



Economic Feasibility & Carbon Emission Reduction of EV Haul Truck Implementation: A Case Study of Pongkeru Nickel Mining Concession

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Abstract

Background: Indonesia's nickel mining supports the global EV battery supply chain but relies on diesel haul trucks, causing high fuel consumption, emissions, and exposure to fuel-price volatility. Electrifying hauling can improve efficiency, reduce direct emissions, and strengthen resilience to energy-price and transition risks.

Objective: This study analyzes the economic feasibility, environmental impact, and energy-efficiency gains of replacing diesel haul trucks with EV hauling at the Pongkeru Block nickel mine, Indonesia.

Methods: A Discounted Cash Flow (DCF) approach using Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP) was applied under Conservative, Base Case, and Optimistic scenarios. The scenarios were combined into a probability-weighted expected NPV. The analysis was complemented by activity-based carbon accounting, ESG-integrated valuation with carbon-price scenarios, energy-efficiency analysis, and one-way sensitivity analysis.

Results: EV hauling yields NPVs of USD 87.85, 116.99, and 138.70 million under the Conservative, Base Case, and Optimistic scenarios, respectively, versus USD 25.15, 52.57, and 85.18 million for diesel. The expected NPV is USD 112.59 million for EV versus USD 50.86 million for diesel. EV payback is two to three years versus three to five years for diesel. Direct diesel-related emissions are estimated at 142,697.48 tCO₂e over the mine life. EV hauling shows 2.1–3.2 times higher energy-conversion efficiency and 49%–65% lower input-energy requirements.

Conclusion: EV-based hauling is economically favorable across all scenarios and delivers substantial environmental and energy-efficiency benefits. Its long-term value depends on reliable electricity supply, adequate charging infrastructure, lower-carbon power sources, effective transition-risk management, and access to sustainable financing.

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INTRODUCTION

The restructuring of mining policy in Indonesia is aimed at ensuring that natural resource utilization provides optimal added value for national development and regional prosperity (Harun et al., 2023; Natsir et al., 2024; Sujono et al., 2025). Based on data from the United States Geological Survey (“USGS”), Indonesia has been recorded as having the largest nickel reserves in the world, with total reserves of 55 million tons, equivalent to 42.31% of the world's total nickel reserves.

To optimize the natural resources owned by Indonesia, the Ministry of Energy and Mineral Resources (“MEMR”) has introduced a set of policies aimed at developing a manufacturing ecosystem that uses nickel as a primary raw material, including the development of local

provinces and regions where nickel is sourced to ensure that the benefits of economic development are distributed primarily to the source areas.

MEMR then announced a new mechanism for obtaining mining concession permits, referred to as the limited and priority auction. Under this mechanism, the first offer is given to local governments, particularly local government-owned enterprises (*Badan Usaha Milik Daerah* or “BUMD”) at the provincial and regional levels. After that, the second offer is given to state-owned enterprises. The Pongkeru Block auction in August 2024 was established using this auction mechanism and resulted in PT Aneka Tambang Tbk (“Antam”), PT Susel Citra Indonesia (“SCI”), and PT Luwu Timur Gemilang (“LTG”) being announced as the winners of the Pongkeru Block. In October 2024, MEMR granted approval for the establishment of a joint venture company named PT Pongkeru Mineral Utama (“POMU”).

POMU is currently in the first phase of its exploration plan and has obtained an exploration mining permit, namely the *Izin Usaha Pertambangan Khusus Eksplorasi* (“IUPK Eksplorasi”), and will commence exploration activities in 2026. Through the auction process, POMU obtained initial reserve and resource data for limonite and saprolite within the mining concession. Based on these initial data, POMU has developed a mining operation and production plan using an open-pit mining system, with fossil fuels as the primary energy source for all operational activities.

Despite holding one of the most significant nickel concessions in Eastern Indonesia, POMU's current operational design relies entirely on fossil fuel-based energy systems. This presents a fundamental tension: on the one hand, nickel mined from this concession is destined for EV battery supply chains that promote global decarbonization; on the other hand, the extraction process itself generates substantial greenhouse gas emissions through diesel-intensive hauling operations. Addressing this paradox requires a rigorous, evidence-based analysis of whether electrifying the hauling system at the Pongkeru Block is both economically viable and environmentally beneficial, a gap that this study seeks to fill.

The global transition toward low-carbon mining operations has accelerated significantly in recent years (Kandpal et al., 2024; Seraj et al., 2023; Wang et al., 2023). According to the International Energy Agency (2023), the mining sector is responsible for approximately 7% of global energy consumption, with diesel-powered hauling systems constituting the single largest source of operational emissions in open-pit mines. Globally, major mining companies (including BHP, Rio Tinto, and Vale) have begun piloting or deploying electric haul truck fleets as part of their net-zero emission strategies. In the Indonesian context, this transition acquires particular strategic relevance, as the government has committed to achieving Net Zero Emissions (NZE) by 2060 under Presidential Regulation No. 98 of 2021, while simultaneously expanding its nickel mining industry to meet growing global demand for EV battery materials. The alignment between Indonesia's industrial development agenda and its climate commitments creates a compelling research context for evaluating the feasibility of electrifying mining operations.

