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# Financial Assessment of Potential Carbon Pricing Policy and Energy Transition Scenarios in Indonesia's Nickel HPAL Project

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## Abstract

Indonesia's mandate to achieve Net Zero Emissions (NZE) by 2060 exerts unprecedented pressure on energy-intensive mineral processing sectors to decarbonize while maintaining economic viability. While the macro-level implications of carbon policies are well documented, project-level financial responses to the simultaneous imposition of domestic carbon pricing (Nilai Ekonomi Karbon - NEK), the EU's Carbon Border Adjustment Mechanism (CBAM), and renewable energy transition pathways remain underexplored. This study quantifies the financial resilience and risk profiles of a representative large-scale state-owned High-Pressure Acid Leach (HPAL) nickel project in Eastern Indonesia under diverse policy trajectories. A 20-year scenario-based Discounted Cash Flow (DCF) model was developed (WACC = 14.89%) and integrated with Monte Carlo simulations to evaluate four configurations: (1) a gas-powered baseline; (2) gas subject to NEK; (3) gas subject to both NEK and CBAM; and (4) a solar-powered configuration incorporating NEK, CBAM, and a 10% carbon-offset allocation. Results demonstrate that while dual carbon-pricing regimes significantly compress project margins, transitioning to solar-powered operations curtails cumulative emissions and hedges against long-term regulatory volatility. Sensitivity analysis identifies nickel pricing, sales volume, and input costs as the primary determinants of valuation. Monte Carlo simulations reveal that the renewable configuration yields a more concentrated Net Present Value (NPV) distribution, indicating enhanced resilience amid extreme policy and price uncertainty. Ultimately, the project maintains financial viability across all scenarios, though performance depends on the architecture of international carbon regimes and energy procurement strategies. This research internalizes carbon-policy uncertainty into project-level capital budgeting, providing a framework for navigating the decarbonization of critical mineral value chains.

**Keywords:** Nickel HPAL, Carbon Pricing, NEK, CBAM, Renewable Energy, Financial Feasibility.

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## A. INTRODUCTION

Indonesia's commitment to achieving Net Zero Emissions (NZE) by 2060 positions the mining and metallurgical sectors, specifically nickel processing, at the vanguard of the national decarbonization agenda. As the global leader in nickel production and a vital node in the electric vehicle (EV) battery value chain, Indonesia faces intensifying pressure to maintain downstream competitiveness while simultaneously curtailing emission intensity (IEA, 2025; OECD, 2022). This transition entails profound regulatory and market risks, encompassing renewable energy mandates, domestic carbon pricing, and emerging international border-adjustment mechanisms.

From a financial standpoint, investment decisions in carbon-exposed industries must internalize not only anticipated cash flows but also policy-driven uncertainties and external cost exposures. Grounded in capital budgeting and risk-adjusted valuation theory (Brealey et al., 2019; Gittman & Zutter, 2020), regulatory interventions recalibrate both risk premiums and cash-flow architectures by introducing novel cost components—such as carbon taxes, emission fees, or compliance obligations—that necessitate rigorous integration into project appraisals. The Discounted Cash Flow (DCF) method, augmented by scenario and sensitivity analyses, offers a systematic framework for evaluating these effects, while the Weighted Average Cost of Capital (WACC) encapsulates the risk profile inherent in dynamic policy transitions (Damodaran, 2012).

The significance of regulatory signals has been extensively explored within environmental economics. The Porter Hypothesis posits that environmental regulations, while initially capital-intensive, can catalyze efficiency-enhancing innovations that bolster long-term competitiveness (Porter & Van Der Linde, 1995). This is particularly salient for resource-intensive industries in developing nations striving to align

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industrial expansion with sustainability objectives (UNCTAD, 2023). Indonesia's evolving Carbon Economic Value (Nilai Ekonomi Karbon—NEK) and the European Union's Carbon Border Adjustment Mechanism (CBAM) represent policy instruments capable of fundamentally reshaping corporate energy strategies, cost structures, and global market access. Concurrently, renewable energy transition initiatives seek to decouple industrial operations from fossil-fuel dependence, thereby influencing both operational expenditures and emission trajectories.

Empirical scholarship on carbon pricing and metallurgical operations offers further depth. (Abrell and Kosch, 2021) observe that while carbon-intensive sectors may suffer short-term margin compression, they potentially derive competitiveness gains through strategic adaptation. (Kamandika and Dhakal, 2023) demonstrate that integrating renewable energy improves financial resilience for metal extraction activities. Furthermore, (Manzoor et al., 2025) highlight that renewable-powered HPAL operations in the Asia-Pacific region exhibit lower emission intensities and reduced exposure to fossil-fuel price volatility, notwithstanding higher initial capital requirements. Despite these insights, a scholarly lacuna persists regarding how domestic NEK policies, international CBAM exposure, and renewable energy transitions synergistically influence the financial feasibility of HPAL projects in Indonesia.

