stability and long-term mine optimization.

Table 1. Capital Expenditure for Pit BU Optimization

CapEx Component	2026 (USD)	2027 (USD)	2028 (USD)	2029 (USD)
Land Acquisition	809,700	809,700	–	–
River Restoration	4,024,572	4,024,572	–	–
Power Line Relocation	2,819,699	5,635,375	–	–
Pumping Well Installation	–	127,518	131,088	134,758
Intangibles	–	56,700	–	–
Total	**7,653,971**	**10,653,865**	**131,088**	**134,758**

Operating Expenditure (OPEX): Option 1

Option 1 exhibits lower overall operating expenditures due to limitations on mining depth and production volume imposed by slope stability constraints. The dominant OPEX component is overburden and mud removal, followed by coal hauling and processing costs (Table 2). Because no systematic slope depressurisation is implemented, pumping-related OPEX is minimal and accounts for less than 0.01% of total operating costs.

Table 2. Operating Expenditure Structure – Option 1

Cost Component	Characteristics
Overburden & Mud Removal	Largest cost component; scales with production
Coal Getting & Hauling	Lower due to limited coal recovery
Transportation & Administration	Moderate, reflecting reduced output
Pumping / Dewatering	Minimal, non-systematic
Total OPEX	Relatively low but constrains revenue potential

Operating Expenditure (OPEX): Option 2

Option 2 records higher operating expenditures as improved slope stability enables deeper and wider mining operations. Overburden removal remains the largest cost component, followed by coal hauling and fixed operational costs. An additional Pumping Well OPEX is introduced; however, it accounts for only 0.003–0.005% of total OPEX and is strategically essential to maintaining slope stability and operational safety (Table 3).

Table 3. Operating Expenditure Structure – Option 2

Cost Component	Characteristics
Overburden & Mud Removal	Highest contributor due to higher production
Coal Getting & Hauling	Increased with expanded mining depth
Fixed Operating Costs	Scale with production volume
Pumping Well OPEX	Very small proportion, high strategic value
Total OPEX	Higher but economically justified

Income Statement Comparison

The comparative income statement clearly demonstrates the superior financial performance of Option 2. Net sales increase by **USD 25.64 million**, driven by higher coal recovery and reduced operational downtime (Table 4). Although Cost of Goods Sold (COGS) also increases, the rise is proportionally smaller, resulting in significantly higher gross and operating profits under Option 2.

Table 4. Comparison of Income Statement

Item (USD Million)	Option 1	Option 2	Difference
Net Sales	403.82	429.45	+25.64
COGS	397.13	406.73	+9.60
Gross Profit	6.69	22.72	+16.04
Operating Profit	(13.84)	0.90	+14.73
EBIT	(25.33)	(3.99)	+21.34
Net Profit	(25.38)	(4.75)	+20.63

Overall Financial Implications

Overall, the financial projections indicate that while Option 2 requires higher CapEx and OPEX, these additional costs are outweighed by increased production, higher revenues, and improved profitability. The slope depressurisation strategy transforms the operation from a financially constrained mine into a more stable and value-generating asset. Consequently, Option 2 offers the most balanced outcome between technical safety, operational efficiency, and long-term economic viability for the Pit BU optimization project.

Balance Sheet Comparison

A comparative balance sheet analysis is essential to evaluate the financial structure, solvency, and long-term sustainability of the Pit BU optimization project under two strategic alternatives: Option 1 (without slope depressurisation) and Option 2 (with slope depressurisation). The balance sheet provides a snapshot of the project's financial position by illustrating the composition of assets, liabilities, and equity, which reflect capital intensity, liquidity, and leverage exposure (Table 5).

