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Discounted Cash Flow Analysis and Real Options Valuation: A Case Study of Downstream Nickel Processing Investments in Indonesia

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ABSTRACT

This research evaluates the feasibility of processing nickel ore and refining it into nickel sulfate, while also assessing the potential for expansion into the production of battery precursor materials. The objective of this research is to provide a more comprehensive investment assessment framework by combining DCF and ROV for nickel down streaming projects, so that the results not only evaluate basic feasibility but also highlight the strategic value of managerial flexibility in dealing with uncertainty. The analysis employed a Discounted Cash Flow (DCF) approach for the base scenario, followed by Real Option Valuation (ROV) to capture the option value of the expansion. The DCF analysis results show a positive Net Present Value (NPV) of USD 1,164 million with an Internal Rate of Return (IRR) of 16.41%. Sensitivity analysis identifies nickel price, capital expenditure (CAPEX), and total resource availability as the most critical parameters affecting the project's value. The novelty of this study lies in the application of ROV in the context of nickel mineral down streaming in Indonesia, which remains rarely explored in the literature compared to other energy sectors such as geothermal or hydropower. The contribution of this research is expanding the literature on the use of real options in the mining industry academically and offers a reference for investors, companies, and regulators to understand the strategic opportunities and risks of investing in nickel processing amid the growing global demand for electric vehicles practically.

INTRODUCTION

The urgency of climate action is driving a significant reconfiguration of the world's energy systems, as the transition to low emission technologies is now universally recognized as a global imperative (Fragkos et al., 2021; Kabeyi & Olanrewaju, 2022; Slameršak et al., 2022; Yuan & Cai, 2021). Central to this transition is the exponential rise in electric vehicle (EV) deployment, which constitutes a key element in transport decarbonization. A growing number of countries have announced the targets of phase out for internal combustion engine vehicles and introduced aggressive policies to accelerate EV penetration in pursuit of the Paris Agreement goal of limiting global warming below 2 °C by 2050 (Adamashvili & Thrassou, 2024; Hakam & Jumayla, 2024; Huo et al., 2024; Setiawan et al., 2025). This trend has consequently triggered an unprecedented surge in demand for lithium-ion (Li-ion) batteries, the core of EV technology (Ding et al., 2019; Ralls et al., 2023; C. Xu et al., 2020).

Nickel is of high strategic importance as a feedstock for cathode materials in high energy Li-ion batteries, particularly nickel–manganese–cobalt (NMC) and nickel–cobalt–aluminum (NCA) chemistries. The addition of nickel enhances performance by increasing energy density, cycle life, and storage capacity characteristics required for long range driving that reduces dependence on frequent charging infrastructure (Bin Abu Sofian et al., 2024; Jung & Yim, 2020; Li et al., 2024; Qu et al., 2022; T. T. Wei et al., 2023). Forecasts indicate that global demand for nickel battery grade will rise dramatically to over 1.27 Mt per year by 2030 (Jannesar Niri et al., 2024; Li et al., 2024; C. Xu et al., 2020). In parallel, battery recycling is being designed to reinforce supply chain resilience and sustainability, with modelling showing the potential to meet up to 97% of EV battery nickel demand by 2050 through recycling (He & Sun, 2022; Islam & Iyer-Raniga, 2022).

With the world's largest nickel reserves, Indonesia is emerging as a major hub in the global EV supply chain. Government instruments including down streaming policies, ore export bans, and fiscal measures have successfully attracted both foreign and domestic investment in nickel processing, battery manufacturing, and EV production (Konewka et al., 2021; Siahaan et al., 2021; Yusgiantoro et al., 2021). Flagship industrial parks in Morowali and Weda Bay exemplify this ambition. The national roadmap is aligned with Indonesia's pledge to achieve net zero emissions by 2060, advancing both domestic electrification and integration into international supply chains (Rahmanta et al., 2023; Santosa et al., 2023; Siregar, 2024).

Nickel raw materials for battery precursors are extracted from two primary ore types which are low grade laterite and high grade saprolite, each requiring distinct processing. Laterite ore is generally treated through high pressure acid leach (HPAL), in which nickel and cobalt are leached under elevated temperature and pressure to produce mixed hydroxide precipitate (MHP). The MHP is subsequently refined via leaching, solvent extraction, and crystallization to yield high purity nickel sulfate ($NiSO_4$), suitable for battery applications (Fan et al., 2024; Gultom & Sianipar, 2020; König, 2021; Rizky et al., 2023; Zhang et al., 2025). In contrast, saprolite ore is processed via pyrometallurgical methods, primarily the rotary kiln–electric furnace (RKEF) process. RKEF routes smelt oxide feed into nickel pig iron (NPI) or ferronickel. NPI is then sulfurized to nickel matte, which can be leached with sulfuric acid to produce $NiSO_4$. Both HPAL and RKEF ultimately crystallize $NiSO_4 \cdot 6H_2O$, the essential precursor for NMC cathode synthesis, although the removal of sulphur residues remains technically challenging (Zhang et al., 2025).

While these pathways deliver added value in line with Indonesia's policy goals, they are also highly intensive capital and energy and raise both financial and environmental challenges. Energy consumption may reach 174 GJ per tonne of nickel metal and 369 GJ per tonne of nickel oxide, with associated emissions of 14–30 tCO_2 equivalent per tonne of product (W. Wei et al., 2020a). With the rise of carbon pricing instruments such as taxes and credit markets, these emissions represent financial liabilities in addition to environmental impacts, influencing the project financing environment (Caragnano et al., 2020; W. Wei et al., 2020b; B. Xu et al., 2022; Zhou & Tang, 2022).

To evaluate feasibility under such conditions, discounted cash flow (DCF) remains a widely used approach due to its rigor and transparency, especially in intensive capital sectors such as mining and smelting. However, its core limitation lies in its inability to capture uncertainty and managerial flexibility which important shortcoming in projects exposed to commodity price volatility, evolving carbon regulation, and operational risk (De la O & Myers, 2018; DRISSI, 2023; Polcanova & Stratila, 2022; Trijayanto & Hakam, 2025; Villadsen et al., 2017). An alternative is real options valuation (ROV), which explicitly incorporates flexibility into investment appraisal by treating projects as financial options that can be deferred, expanded, reduced, or abandoned depending on market conditions. ROV has been shown to more accurately represent project value in volatile, regulated industries (Čulík, 2016; Karel & Windiati, 2019; J. J. Tan, 2018).