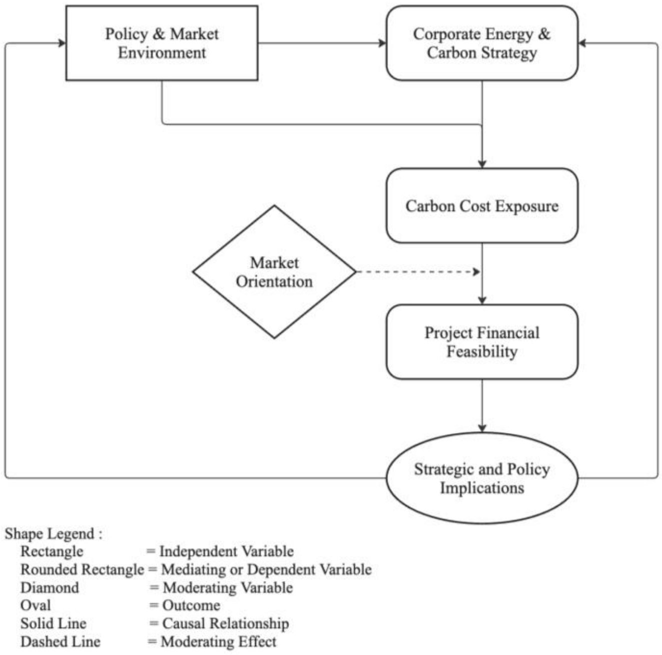


**Figure 1. Conceptual Framework of Carbon Policy, Energy Strategy, and HPAL Project Feasibility**

Source: Research data, 2025

Given the capital intensity of HPAL technology and Indonesia's strategic position in the global EV supply chain, a project-level assessment integrating carbon policy risks, energy transition pathways, and financial valuation remains conspicuously absent from the literature. This gap is increasingly critical for major state-owned enterprises (SOEs), whose downstream investments are uniquely susceptible to both domestic policy shifts and international trade regulations. To elucidate these relationships, the analytical foundation of this research is summarized in Figure 1. The framework illustrates the causal links between policy environments, corporate energy strategies, carbon-cost exposure, and ultimately, project-level financial feasibility.

Accordingly, this study evaluates the financial and strategic impacts of prospective carbon-pricing policies and renewable energy transitions on a representative large-scale HPAL project managed by a leading Indonesian SOE in a strategic industrial zone in Eastern Indonesia. Using a 20-year scenario-based DCF model, the research assesses four configurations that reflect varying energy sources and carbon policy exposures. This study contributes to the literature by merging capital budgeting techniques with industrial decarbonization frameworks, providing a seminal project-level analysis of how NEK, CBAM, and renewable energy pathways jointly dictate investment feasibility in Indonesia's downstream nickel sector.

## B. METHODS

The primary objective of this study is to evaluate the financial viability of a nickel High-Pressure Acid Leach (HPAL) project under diverse configurations of carbon-pricing policies and energy-transition pathways. The research employs a quantitative, scenario-based financial modeling framework that integrates Discounted Cash Flow (DCF) analysis with rigorous sensitivity and risk assessments over a 20-year operational horizon. The methodology is structured into four distinct components: research design, data and model inputs, scenario and risk modeling, and model validation.

### *Research Design and Approach*

The analytical framework is grounded in capital budgeting theory, utilizing the DCF method as the primary valuation instrument. This approach facilitates the determination of the project's intrinsic value by projecting future cash flows and discounting them at a risk-adjusted cost of capital. The model architecture encompasses three analytical tiers:

1. Deterministic Financial Modeling: Establishes baseline values for Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period for each fixed scenario.
2. Sensitivity Analysis: Quantifies the responsiveness of project valuation to fluctuations in key parameters.
3. Monte Carlo Simulation: Evaluates probabilistic uncertainty and the likelihood distribution of financial outcomes.

This multi-tiered approach ensures a robust ex-ante feasibility analysis and post-robustness validation amidst uncertainties in carbon and energy policy.