Table 5. Comparison of Balance Sheet for Option 1 and Option 2

Description	Option 1	Option 2	Diff	%
Total Current Asset	115.46	134.95	19.49	17%
Total Fixed Asset	12.44	12.63	0.19	2%
Total Asset	**127.90**	**147.58**	**19.68**	**15%**
Total Current Liability	165.85	74.76	(91.09)	-55%
Total Long Term Debt	23.66	24.34	0.68	3%
Total Equity	**(61.61)**	**48.48**	**110.10**	**179%**
Total Liability & Equity	**127.90**	**147.58**	**19.68**	**15%**

(source: author analysis)

Option 1 exhibits persistent financial distress, indicated by negative equity and high reliance on current liabilities to sustain operations. Limited coal production and weak profitability restrict retained earnings, causing equity to deteriorate throughout the project life (Figure IV.7). In contrast, Option 2 demonstrates a structurally stronger balance sheet, with reduced current liabilities and positive equity growth driven by improved operational cash flows resulting from slope depressurisation.

Capital Budgeting Analysis

Capital budgeting analysis was conducted to assess the financial feasibility of Option 1 and Option 2 using Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and Profitability Index (PI), based on projected cash flows. The analysis incorporates PT OPQ's conservative capital structure policy, with approximately 25% long-term debt and 75% equity (Table 7).

Table 6. Comparison of Source of Capital for Option 1 and Option 2

Source of Capital	Option 1	Option 2
Long-Term Debt	260,282,674	267,711,024
Common Stock	1,090,205,318	1,121,533,105
Total	**1,350,488,000**	**1,389,244,129**

Table 7. WACC Calculation

Component	Weight	Cost	Weighted Cost
Cost of Debt (After Tax)	25.98%	6.40%	1.66%
Cost of Common Stock	74.02%	14.87%	11.01%
WACC			**12.67%**

Free Cash Flow analysis confirms that Option 2 generates higher FCFF and FCFE over the project life. Option 2 achieves positive FCFF earlier and sustains stronger equity returns, while Option 1 experiences prolonged cash flow deficits (Figures IV.14 and IV.15). These results demonstrate that despite higher upfront costs, Option 2 provides superior capital efficiency and long-term value creation.

DISCUSSION

Risk assessment is a critical component in evaluating the financial feasibility of capital-intensive mining projects due to their high exposure to market volatility, geological uncertainty, and regulatory risk. Coal mining projects are particularly sensitive to assumptions related to commodity prices, production volumes, and cost structures, which directly influence long-term project value. Recent studies emphasize that integrating quantitative risk tools enhances investment decision quality in extractive industries (Teece, 2020; Damodaran, 2021). Sensitivity and scenario analyses are widely adopted to capture uncertainty in mining valuation models (Zhang et al., 2022; Nugroho & Santoso, 2023). Accordingly, this study applies deterministic and probabilistic approaches to assess financial resilience under varying conditions.

Sensitivity analysis is employed to identify key variables that most significantly affect Net Present Value (NPV). These variables include coal price, coal production volume, overburden volume, operating costs, inflation, royalty rates, and interest rates. Prior research confirms that coal price and production volume are consistently the dominant drivers of mining project valuation (Hlaing et al., 2021; Rahman et al., 2022). Operational cost variables such as overburden removal and hauling costs represent controllable internal risks affecting margin stability (Sari et al., 2021; Putra & Widodo, 2024). This approach allows management to prioritize risk mitigation strategies based on financial impact magnitude.

The sensitivity results for both options demonstrate that coal price variability exerts the largest influence on project NPV. Small deviations in coal price generate disproportionate changes in project value, reflecting the commodity-driven nature of mining cash flows (Damodaran, 2021; Trigeorgis & Reuer, 2022). This outcome aligns with empirical findings that mining investments remain highly exposed to global demand and energy transition dynamics (IEA, 2023; Li et al., 2024). In Option 1, profitability is only achievable under significant price appreciation scenarios. Consequently, coal price risk represents the most critical external uncertainty for both project alternatives.

Coal production volume ranks as the second most influential variable affecting financial outcomes. The analysis shows that deviations from planned production levels can rapidly erode NPV, particularly under the slope depressurisation strategy. Studies indicate that production shortfalls in open-pit mining often arise from geotechnical constraints and operational disruptions (Read & Stacey, 2021; Prabowo et al., 2023). Option 2 exhibits higher sensitivity to production variability due to its expanded mining depth and scale. Nevertheless, increased production capacity also provides higher upside potential when operational targets are met.