Previous studies have applied ROV in various mining and energy contexts. Ajak and Topal (2015) demonstrated flexible decision-making at the mine operational level using real options, while Guj and Chandra (2019) compared different ROV approaches applied to a copper mine. Haque, Topal, and Lilford (2014) conducted a numerical study for a mining project using ROV under commodity price uncertainty. In the nickel sector specifically, Husin, Prawoto, and Rosyid (2020) applied real options to evaluate investment plans for nickel pig iron smelters in Indonesia, while Ardhiansyah, Adachi, and Oda (2023) employed a stratified state aggregation approach combining price and grade uncertainties in tin mining projects. Espinoza and Rojo (2017) valued investment opportunities in the mining sector with a focus on sustainability, and Chandra and Hartley (2024) examined sequential investment decisions using compound multiple volatility real options. However, research specifically applying ROV to integrated nickel downstream processing facilities particularly those producing battery-grade nickel sulphate and precursor materials within Indonesia's EV ecosystem remains rarely explored compared to other energy sectors such as geothermal or hydropower. This study addresses this gap by evaluating the feasibility of processing nickel ore and refining it into nickel sulphate, while also assessing the potential for expansion into the production of battery precursor materials.

The overall objective of this research is to provide a more comprehensive investment assessment framework by combining DCF and ROV for nickel down streaming projects, so that the results not only evaluate basic feasibility but also highlight the strategic value of managerial flexibility in dealing with uncertainty. The novelty of this study lies in the application of ROV in the context of nickel mineral down streaming in Indonesia, which remains rarely explored in the literature. The contribution of this research is twofold. Academically, this study expands the literature on the use of real options in the mining industry, particularly for nickel processing investments, and provides a methodological framework that integrates DCF, ROV, and return-to-risk ratio analysis. Practically, this research offers a valuable reference for investors, companies, and regulators to understand the strategic opportunities and risks of investing in nickel processing amid the growing global demand for electric vehicles, while also providing insights for policymakers in designing supportive fiscal and regulatory frameworks that encourage downstream investment while managing environmental and market risks.

METHOD

DCF AND ROV MODEL

DCF is one of the most popular methods for evaluating the financial feasibility of investment projects. The principle is that the value of an investment equals the present value of expected future cash inflows or outflows, discounted at an appropriate rate of interest, commonly referred to as the discount rate. The key components are NPV and Internal Rate of Return (IRR) (Caríssimo, 2024; Fernandez, 2020; Pariugina, 2023a; Polcanova & Stratila, 2022; Solodov, 2021).

NPV is a measure of whether an investment generates value greater than its cost. If the present value of cash inflows exceeds the initial investment, the project is considered profitable. NPV was calculated based on equation (1) Where CFt is expected cash flow at year t, r is discounted rate usually using weighted average cost of capital, T is total period and C0 is an initial investment cost (d'Amato & Bambagioni, 2023; Pariugina, 2023; Pintarič & Kravanja, 2017; Solodov, 2021). The decision rule for NPV is that when NPV is above 0 it is a profitable investment (adding more value than costs of the project) and when the value is negative this indicate and unprofitable investment.

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{\mathrm{CF}_t}{(1+r)^t} - \mathrm{C}_0 \qquad \ldots(1)$$

The IRR is another important measure used in DCF analysis, which is the discount rate at which the NPV of a project is zero (simply, the discount revenue is equal to the discount expense) as written in equation (2). IRR is the rate at which a project's NPV equals zero, meaning that if the IRR is more than the required return the project is considered feasible and if the IRR is less than the required return the project is deemed not feasible. However, IRR has some shortcoming such as multiple IRRs in the case that the project with untraditional cash flow; and misinterpretation for comparing two mutually exclusive projects (Magni, 2020, 2021).

$$0 = \sum_{t=0}^{T} \frac{\mathrm{CF}_t}{(1+\mathrm{IRR})^t} - \mathrm{C}_0 \qquad \ldots(2)$$

The DCF, however, is based on passive investments and this decision do not change in response to the future uncertainties. This restriction is among the main rationale to think about finance analysis techniques that model uncertainties in the future. ROV is one of the beneficial methodologies to be adopted in this area. As with the ROV, the value to a specific company is based on investment, in an analogous way to financial options, managers can exercise options according to market and business conditions.

ROV is applicable to intensive capital industries such as mining, oil & gas and infrastructure as these industries are characterized by the presence of uncertainty (Klayme et al., 2023; Koroteev & Tekic, 2021; S. H. Tan & Barton, 2017). ROV are based on Dynamic Decision Making (DDM) models, which are adapted to risk, uncertainty and dynamic environments. Key real option categories are deferral option, expansion option, abandonment option, and switching option. (Alexander & Chen, 2021; Chen, 2022; Čulík, 2016; Gulabyan, 2020; Palma & Ibarra, 2020; J. J. Tan, 2018).

Various techniques are utilized to value these options, including the Black Scholes model, Monte Carlo simulation, and the binomial lattice model. This analysis uses the binomial lattice model for it is flexible enough to express multistage investment decision (Čulík, 2016; Dai & Lyuu, 2010; De Lamare Bastian-Pinto, 2015). The BLM adopts a stepwise and adaptable numerical procedure, which determines the investment decision in different time subintervals. It does not calculate a single NPV but generates instead a decision tree for the possible future worlds.

The underlying idea in binomial lattices is that one modifies cash flows for risk all over the lattice by risk neutral probabilities and that one discounts at risk free rate. As can be seen in Figure **1**, the binomial lattice model involves two or more connected lattices. The first lattice (left hand side of Figure **1**) is used to describe the evolution of the value of the underlying asset as a function of time, and the second lattice (right hand side of Figure **1**) applies backward induction to price the option at each node. It is attributed to some of the important inputs of the model namely: volatility, movement factors, risk neutral probability (Alexander & Chen, 2021; Maier et al., 2020; Rębiasz, 2019; Zmeškal et al., 2022). Equation 3–6 present the equation to calculate them.