### *Data and Model Inputs*

The model utilizes secondary data categorized into four essential areas:

1. Technical and Operational Parameters: Plant capacity, ore grade, metal recovery, and mass-energy balances are derived from large-scale HPAL benchmark studies and industry reports for laterite operations in the Asia-Pacific region.
2. Cost and Financial Parameters: Capital and operating cost benchmarks are sourced from published HPAL project data and cost-engineering references. Operating expenditures (OPEX) encompass energy, reagents, labor, maintenance, and overhead. The capital structure, tax rates, and inflation assumptions align with Indonesian market practices.
3. Emission Factors: Emission intensities for gas-fired power, thermal energy, and reagents are sourced from IEA and IPCC guidelines, supplemented by life-cycle assessment (LCA) datasets such as EcoInvent. Solar PV intensity is based on established LCA studies.
4. Carbon-Policy Parameters: Domestic carbon prices follow the Nilai Ekonomi Karbon (NEK) roadmap outlined in Presidential Regulation No. 98/2021. CBAM price trajectories and voluntary offset assumptions are based on European Commission regulations and global market standards, respectively.

Key numerical assumptions and data sources are summarized in Table 1.

**Table 1. Summary of Key Model Assumptions and Data Sources**

| Category | Parameter | Value / Range | Source / Basis |
|---|---|---|---|
| Production | Total Ni production | 55,000 t Ni/year | Industrial HPAL benchmark (Antam, 2025; Nickel Institute, 2025) |
| | Ni content in MHP | 40% | Industry average for HPAL MHP |
| | Ore Ni grade | 1.20% | Limonitic feed benchmark for East Halmahera |
| | Ni recovery | 90% | Peer HPAL performance (Manzoor et al., 2025; Peh, 2024) |
| Energy & Reagents | Electricity use | $5.09\times10^{8}$ kWh/year | Mass-energy balance calculation |
| | Thermal energy | $8.66\times10^{6}$ GJ/year | Mass-energy balance calculation |
| | Acid, lime, NaOH, other chemicals | As per the HPAL intensity table | HPAL design and EcoInvent factors |
| Emissions | PLTG EF | 0.45 $tCO_2e$/MWh | (IEA, 2025; IPCC, 2019) |
| | Solar PV EF | 0.05 $tCO_2e$/MWh | (NREL, 2012) |

| Category | Parameter | Value / Range | Source / Basis |
|---|---|---|---|
| | $H_2SO_4$ EF | 0.20 $tCO_2e/t$ | (Ecoinvent, 2023) |
| | Lime EF | 0.75 $tCO_2e/t$ CaO | (IPCC, 2019) |
| Carbon Policy | NEK tariff | 3.5 to 8.5 $USD/tCO_2e$ (2025-2045) | (Directorate General of Taxes, 2023; International Carbon Action Partnership, 2024) |
| | CBAM tariff | 93.5 to 132 $USD/tCO_2e$ | (European Commission (DG TAXUD), 2023) |
| | Voluntary offsets | 2.5-8 $USD/tCO_2e$; 10% of emissions | (Bursa Efek Indonesia, 2023; International Carbon Action Partnership, 2024; PwC Indonesia, 2024) |
| Financial | Capital structure | 30% debt, 70% equity | Derived from ANTAM DER and sector norms |
| | WACC | 14.89% | CAPM-based computation (Aswath Damodaran, 2012; Damodaran, 2003, 2025) |
| | Tax rate | 22% | Indonesian income tax law |
| Investment | Total CAPEX for S1-S3 | USD 1.96 billion | Sum of process lines, acid plant, PLTG, infra, FEED, contingency, intangibles |
| | Total CAPEX for S4 | USD 2.35 billion | 210 MW PV and 420 MW BESS at 1,000 and 500 USD/kW |

Source: Research data, 2025

***Cost of Capital Determination***

The project discount rate is aligned with the WACC, reflecting the weighted proportions of debt and equity. Following (Damodaran, 2012), the cost of equity ($r_e$) was calculated using the Capital Asset Pricing Model (CAPM):

$$r_e = r_f + \beta(ERP + CRP)$$

Where $r_f$ denotes the risk-free rate (10-year Indonesian government bond yield), β represents project-specific systematic risk, ERP is the equity risk premium, and CRP is the country risk premium. The cost of debt (r_d) was adjusted for the after-tax effect: r_d(1-T). Based on these inputs, the project WACC was estimated at 14.89%, which reflects moderate leverage (30:70 debt-to-equity ratio) and emerging-market risk conditions.

***Scenario Development***

Four scenarios reflect plausible combinations of policy exposure and energy strategies:

1. Scenario 1 (Gas Baseline): A conventional configuration utilizing a captive gas-fired power plant without carbon internalisation. Gas is treated as a transition fuel in line with regional power-system plans.
2. Scenario 2 (Gas + NEK): Applies the Indonesian NEK framework to the baseline, following sector-specific carbon price trajectories.
3. Scenario 3 (Gas + NEK + CBAM): Integrates EU CBAM exposure on exports to Europe alongside domestic NEK pricing.
4. Scenario 4 (Solar + NEK + CBAM + Offsets): Explores a renewable configuration where electricity demand is met by solar power with storage, complemented by a 10% allocation of verified carbon offsets.