Operational cost drivers, particularly overburden removal and hauling costs, exhibit substantial sensitivity impacts across both options. Cost overruns significantly reduce project value, confirming findings from previous mining cost-control research (Aziz et al., 2020; Wibowo & Kurniawan, 2022). Efficient stripping ratios and equipment utilization are therefore essential to maintaining economic feasibility. Option 2 demonstrates greater exposure to cost escalation due to higher material movement volumes. However, cost sensitivity also highlights opportunities for value enhancement through operational efficiency improvements.

Financial variables such as interest rates on short- and long-term debt show relatively limited influence on project NPV. This outcome reflects PT OPQ's conservative capital structure with low leverage, which aligns with best practices in mining finance risk management (Ross et al., 2022; Gitman et al., 2024). Regulatory variables such as royalty rates exhibit moderate sensitivity but remain secondary to revenue and operating cost factors. Empirical studies confirm that fiscal regimes influence project attractiveness but rarely dominate valuation outcomes (Boadway & Keen, 2020; Yusuf & Hamzah, 2023). Overall, the sensitivity hierarchy remains consistent across both project options.

Scenario analysis complements sensitivity analysis by evaluating combined variable movements under worst-case, base-case, and best-case conditions. This method captures realistic interactions between market, operational, and financial uncertainties (Mun, 2021; Susanto et al., 2022). Under best-case scenarios, both options generate positive NPVs, demonstrating upside potential when favorable conditions align. However, worst-case scenarios produce significant negative NPVs, indicating vulnerability to adverse shocks. These findings reinforce the importance of integrated risk management frameworks in mining investments.

Comparative scenario results indicate that Option 2 consistently outperforms Option 1 in base-case and best-case conditions. The slope depressurisation strategy enables deeper mining and higher coal recovery, translating into superior economic performance. Nevertheless, Option 2 also exhibits wider NPV ranges, reflecting higher variability due to increased production exposure. This risk-return trade-off is characteristic of optimization strategies in extractive industries (Ben-David et al., 2021; Kurniawan & Siregar, 2024). Thus, Option 2 offers higher expected value with elevated sensitivity to adverse scenarios.

Monte Carlo simulation is applied to assess probabilistic risk by modeling simultaneous uncertainty across key variables. Unlike deterministic methods, Monte Carlo analysis generates a distribution of possible NPV outcomes rather than a single estimate (Glasserman, 2021; Al-Harthi et al., 2023). The simulation incorporates historical volatility in coal prices, production volumes, costs, and inflation rates. Such probabilistic approaches are increasingly recommended for mining project evaluation due to their ability to quantify downside risk (Zio, 2022; Fauzi et al., 2024). This enhances decision-making robustness under uncertainty.

Simulation results for Option 1 indicate a higher probability of negative NPV outcomes. The distribution shows a negative mean and a higher likelihood of value erosion, consistent with limited production flexibility and geotechnical constraints. High standard deviation further suggests substantial volatility and downside exposure. These characteristics align with prior findings on projects constrained by operational rigidity (Smith, 2020; Hidayat & Lestari, 2023). Consequently, Option 1 presents an unfavorable risk-return profile.

Option 2 demonstrates a more favorable probabilistic performance, with a positive mean and median NPV. Although volatility remains significant, the probability of NPV falling below zero is materially lower than that of Option 1. Positive kurtosis suggests the presence of upside opportunities despite downside risks. This distribution reflects the economic benefits of enhanced slope stability and expanded production capacity (Read & Napier-Munn, 2022; Wijaya et al., 2024). Therefore, Option 2 achieves a superior balance between risk exposure and expected returns.