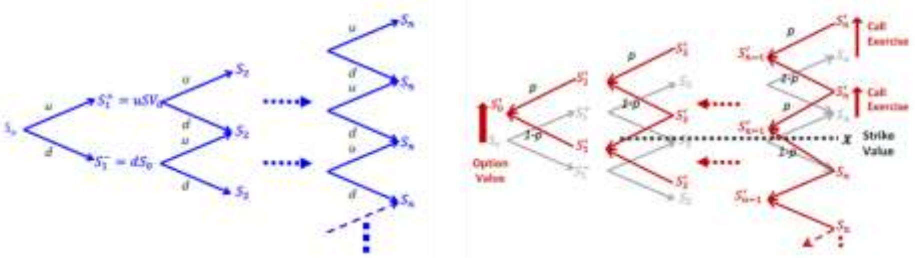

Figure 1. Binomial lattice tree for calculation of underlying assets and option value

(Alexander & Chen, 2021; De Lamare Bastian-Pinto, 2015; Gustino et al., 2025)

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{t=i=10}^{n}(r_i - \bar{r})^2} \quad \ldots(3)$$

$$u = e^{\sigma\sqrt{\Delta t}} \quad \ldots(4)$$

$$d = \frac{1}{u} \quad \ldots(5)$$

$$p = \frac{e^{r\Delta t} - d}{u - d} \quad \ldots(6)$$

Where volatility represents the uncertainty in the value of the asset, the "upward" and "downward" factors are the parameters used to determine movement direction, and the risk neutral probability is the rate applied to discount expected future cash flows as mentioned in equation (3) to (6). The result of the binomial lattice model is the expanded NPV (ENPV), which combines the classic NPV with the ROV (Di Bari, 2020; Rocha et al., 2023; Smith et al., 2018).

$$\text{ENPV} = \text{NPV} + \text{ROV} \quad \ldots(7)$$

This approach will yield a full financial assessment” that will include the intrinsic value (NPV) and strategic options (ROV) as of formula in equation (7). In the context of real option valuation, the return to risk ratio (RRR) serves as an essential performance metric, as it provides a comparative assessment of investment scenarios by relating expected returns to the degree of uncertainty inherent in the project. A higher value of this ratio indicates that the proposed investment is able to deliver relatively greater returns per unit of risk, there by offering a more efficient allocation of capital under conditions of uncertainty. This concept builds upon the foundational work of Sharpe (1977), who emphasized the importance of adjusting returns for risk when evaluating financial performance. Mathematically, the ratio can be expressed in equation (8).

$$\text{Return to Risk Ratio} = \frac{V^{RO}}{ENPV} x \frac{100}{\sigma} \qquad \ldots(8)$$

Conceptual Framework

“A theoretical framework describes the main things to be studied the key factors, concepts, or variables and the presumed relationships among them”. The conceptual framework has long been established and serves as a reference for researchers. The framework applied in this study is adapted from (Kemala & Hakam, 2025) and modified to assess the economic feasibility of an integrated nickel smelter project in order to answer the research questions as written in Figure **2**.

Step 1 is scenario planning, which defines three different investment options, ranging from the upstream business (nickel ore mining) to the downstream option (a fully integrated business process). Step 2 is data acquisition and financial modelling, which involves collecting input parameters for the financial model, including CAPEX, OPEX, commodity price data, interest rates, and government related financial costs (such as royalties, corporate tax, and carbon credit mechanisms). Step 3 applies the DCF model for cost benefit analysis, calculating NPV, IRR, and PI, supported by sensitivity analysis (SA) using MCS, which incorporates hybrid risk parameters to strengthen investment prospects.

Step 4 applies the ROV approach to develop the option value for ENPV. This step requires defining key ROV parameters, including volatility, risk free interest rate, implementation cost, and option maturity. Step 5 then synthesizes the ENPV results to provide well informed investment decisions with optimum financial returns, strategic growth potential, and risk mitigation strategies across the nickel processing value chain. Importantly, this stage does not merely present numerical results but also integrates insights from previous steps scenario planning, data acquisition, and DCF analysis to form a coherent decision framework. By linking financial feasibility with managerial flexibility and regulatory considerations, the conceptual framework enables investors, policymakers, and practitioners to evaluate integrated nickel projects more comprehensively, ensuring that decisions are based not only on deterministic financial indicators but also on the dynamic uncertainties of market volatility and carbon policy.

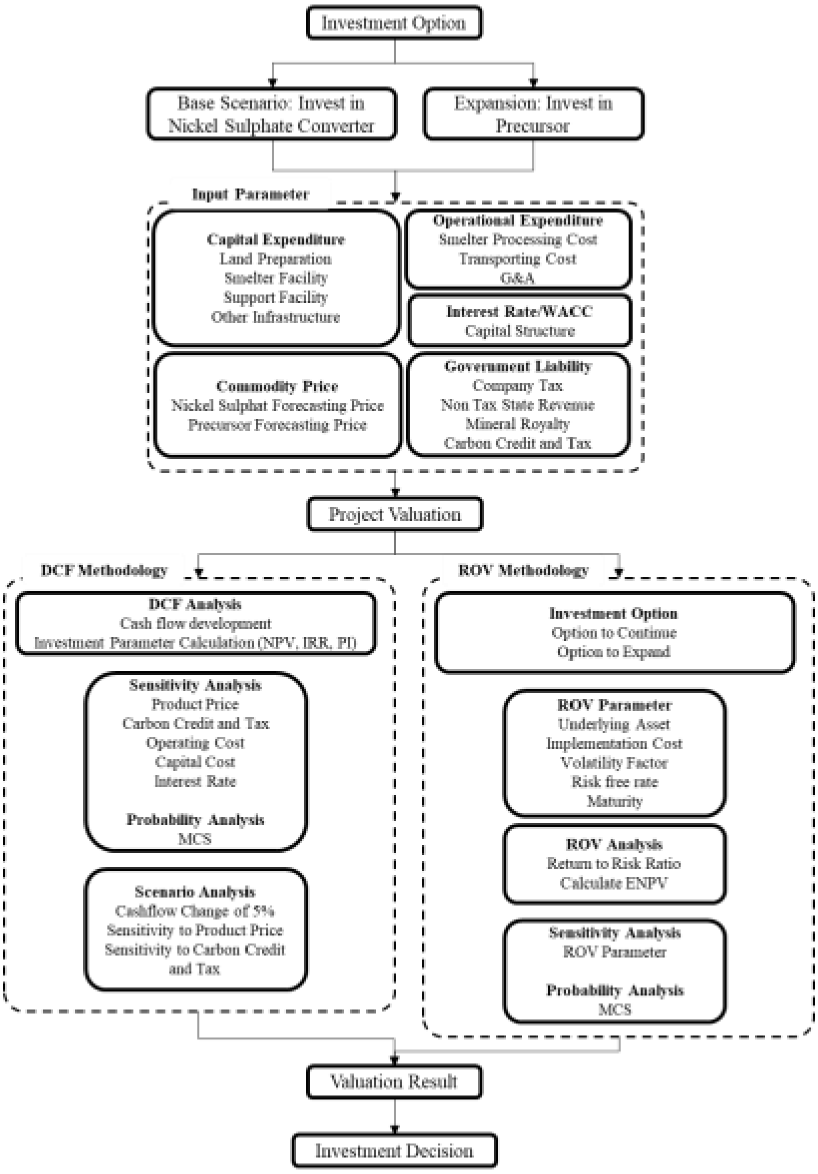

Figure 2. **Conceptual Framework**

Source: Adapted from Kemala & Hakam (2025), modified by the author for nickel downstream processing investment analysis, 2025

Case Study Overview

The first investment pathway under evaluation entails the establishment of an integrated facility focused on the production of nickel sulphate and cobalt sulphate as its primary outputs, with project assumption stated in **Error! Reference source not found.**. The project timeline begins with investment initiation in 2025, followed by a three years construction period leading to the Commercial Operation Date (COD) in 2028. At this milestone, the company plans to conduct a comprehensive reassessment of both internal performance and external market conditions to determine the feasibility of proceeding with an expansion into precursor production. By adopting this sequential development framework, the firm ensures flexibility in capital allocation while retaining the strategic option to advance further downstream in the nickel value chain.