***Scenario and Risk Modeling***

The DCF model calculates annual Free Cash Flow to the Firm (FCFF) by integrating revenues, operating costs, carbon-related expenditures, and capital adjustments 44. Financial feasibility is assessed by comparing NPV and IRR against the WACC benchmark45. Uncertainty is analyzed through a two-stage process: a one-at-a-time sensitivity analysis varying key drivers by $\pm 20\%$ 46, followed by a Monte Carlo simulation with 3,000 iterations47. Stochastic variables are assigned probability distributions (lognormal for prices/costs, beta-PERT for production and carbon trajectories, and normal for interest rates) to compare expected value and downside risk48.

***Model Validation***

Methodological robustness is ensured through three validation steps: cross-checking parameter values against reputable sources, benchmarking the resulting cost structures and returns against comparable regional HPAL projects, and performing internal consistency checks to ensure that policy changes yield logically coherent outcomes.

## C. RESULTS AND DISCUSSION

### *Financial Outcomes under Different Policy and Energy Scenarios*

The scenario-based financial analysis elucidates how varied energy configurations and carbon-pricing exposures influence project valuation and emission profiles. The core financial and environmental indicators are summarized in Table 1. Under the conventional gas-powered baseline without carbon internalisation (Scenario 1), the project yields a Net Present Value (NPV) of USD 332.76 million and an Internal Rate of Return (IRR) of 18.90%, notably exceeding the 14.89% WACC3. The total Capital Expenditure (CAPEX) for this baseline is USD 1.95 billion, with operating costs (OPEX) averaging USD 13,541 per ton of Ni4. Cumulative 20-year emissions reach 14.40 million $tCO_2e$, reflecting an intensity of 16.53 $tCO_2$ per ton of Ni, though no explicit carbon costs are incurred in this state.

**Table 2. Summary of Financial and Environmental Results across Scenarios**

| Indicator | Unit | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|
| Energy Source | - | Gas | Gas | Gas | Solar |
| Policy Context | - | No carbon policy | NEK | NEK, CBAM | NEK, CBAM, Offset |
| Total Emission | $MtCO_2e$ | 14.40 | 14.40 | 14.40 | 12.46 |
| Emission Intensity | $tCO_2$/t Ni | 16.53 | 16.53 | 16.53 | 14.30 |
| Total Carbon Cost | USD million | 0.00 | 89.73 | 937.80 | 810.61 |
| Carbon Cost per Unit | USD/t Ni | 0.00 | 102.96 | 1,076.07 | 930.13 |
| Total CAPEX | USD billion | 1.95 | 1.95 | 1.95 | 2.35 |
| OPEX per Unit | USD/t Ni | 13,541 | 13,644 | 14,617 | 14,044 |
| NPV | USD million | 332.76 | 316.43 | 154.60 | 154.49 |
| IRR | - | 18.90% | 18.72% | 16.84% | 16.43% |
| PI | - | 1.38 | 1.36 | 1.17 | 1.14 |
| Payback | - | 7 Year 12 Months | 7 Year 12 Months | 8 Year 7 Months | 8 Year 7 Months |
| DPP | - | 13 Year 12 Months | 14 Year 3 Months | 17 Year 8 Months | 19 Year 1 Months |

Source: Author's calculation based on DCF simulation, 2025

The introduction of the domestic Nilai Ekonomi Karbon (NEK) in Scenario 2 marginalizes the economic buffer, though the project remains feasible. NPV declines slightly to USD 316.43 million, while the total lifetime carbon cost amounts to USD 89.73 million (approximately USD 103 per ton of Ni)8. Because NEK tariffs are implemented progressively at levels lower than international benchmarks, domestic pricing alone does not jeopardize project viability. Scenario 3 represents a significant inflection point, where the combination of NEK and CBAM exposure on European exports markedly compresses profitability. In this scenario, NPV falls to USD 154.60 million and IRR to 16.84%, while cumulative carbon costs escalate to USD 937.80 million—a tenfold increase over Scenario 2. While the project remains marginally attractive, its valuation becomes highly sensitive to international carbon price trajectories and export volumes.