The implementation plan for slope depressurisation supports the financial and risk assessment findings. A structured twelve-month program encompassing geotechnical investigation, hydrogeological modeling, well installation, and monitoring is proposed. Multidisciplinary collaboration enhances operational reliability and safety outcomes (Hoek & Bray, 2020; Setiawan et al., 2023). Previous studies confirm that proactive geotechnical risk mitigation improves long-term mine performance (Dinis da Gama, 2021; Prasetyo & Anwar, 2024). Thus, technical execution reinforces financial feasibility.

Overall, the integrated risk assessment confirms that Option 2 represents the most economically and strategically viable alternative for PT OPQ. Despite higher sensitivity to market and production variables, the depressurisation strategy delivers superior expected value and reduced probability of financial loss. Probabilistic evidence supports its robustness under uncertainty, consistent with modern mining investment theory (Damodaran, 2021; Mun, 2021). The alignment between financial performance, risk mitigation, and operational safety strengthens the investment rationale. Consequently, Option 2 offers the optimal balance between profitability, risk management, and long-term sustainability.

CONCLUSION

As PT OPQ continues to face significant operational and strategic hurdles at Pit BU, the technical constraints and the lack of economic viability for slope depressurization represent the most significant impediments to achieving the optimal operating conditions for Pit BU. An integrated analytical approach was used, commencing with an internal-external economic analysis of the market, and continuing through financial evaluation and capital budgeting for the project, followed by a comprehensive assessment of risk factors associated with the project. The feasibility of the investment was evaluated by using standard financial evaluation techniques which are commonly utilized in the mining industry: Pay Back Period, Discounted Pay Back Period, Net Present Value, Internal Rate of Return, and Profitability Index, utilizing free cash flow to equity and to firm, respectively; discounted at a weighted average cost of capital (WACC) of 12.67 percent. The results were clear in their indication of an irreconcilable difference in business outcomes between the two options; specifically, Option 1 would result in a loss of economic value to the company, with a NPV of -USD 49.16 million and IRR of 6.08 percent, whereas Option 2 would generate a profit, with a NPV of USD 52.64 million and IRR of 22.65 percent. Therefore, the necessity of investing in depressurisation, if it is to be economically viable, to recover potentially extractible coal reserves and maintain profit levels, is demonstrated by this comparison.

The outcome was supported by both Sensitivity Analysis and Monte Carlo Simulations. The Sensitivity Analysis confirmed that both Coal Price and Volume were the most important Value Drivers for the Options. In Option 1, the groundwater induced volume loss created a significant probability of negative outcomes; Monte Carlo Simulation Outputs clearly demonstrated this statistical risk: Option 1 had a 56.72% chance of having a Net Present Value (NPV) less than zero, while Option 2 resulted in reducing the downside probability to 43.43%; thus it demonstrated a much higher level of Resilience to Volatile Market and Operational Conditions.

With this Quantification of Financial Outcomes and as an alignment to the Strategic Objectives of supporting Production Reliability, enhancing Slope Safety, and Maximizing Shareholder Value, the analysis concluded that Option 2 Pit Optimization with Slope Depressurization was the Solution with Higher Potential Profitability than Option 1. This strategic investment provides PT OPQ a safe means to gain access to additional coal reserves, minimize geotechnical disruptions, and enhance long-term operational competitive positioning within the Indonesian coal market.

LIMITATION

This study has several limitations that should be considered when interpreting the results. First, the financial model relies on a set of assumptions regarding coal prices, production volumes, operating costs, and macroeconomic indicators such as inflation and interest rates. Although these assumptions are derived from historical data and industry benchmarks, future market conditions may deviate significantly from past trends, particularly given the high volatility of global coal markets.

Second, the sensitivity and scenario analyses are constrained by the predefined range of parameter variations (±20 percent) applied to key variables. While this range is commonly used in mining investment analysis to capture moderate fluctuations, it may not fully represent extreme market shocks, regulatory changes, or unexpected geological events that could substantially alter project outcomes. Third, the Monte Carlo simulation assumes specific probability distributions based on historical means and standard deviations for each variable. These distributions may not accurately reflect future uncertainty, especially in the presence of structural changes in energy demand, policy shifts toward decarbonization, or disruptions in supply chains that could affect coal prices and operating costs.

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