The overall operation is designed to extend until 2042, aligning with the life of mine schedule and the projected resource availability to sustain feedstock supply. In the base case, the facility configuration encompasses four lines of RKEF, six lines of HPAL, and four lines of refining plants. This integrated setup provides sufficient processing capacity to convert raw ore into nickel sulphate and cobalt sulphate for both domestic and international markets. In the event that the expansion scenario is selected, an additional three lines of precursor plants will be incorporated, enabling the production of NMC811 precursor materials and further embedding the project within the global electric vehicle battery supply chain.

The investment magnitude underscores the intensive capital nature of the project. The base case scenario requires an estimated capital expenditure of USD 7.29 billion, while the expansion option entails an additional USD 1.43 billion. These estimates are based on internal feasibility studies and represent consolidated values of major plant schemes, the detailed breakdown of which is provided in Table 1. By structuring the project in phases, the company is able to mitigate financial exposure in the early stages while preserving the capacity to expand operations in line with market developments and technological readiness.

Table 1. Capital Expenditure (CAPEX) of Processing Facilities

Processing Facilities	Throughput Capacity	CAPEX (USD)	Source
RKEF	5.6 million wet ton ore per annum	$1,000,317,623	*Company Data*
HPAL	18.5 million wet ton ore per annum	$4,282,236,161	*Company Data*
Matte Converter	55,600-ton nickel in Ferronickel	$262,460,572	*Company Data*
Matte Refinery	53,090 ton nickel in Nickel Matte	$533,985,000	*Company Data*
MHP Refinery	110,000-ton nickel in MHP	$1,211,263,000	*Company Data*
2 Phase Precursor	94,630-ton nickel in NiSO4	$1,433,538,000	*Company Data*

Source: Internal company feasibility study, 2024

For the purposes of financial appraisal, a discount rate of 11.30% is applied, representing the company’s weighted average cost of capital (WACC). This rate reflects the combined assessment of financing structure, cost of debt, and cost of equity under prevailing market conditions. The application of this discount rate provides a consistent benchmark for evaluating both the base case and expansion scenarios, thereby ensuring that investment decisions are guided by a robust and transparent financial framework.

RESULT AND DISCUSSION

Discounted Cash Flow Analysis

The cash flow profile for the Nickel Sulphate Integrated Processing Plant, modelled over 18 years of the operating life, including three years of construction, clearly demonstrates the unique financial character of the project life cycle in Figure **3**. The construction period suffers large negative cash flows as a result of large amount of CAPEX and disbursement from a staged financing. Commercial service starts in Year 4 (2028), while ramping up to nameplate capacity by 2029. Cash flows in the first 7 years are driven by the need to service the creditors (through repayments with a 7 years repayment term), and available funds for distribution are reduced by the servicing of the loans. This device slows but does not eliminate the process of maximising free cash flows while liquidating assets. Post repayment, there is a stabilization of cash flows which are now fully available for making financial statements, retained earnings and financial residuary strength.

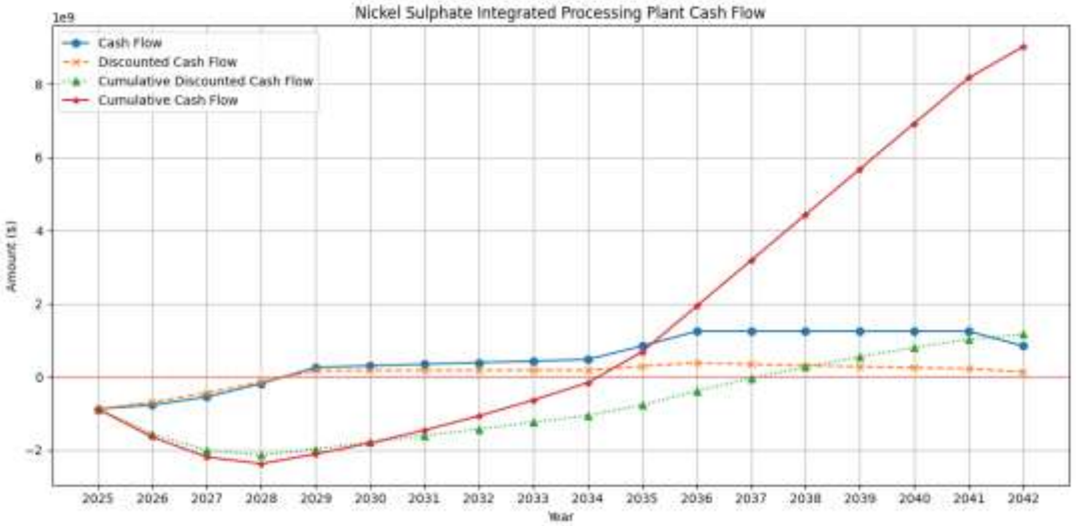

Figure 3. Cashflow of Basecase Scenario

Source: Author's calculation based on company financial data, 2025

The economic evaluation in Table 2 shows the payback period about 10 years, NPV of the project USD 1,164 million and IRR of 16.41%. Average annual OPEX is projected to stand at USD 1,314m, carbon costs related expenses representing just 1% of total revenue. This limited exposure to low carbon costs indicates that profitability should be quite resilient to potential future prices for carbon in the market. Once the nominal cumulative cash flow turns breakeven precedes the cumulative discounted cash flow, reflecting the effect of time value of money on long run returns. Although a long payback horizon for capital has been realized, it is demonstrated that there is strong project viability, assuming cost control during construction and optimized ramping up of production balances the impacts of volatile market conditions and if there are appropriate risk management measures are taken on set up to maintain the confidence of long-term investors.