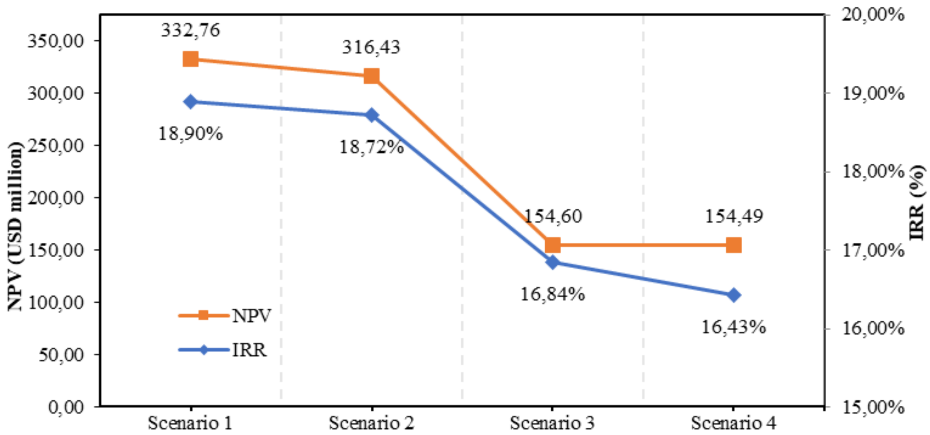


**Figure 1. Comparative NPV and IRR under Different Policy-Energy Scenarios**
Source: Author's Computation, 2025

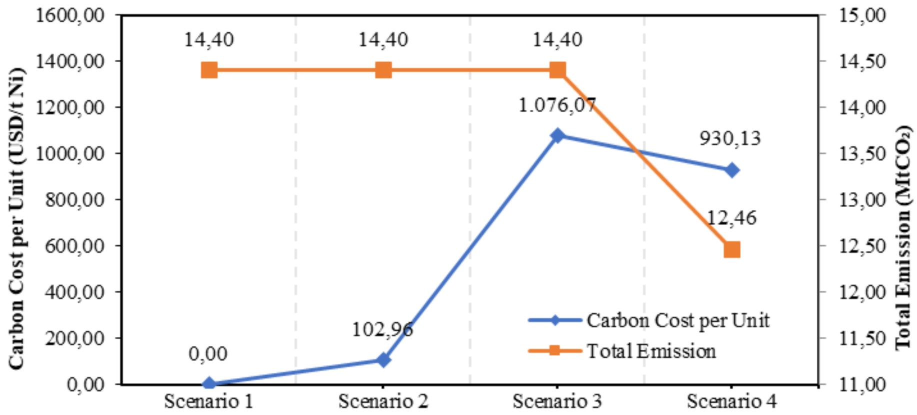


**Figure 2. Relationship between Carbon Cost and Total Emissions by Scenario**
Source: Author's Computation, 2025

The renewable-centric configuration in Scenario 4, which uses solar generation alongside NEK, CBAM, and a 10% offset allocation, requires an initial investment of approximately USD 2.35 billion (20.66% above the baseline). Despite higher CAPEX, the NPV remains resilient at USD 154.49 million with an IRR of 16.43%14. The primary advantage is environmental: cumulative emissions drop to 12.46 million $tCO_2e$ (a 13.45% reduction), and total carbon costs decrease to USD 810.61 million compared to the gas-based CBAM scenario. Figures 1 and 2 elucidate the fundamental trade-off: more stringent carbon policies and cleaner energy configurations entail higher capital outlays and lower deterministic NPV, but they also mitigate cumulative emissions and exposure to carbon-related costs. These findings align with (Abrell and Kosch, 2021; Kamandika and Dhakal, 2023), suggesting that while carbon pricing may dampen short-term returns, it catalyzes carbon-efficient innovations that are balanced with long-term economic interests. Ultimately, the renewable transition provides a strategically sensible equilibrium between sustainability and financial performance. Although Scenario 4 exhibits NPV and IRR reductions of 53.57% and 13.05%, respectively, compared to the baseline, it achieves a 13.56% reduction in carbon-cost exposure compared to Scenario 3. Improved ESG positioning facilitates deeper integration into CBAM-sensitive markets and allows the project to lead in "green" nickel exports20. Furthermore, using renewable energy and verified offsets stabilizes cash flows against the volatility of future carbon pricing regimes.

***Risk And Sensitivity Assessment***

The project's financial resilience is evaluated through a comprehensive assessment of risks and uncertainties across economic, operational, and strategic dimensions. This analysis utilizes a dual-methodological approach: deterministic Net Present Value (NPV) sensitivity testing and probabilistic Monte Carlo simulations to quantify how fluctuations in key variables influence the project's intrinsic economic value.

*Deterministic Sensitivity Analysis*

Sensitivity analysis reveals that the Mixed Hydroxide Precipitate (MHP) selling price, direct material costs, and production volume constitute the primary determinants of valuation. These factors have the greatest impact on NPV within a ±20% deviation range. For both gas and solar configurations, price realization per unit accounts for approximately 68% of the total NPV variance, followed by material costs (23%) and sales volume (9%). Conversely, fluctuations in labor costs, energy prices, and interest rates produce negligible effects on NPV, with a total deviation estimate of less than 1%. This suggests that the project's financial performance is more contingent upon global market conditions than internal operational cost variations.

**Table 3. Sensitivity of NPV to Key Input Variables**

| Input Variable | Swing Range | Gas | | Solar | | Rank |
|---|---|---|---|---|---|---|
| | | Swing (USD m) | Contribution (%) | Swing (USD m) | Contribution (%) | |
| Price per Unit Realization | 80-120% | 1,263.67 | 67.9 | 1,298.45 | 67.3 | 1 |
| Direct Material Cost Realization | 120-80% | 727.00 | 22.5 | 758.23 | 23.0 | 2 |

| Input Variable | Swing Range | Gas | | Solar | | |
|---|---|---|---|---|---|---|
| | | Swing (USD m) | Contribution (%) | Swing (USD m) | Contribution (%) | Rank |
| Quantity Sold Realization | 80-120% | 447.42 | 8.5 | 471.72 | 8.9 | 3 |
| Direct Labor Cost Realization | 120-80% | 119.60 | 0.6 | 121.80 | 0.6 | 4 |
| Energy & Utilities Cost Realization | 120-80% | 105.84 | 0.5 | 77.96 | 0.2 | 5 |
| Long-Term Debt Interest Rate | 12-8% | 1.07 | 0.0 | 1.34 | 0.0 | 6 |

Source: Author's Computation, 2025

The Tornado charts in Figure 3 illustrate the proportional effect of each variable. While both configurations exhibit identical sensitivity hierarchies, the solar-based model shows a markedly narrower swing for energy and utility costs. This confirms that integrating renewables effectively hedges the project against the price volatility of fossil fuels. A ±10% fluctuation in the MHP price results in an approximately ±9% variation in project NPV, reinforcing the high sensitivity to commodity market cycles.

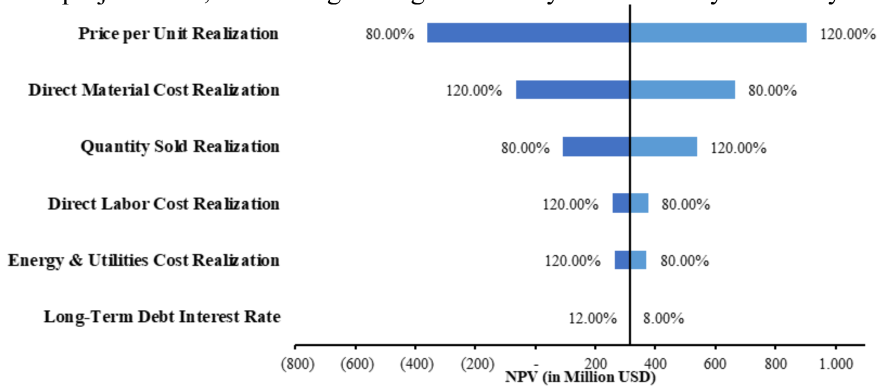


**Figure 3. Tornado Chart of NPV Sensitivity for Gas Scenario**
Source: Research Data, 2025

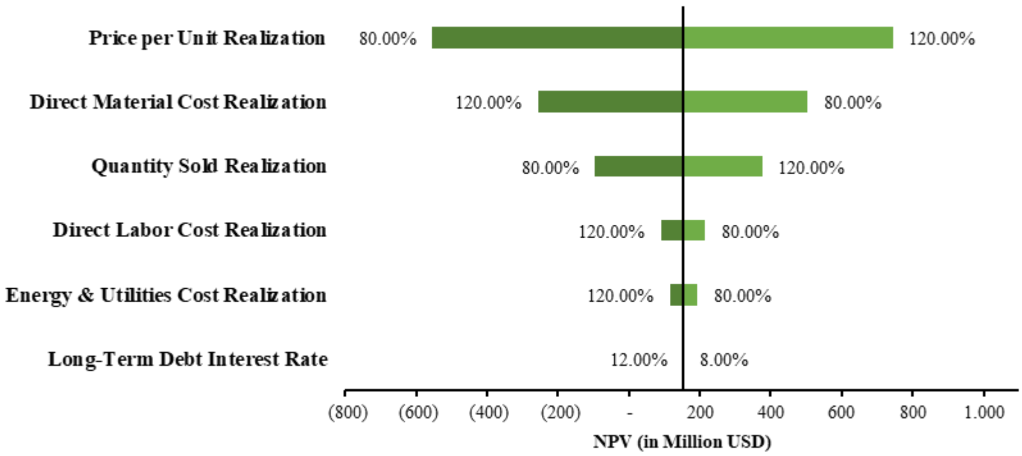


**Figure 4. Tornado Chart of NPV Sensitivity for Solar Scenario**
Source: Research Data, 2025

*Monte Carlo Simulation and Probabilistic Risk*

To further evaluate resilience under extreme uncertainty, Monte Carlo simulations with 3,000 iterations were conducted using the probability distributions detailed in Table 3.