Table 2. DCF Analysis Result

Aspect	Unit	Nickel Sulphate Project
Annual OPEX (Average, in million USD)	m.USD	1,314
Carbon Cost Percentage to Revenue (%)	%	1
IRR	%	16.41
NPV	m.USD	1,164
Payback Period	years	10

Source: Author's calculation based on company financial data, 2025

Figure 4 show variance of cash flow at ±10%, as used in a further sensitivity study, that highlights the robustness of the NPV of the Nickel Sulphate Integrated Processing Plant. The NPV for the project remains positive under both the worst- and best-case scenarios: the worst case NPV is USD 1,047.8 million (–10% cash flow), while the best case NPV is USD 1,280.7 million (+10% cash flow), with the base case NPV calculated at USD 1,164.2 million. The NPV also remains significantly above zero even under adverse weather conditions, which indicates a considerable financial cushion to absorb implementation measures or market swings.

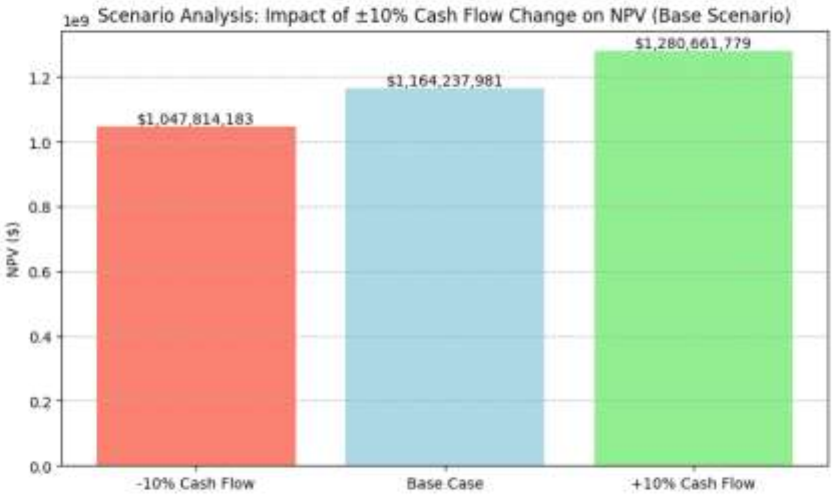

Figure 4. Cashflow Change Scenario on Base Case

Source: Author's calculation using sensitivity analysis, 2025

Figure 4 show sensitivity analysis on the nickel price in further underscores the importance of market price fluctuations to the project's viability. The results show that a long-term nickel price below USD 18,000 per dry tone Ni would render the project commercially unviable and potentially result in a negative NPV. This demonstrates the project's vulnerability to commodity price risk and emphasizes the importance of mitigation strategies, such as securing long term offtake agreements or employing hedging mechanisms.

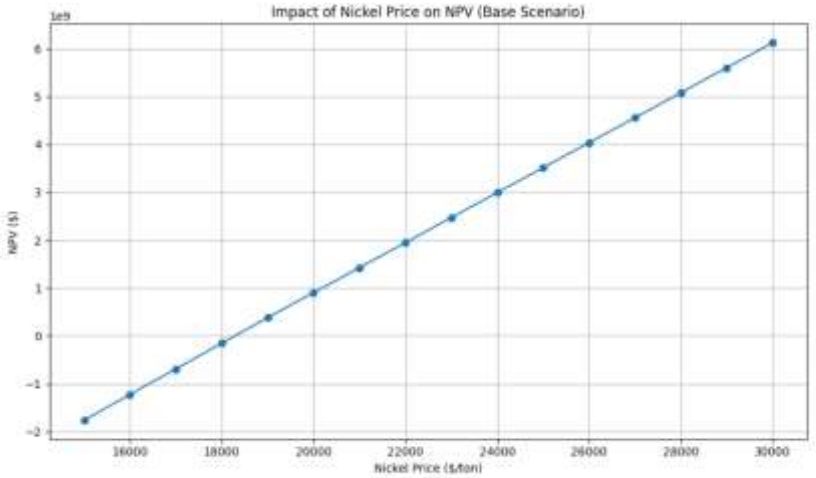

Figure 5 Impact on Nickel Price Change on Base Scenario

Source: Author's calculation using sensitivity analysis, 2025

In addition to considerations of cash flow under the base case scenario, the intensive energy nature of nickel processing operations places this sector among the higher emitters in terms of carbon footprint. While existing government policy is largely focused on coal fired power plants, future regulatory provisions may extend to extractive industries and mineral processing facilities. If all CO_2 emissions are subjected to carbon tax or carbon credit pricing, Figure **6** show a minimum price of USD 20/tCO_2 is identified as critical. At carbon prices well above this threshold, the project's NPV would turn negative, rendering it uneconomic.

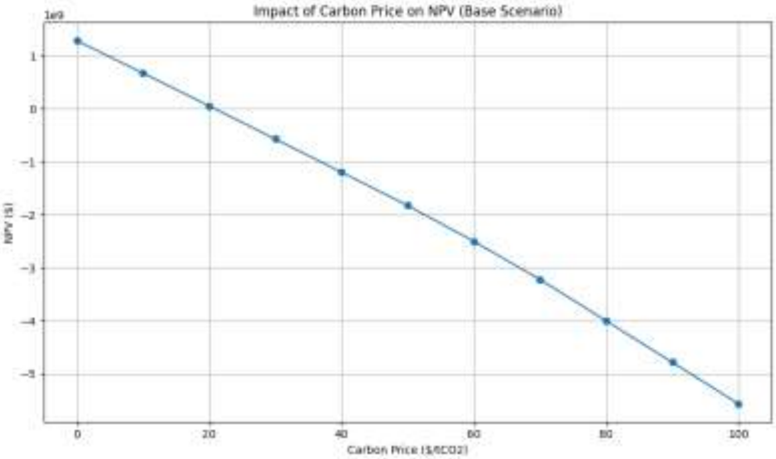

Figure 6. Impact on Carbon Price Change on Base Case Scenario
Source: Author's calculation using sensitivity analysis, 2025

The sensitivity analysis in Figure **7** conducted for ±50% variations in the input data showed that CAPEX, nickel price, and total resources have the greatest impacts on the economic performance of the project, consistent with the scenario results. Nickel price poses the highest risk to profitability, as the project is heavily dependent on revenue from nickel sulphate sales, whereas CAPEX is directly correlated with capital recovery and return ratios. Resources are also a critical factor for project feasibility, as they ensure long term project sustainability and directly influence the project's operational lifetime. By contrast, OPEX, carbon price, and cobalt price exhibit smaller but still observable impacts on both NPV and IRR.