**Table 4. Probability Distributions for Monte Carlo Simulation**

| Variable | Distribution | Description |
|---|---|---|
| Quantity Sold Realization (%) | Beta-PERT | Bounded production variability |
| Price per Unit Realization (%) | Lognormal | Asymmetric commodity price fluctuations |
| Direct Material Cost Realization (%) | Lognormal | Inflation and input cost risk |
| Direct Labor Cost Realization (%) | Lognormal | Wage and productivity variation |
| Energy & Utilities Cost Realization (%) | Lognormal | Uncertainty in fuel and electricity prices |

| | | |
|---|---|---|
| Long-Term Debt Interest Rate (%) | Normal | Symmetric variation around the policy rate |
| NEK-CBAM Tariff Realization (%) | Beta-PERT | Carbon tax parity progression |
| Offsets to CBAM Tariff Realization (%) | Beta-PERT | Value of offset credits |

Source: Research Data, 2025

The simulation outcomes, presented in Figure 5 and Table 5, highlight the divergent risk profiles of the gas and solar configurations.

**Table 5. Summary Statistics of NPV Distributions**

| Parameter | Gas Scenario | Solar Scenario |
|---|---|---|
| Minimum (USD m) | -15,757.06 | -23,201.75 |
| Maximum (USD m) | 31,802.96 | 20,975.32 |
| Mean (USD m) | 1,355.58 | 1,119.90 |
| Standard Deviation (USD m) | 4,557.27 | 4,443.98 |
| Skewness | 1.13 | 0.00 |
| Kurtosis | 4.15 | 2.81 |
| Probability (NPV < 0) | 38.31% | 40.05% |
| Probability (NPV < 332.76 baseline) | 41.12% | 42.97% |

Source: Research Data, 2025

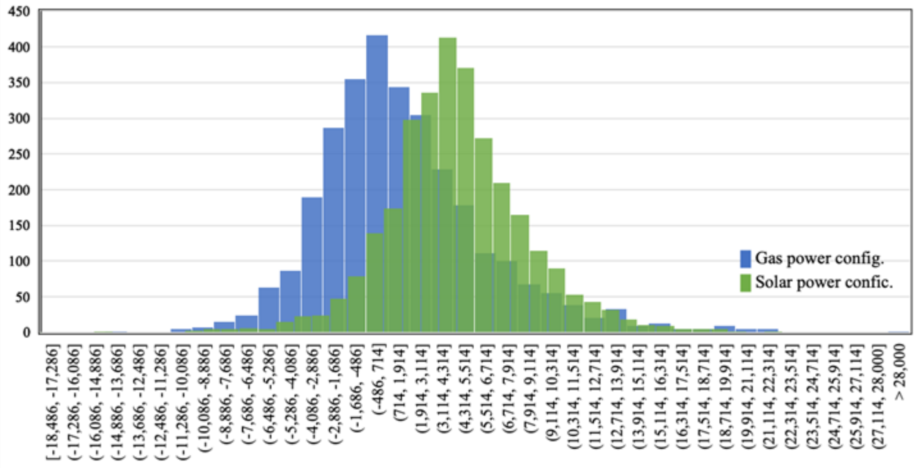


**Figure 5. Probability Distribution of NPV for Gas and Solar Configurations**

Source: Research Data, 2025

The gas-powered configuration exhibits a right-skewed distribution (skewness=1.13), indicating higher upside potential in favorable market conditions but significantly greater volatility. In contrast, the solar-powered configuration demonstrates a more symmetrical and concentrated distribution, reflecting enhanced price stability and a reduced exposure to carbon-price shocks. The probability of achieving a non-negative NPV is approximately 61.69% for gas and 59.95% for solar. These results align with (Manzoor et al., 2025), who demonstrated that while renewable systems require higher capital intensity, they yield positive NPV outcomes and serve as a vital hedge against carbon-cost volatility. Ultimately, the transition to renewables improves the project's value equilibrium, trading off excessive upside volatility for long-term strategic stability.

### *Discussion*

The scenario-based results and risk assessments provide critical insights into how carbon pricing and energy transitions dictate the economics of nickel HPAL projects within an emerging-market context.