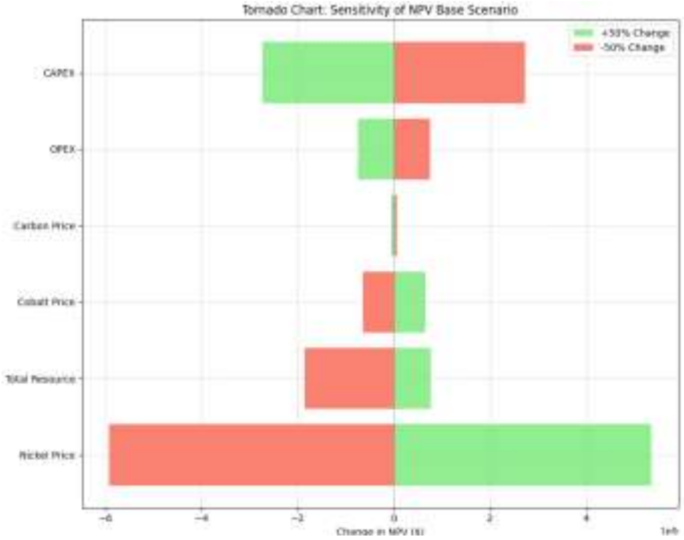

Figure 7. Tornado Chart Sensitivity on Base Case Scenario
Source: Author's calculation using Monte Carlo simulation, 2025

ROV Analysis on Expansion Project

The expansion into precursor battery materials is evaluated using a real options framework to capture the value of managerial flexibility under uncertainty. Figure **8** show the projected cash flows for the precursor expansion scheme remain consistently positive throughout the operational horizon, with peak values occurring during the mid to end of production years. Although a decline in nickel price in the eleventh year exerts downward pressure on revenue, overall cash flow remains positive across the project life cycle. Sensitivity analysis identifies CAPEX, nickel price, and OPEX as the most significant parameters influencing profitability, underscoring the importance of cost control and commodity price stability for long term project performance.

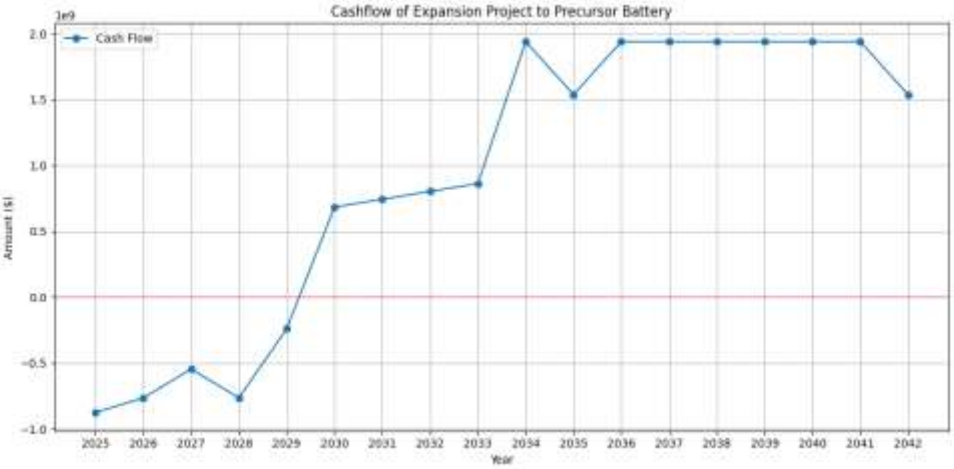

Figure 8. Cashflow Expansion Project to Precursor Battery

Source: Author's calculation based on company financial data and expansion scenario assumptions, 2025

These key parameters were incorporated into a Monte Carlo simulation to evaluate the volatility associated with the expansion project. Table present the simulation produced a volatility factor of 80.26%, reflecting the combined effects of variability in capital investment, operating costs, and commodity prices. The stochastic distribution for the input parameters includes OPEX with a mean of USD 8.46 million and standard deviation of USD 2.2 million, CAPEX centered at USD 7.29 billion with a deviation of USD 3.11 billion, nickel price averaging USD 20,500/ton with a standard deviation of USD 3,000, cobalt price with mean USD 40,000/ton and deviation USD 6,000, and carbon price modeled with a mean of USD 3/tCO_2 and deviation of USD 2.

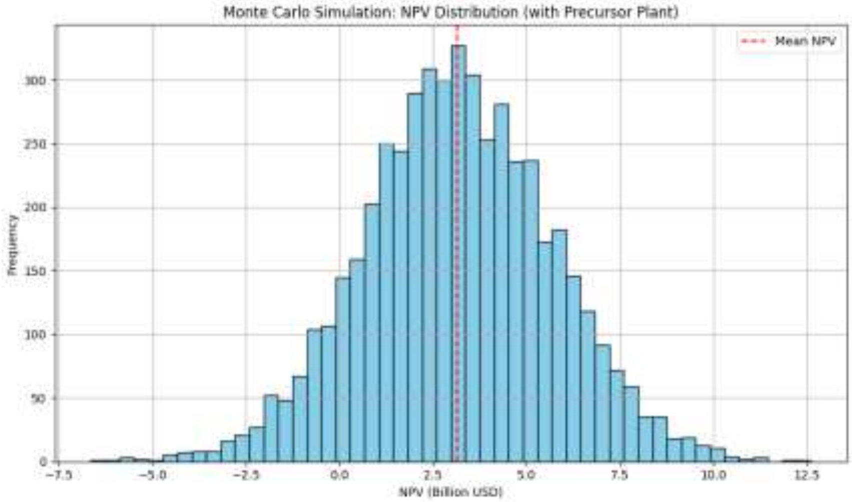

Figure 9. Monte Carlo Analysis for Volatility Factor Calculation

Source: Author's calculation using Monte Carlo simulation (10,000 iterations), 2025

The results further indicate an average NPV of USD 3.16 billion with a standard deviation of USD 2.54 billion, highlighting both substantial upside potential and considerable downside risk. Figure **9** illustrates the probability distribution of project outcomes, with the mean NPV positioned near the central peak but with a wide spread that confirms the project's risk–return profile.

Table 3. Real Option Valuation Parameter

Parameter	Base Case	Mean Value	Std Dev
OPEX ($)	16,287,724	8,464,807	2,200
CAPEX ($)	7,290,262,356	7,290,262,356	3,110,903,507
Nickel Price ($/ton)	20,500	20,500	3,000
Cobalt Price ($/ton)	40,000	40,000	6,000
Carbon Price ($/tCO2)	2	3	2
NPV Mean			$3,161,633,203
NPV Standard Deviation			$2,537,409,095
Volatility Factor			80.26%
Initial Project Value (S_0)			$3,126,972,230
Strike Price (K – Expansion Cost)			$1,433,538,000
Risk Free Rate (r)			6.87%
Total Time to Expiration (T)			3 Years (European Call Option)
Expansion Timing (Year)			2028

To quantify the strategic value of flexibility, the expansion option was evaluated using a binomial lattice model. Table 3 summarizes the parameters applied, including an initial project value of USD 3.13 billion, an expansion strike cost of USD 1.43 billion, a risk-free rate of 6.87%, a three years' time to expiration (corresponding to the decision window post COD in 2028), and a volatility factor of 80.26% obtained from the Monte Carlo analysis. Figure **10** shows the binomial lattice model for the precursor expansion option value.

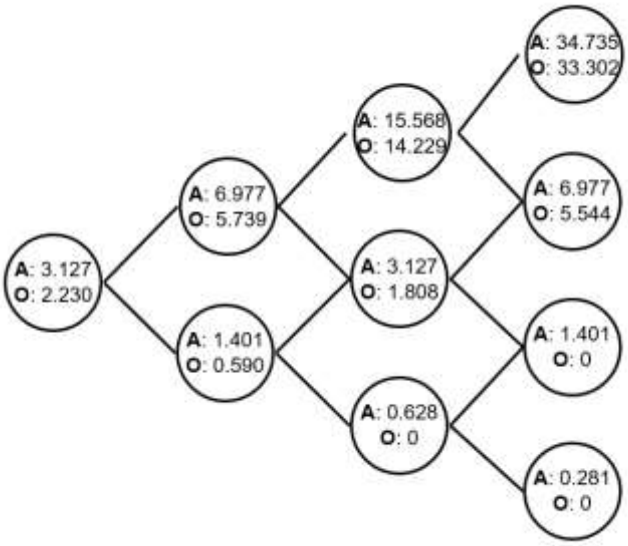

Figure 10. **Binomial Lattice Model for Precursor Expansion Option Value**
Source: Author's calculation using real options valuation, 2025

The option valuation results are presented in Figure **11**. The option value of investing in the precursor expansion in 2028 is estimated at USD 2.23 billion. When added to the base case

NPV of USD 1.16 billion, this yields an ENPV of USD 3.45 billion. This outcome demonstrates that incorporating managerial flexibility to defer or execute the expansion substantially enhances the project's economic attractiveness compared to a rigid investment pathway. The findings confirm that real options analysis serves as an important complement to traditional discounted cash flow methods by explicitly valuing uncertainty, timing flexibility, and the capacity to adapt to evolving market conditions.

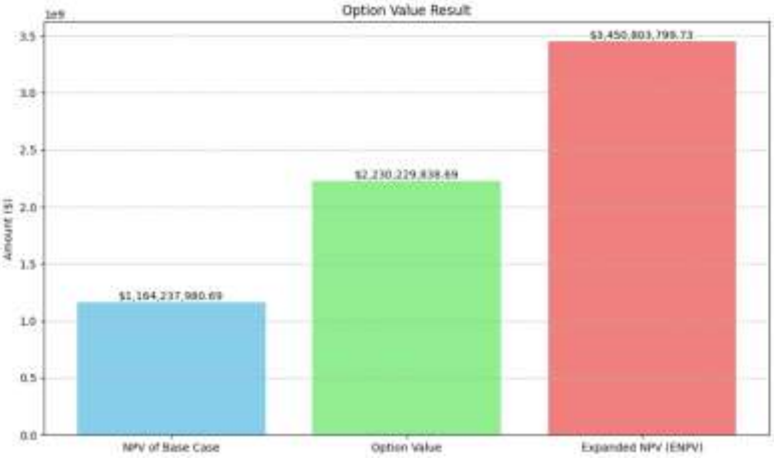

Figure 11. Option Value Result of Expansion Project

Source: Author's calculation using Monte Carlo simulation, 2025

Table show that the RRR of 0.804 demonstrates that the expansion project generates substantial additional value through the real option mechanism, with an option value of USD 2.23 billion relative to an expected NPV of USD 3.45 billion. However, when this value creation is adjusted for the project's volatility level of 80.26%, the resulting ratio falls below unity, indicating that the magnitude of uncertainty still exceeds the efficiency of the option in compensating for risk. An RRR below one implies that although managerial flexibility contributes positively to project valuation, it does not yet provide a sufficient buffer against the high degree of uncertainty inherent in nickel market dynamics and intensive capital downstream processing. This finding suggests that further improvements in risk management strategies such as hedging price fluctuations, securing long term offtake agreements, or pursuing fiscal support mechanisms are required to enhance the project's risk adjusted attractiveness to potential investors.

Table 4. Return to Risk Ratio of Expansion Project

Option Value (USD)	2,230,229,839
ENPV (USD)	3,450,803,800
Volatility Factor (%)	80.26%
Return to Risk Ratio	0.80

Source: Author's calculation using sensitivity analysis, 2025

Sensitivity Analysis for ROV Method

The robustness of the expansion project under uncertainty was examined through a series of sensitivity analyses within the ROV framework. The main objective of this stage was to assess how probabilistic variations in key parameters affect the ENPV and option value outcomes. The first stage of analysis employed a Monte Carlo Simulation (MCS) on the option value, which enabled the derivation of probabilistic distributions for ENPV. Based on the simulation, the mean ENPV was estimated at USD 3.46 billion, with a standard deviation of USD 447.40 million, as illustrated in Figure 12. These results suggest that the project delivers strong economic potential under uncertain conditions, thereby supporting the feasibility of the expansion project despite the inherent risks.

Building on the MCS results, the subsequent analysis investigated the interaction between volatility and implementation cost, both of which significantly influence project economics. Two dimensional heatmap in Figure 12 was developed to visualize the relationship between project volatility (σ) and implementation cost (K) against ENPV outcomes. The results reveal a positive correlation between volatility and ENPV, reflecting the potential for higher prices to increase project value. At the same time, the analysis highlights the exchange between opportunity and uncertainty, since greater volatility raises ENPV but also amplifies the risks captured in the RRR. These findings underscore the importance of incorporating the option methods into project appraisal, as deterministic approaches would not capture the upside potential created by volatility in market conditions.