#### *Comparison with Extant Literature*

The findings of this study demonstrate that project returns diminish as carbon prices are internalized, a result consistent with (Abrell and Kosch, 2021), who observed that energy-intensive sectors face margin compression despite regulatory support schemes. The observed transition from a gas baseline to more stringent carbon regimes reflects a progressive erosion of Net Present Value (NPV) and Internal Rate of Return (IRR), reinforcing the conclusion that strict carbon policies reconfigure the distribution of returns rather than automatically precipitating project exit.

Furthermore, identifying renewable energy as a strategic risk-mitigation tool aligns with (Kamandika and Dhakal, 2023), who argue that low-carbon power helps preserve financial performance amid rising carbon and fuel costs. While the solar-based configuration necessitates higher upfront capital expenditure (CAPEX), it effectively hedges against long-term policy-driven carbon risks. These results also complement recent HPAL-specific analyses in the Asia-Pacific region, such as those by (Manzoor et al., 2025), which document that renewable-powered facilities are less emission-intensive but are more capital-intensive.

*Theoretical Implications*

From a theoretical perspective, this research integrates carbon-policy uncertainty into project-finance risk assessments, treating climate policy as a systematic risk factor. First, Internalization of Costs: Carbon expenditures are treated as policy-driven cash outflows within a standard Discounted Cash Flow (DCF) framework, rather than external factors. Second, Porter Hypothesis: The findings provide a nuanced reading of the Porter Hypothesis. While regulation initially imposes costs, technological reconfiguration toward cleaner energy portfolios fosters more resilient and sustainable cash-flow trajectories, supporting a "weak" form of the hypothesis.

*Managerial and Policy Implications*

For project sponsors and managers within the nickel value chain, three practical implications emerge:

1. Investment Appraisal: Carbon pricing (NEK and CBAM) must be explicitly embedded in financial models to avoid overstating valuation and understating downside risks.
2. Energy as a Financial Lever: Energy strategy has evolved into a core financial decision; transitioning to renewables stabilizes the NPV distribution, which is increasingly attractive to risk-averse financiers and state-owned entities.
3. Strategic Offsetting: While verified carbon offsets can mitigate residual exposure, their financial impact remains secondary to core market variables such as commodity pricing and energy configuration.

For policymakers, the analysis suggests that well-sequenced carbon-pricing schemes and renewable incentives can steer industrial investments toward decarbonization without compromising financial bankability. Clear signaling and support mechanisms for industrial renewables will be essential to align project-level capital budgeting with the national Net Zero Emissions (NZE) 2060 roadmap.

## D. CONCLUSIONS

This research evaluated the financial viability of a representative large-scale state-owned High-Pressure Acid Leach (HPAL) project within the shifting frameworks of carbon pricing and energy transition in Indonesia. The results indicate that while the internalization of carbon pricing and the adoption of renewable energy options decrease the project's Net Present Value (NPV) in the immediate term, they enhance both the environmental and economic viability over the long horizon. Crucially, the project remains financially viable across all scenarios tested. The analysis highlights a distinct trade-off between configurations: 1) The gas-powered baseline yields the highest deterministic NPV and Internal Rate of Return (IRR) but is associated with the highest cumulative emissions and zero explicit carbon-cost internalization; 2) The solar-powered configuration, while requiring a higher initial investment and yielding a lower deterministic NPV, significantly curtails lifetime emissions and carbon costs. 3) Moreover, the renewable configuration produces a narrower NPV distribution, indicating more stable financial outcomes under conditions of carbon-price uncertainty.

***Policy Recommendations***

For policymakers, this study suggests that Indonesia's downstream nickel decarbonization agenda can be pursued without rendering strategic HPAL investments unbankable, provided that policy instruments are sequenced and coordinated. First, the gradual implementation of NEK, transparent signaling of CBAM expectations, and targeted incentives for industrial renewable power can steer projects toward lower-carbon configurations while maintaining positive NPV. Second, the role of offsets in the model indicates that credible carbon-market infrastructure and robust standards are necessary to ensure that offsets complement, rather than substitute for, structural emission reductions.

***Research Limitations and Future Work***

This analysis focused on a single HPAL project and relied on secondary data and stylized assumptions for Scope 1 emissions under a fixed capital structure. Future research could extend this framework to: 1) Portfolio-level optimization for state-owned mining groups; 2) Incorporation of Scope 2 and 3 emissions and supply-chain effects; 3) Testing of alternative financing schemes such as green bonds, blended finance, or Islamic financial instruments; and 4) Evaluation of different technology pathways and market-share strategies to identify the most robust routes toward low-carbon nickel production in Indonesia.

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