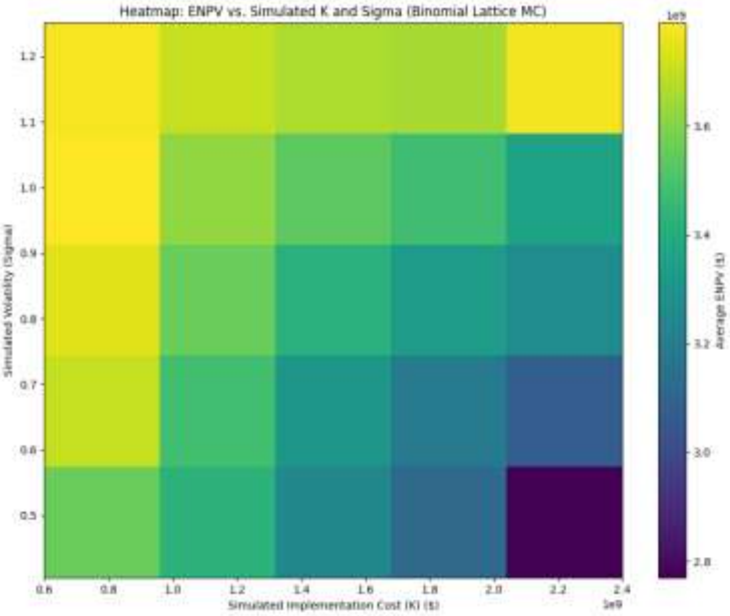

Figure 12. Heat Map MCS of ENPV

Source: Author's calculation using Monte Carlo simulation, 2025

Consideration of resource availability was also critical in this study, since the total mineable resources determine the ultimate project life and the sustainability of feed supply to the smelter facility. Sensitivity analysis was therefore extended by varying the project end year, which represents the effective production horizon. Figure **13** presents the results of this test, showing the effect of project end year on the base case NPV, European option value, and ENPV. The analysis demonstrates that precursor expansion yields a positive ENPV of USD 0.46 billion even if operations terminate in 2036, at which point the base case NPV without options falls into negative territory at USD –0.12 billion. In contrast, 2035 emerges as a critical threshold, as the base case NPV at this horizon is USD –0.455 billion, while the inclusion of the precursor expansion option still results in a negative ENPV of USD –0.33 billion. These results indicate that if resources are only sufficient to sustain operations until 2035, the expansion scenario loses its economic attractiveness, whereas extending resource availability by even one year fundamentally alters the valuation trajectory in a more favourable direction.

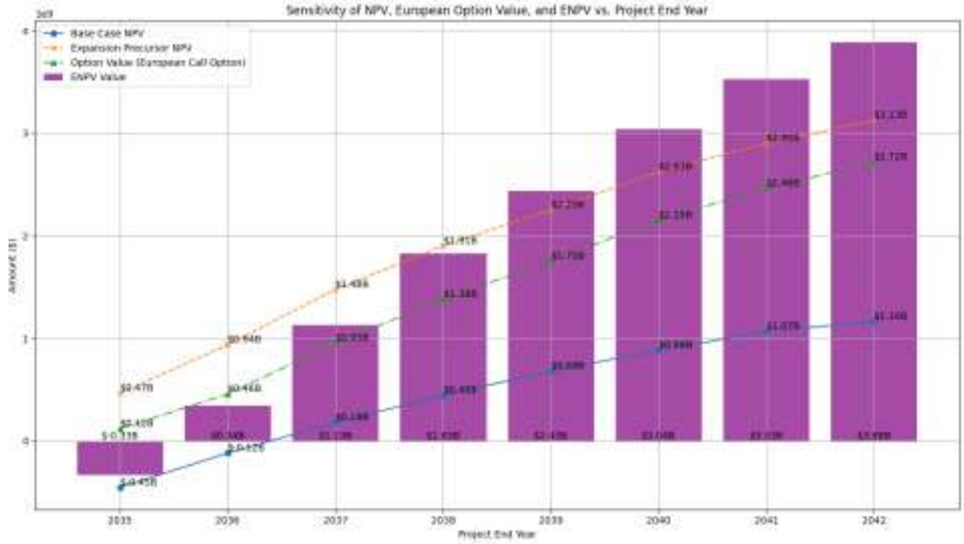

Figure 13. Sensitivity Analysis on the Expansion Project

Source: Author's calculation based on project end year variation, 2025

Overall, the findings emphasize that the viability of the expansion project is highly sensitive not only to external uncertainties, such as price volatility, but also to internal constraints, particularly the sufficiency of project resources. The Monte Carlo simulations confirm that the project offers a favorable risk–return profile under probabilistic conditions, while the heatmap analysis underscores the dual nature of volatility as both a source of value and risk. Most importantly, the sensitivity analysis of the project end year demonstrates that resource availability constitutes the decisive factor in shaping the project's long term economic outcome. Integrating option approaches into investment evaluation therefore provides a more comprehensive framework for capturing value under uncertainty compared to conventional static valuation methods. **Error! Reference source not found.** presents a comparative analysis of prior related studies. While research on ROV for nickel smelters remains relatively scarce, this study offers a comparison with ROV valuations conducted within the same industry specifically the upstream sector highlighting the options exercised and the resulting ENPV.

CONCLUSION

The findings of this study demonstrate that the project is financially feasible under the base case scenario, as indicated by a positive NPV of USD 1.164 million and an IRR of 16.41%, reflecting returns that exceed the typical cost of capital in the mining sector. However, the DCF analysis also reveals a high sensitivity to external variables, particularly nickel prices and raw material availability, where feasibility is threatened if prices fall below USD 18,000 per ton or carbon-related costs exceed USD 20 per ton of CO_2. This indicates that the project operates with a relatively thin margin and is highly exposed to market volatility and policy dynamics. In contrast, the Real Options Valuation (ROV) approach highlights a significantly higher potential value in the expansion scenario, with an option value of USD 2.23 billion and an ENPV of USD 3.45 billion, suggesting that managerial flexibility can dramatically enhance project value despite a return-to-risk ratio of 0.80. These results confirm that while DCF provides a static feasibility assessment, ROV captures strategic value under uncertainty, making it more suitable for projects characterized by high volatility such as nickel downstream processing. Furthermore, the study contributes academically by extending the application of ROV to the mineral sector, particularly in the context of Indonesia's nickel industry, and demonstrates its relevance in addressing uncertainty and supporting strategic decision-making. Practically, the results imply that investors must balance high return potential with disciplined risk management, governments should design supportive and stable policies, companies need to ensure reserve sustainability to maintain flexibility, and local communities stand to benefit from sustained economic and environmental outcomes. Thus, the study concludes that financial metrics not only indicate feasibility but also serve as a strategic guide for managing risks and leveraging opportunities in a volatile global environment.

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