According to Azadi (2020), the mining sector contributes roughly 1.9 to 5.1 gigatons of CO₂-equivalent emissions each year, primarily due to coal extraction and energy use. The broader metals industry, especially steel and aluminum manufacturing, exacerbates this issue by generating an additional 4.2 gigatons of CO₂-equivalent emissions annually. In accordance with the goals of the Paris Agreement, the industry must reduce emissions by 50% by 2050 to adhere to a 2 °C scenario and by 85% for a 1.5 °C scenario (Deleavingne, 2020).

Open-pit mining is among the most energy-intensive mining operations. The Coalition for Energy Efficient Communitation (“CEEC”) study indicates that diesel equipment in an open-pit copper mine accounts for 60% of overall energy use. Material transport, including overburden and ore, constitutes most of the diesel consumption (Bharathan et al., 2017; Dindarloo & Siami-Irdemoosa, 2016). Notwithstanding advancements in engine efficiency, diesel haulage trucks remain the predominant diesel consumers in open-pit mines (Nobahar, 2026). Feng et al. (2022) emphasize that the excavation and transportation of materials using diesel machinery contribute to more than 51% of greenhouse gas emissions. Accordingly, this research focuses on material transport as the primary diesel-consuming and greenhouse gas-intensive operation in an open-pit mine.

Echoing the current issues facing mining operations, PT VKTR Teknologi Mobilitas (“VKTR”) has, since 2007, pursued the development of the electric vehicle industry, focusing on mass transportation and specialized industry fleets, such as mining fleets. VKTR has collaborated

with well-known EV manufacturers, including BYD Auto and JAC Motors. Their collaboration is not limited to producing EV products for the Indonesian market but also extends to research and development partnerships aimed at establishing solutions that are efficient and well suited to the Indonesian landscape. VKTR's electric dump truck was introduced to the Indonesian market in 2022 and has subsequently become one of the products considered by mining companies seeking to transform their operations into more sustainable and environmentally responsible mining operations.

Several prior studies have examined aspects of EV adoption in mining contexts. Feng et al. (2022) evaluated energy efficiency and CO₂ emission comparisons of alternative powertrain solutions for mining haul trucks, demonstrating the efficiency advantage of electric powertrains over diesel systems. Balboa-Espinoza et al. (2023) conducted a comparative life-cycle assessment of battery-electric and diesel underground mining trucks, confirming significant emission-reduction potential. Norgate and Haque (2010) provided foundational analysis of energy and greenhouse-gas impacts in mining and mineral processing. However, these studies predominantly focus on environmental performance and are generally situated in non-Indonesian and non-nickel mining contexts. This study addresses the gap by integrating financial feasibility through DCF analysis with carbon valuation, energy-efficiency assessment, and ESG considerations under the specific policy and market conditions of Indonesia's nickel mining sector. Feng et al. (2022) Azadi et al. (2020) Norgate & Haque (2010)

The electric dump truck fleet is evaluated as an alternative because of its potential efficiency improvements, replacing the internal combustion engine with an electric powertrain. The study evaluates the electrification of overburden and ore transportation in the Pongkeru Block over the modeled 15-year production period and assesses the associated economic, environmental, and energy-efficiency implications, including potential value from carbon pricing and sustainable-finance mechanisms.

The scientific novelty of this study lies in the development of an integrated analytical framework that simultaneously evaluates financial feasibility, environmental performance, and ESG value within a single investment appraisal model. Financial feasibility is assessed using Discounted Cash Flow (DCF) analysis through Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP), while environmental performance is measured through activity-based carbon accounting, and ESG value is incorporated using carbon pricing scenario analysis. Unlike previous studies that generally examine these dimensions separately, this research demonstrates how environmental externalities can be monetized and integrated into investment decision-making, thereby providing a more comprehensive evaluation of mining electrification projects. Moreover, this study offers one of the first empirical applications of such an integrated framework in Indonesia's nickel mining sector under the country's evolving regulatory and carbon market environment.

Against this backdrop, the study investigates the feasibility of replacing diesel-powered hauling fleets with electric dump trucks in the Pongkeru Block open-pit nickel mine. Specifically, it evaluates the economic feasibility of the investment, estimates the potential reduction in greenhouse gas emissions together with their economic value under carbon pricing mechanisms, analyzes the energy efficiency gains achieved through fleet electrification, and examines the implications of these findings for sustainable mining investment and green financing initiatives, including carbon trading and green bonds.

The findings are expected to contribute across theoretical, practical, and policy dimensions. Theoretically, this research enriches the literature on sustainable mining, energy transition economics, and ESG-based investment evaluation by introducing an integrated framework that links financial performance with environmental value creation. Practically, the results provide strategic guidance for mining companies and investors in designing low-carbon operations, improving long-term cost efficiency, and incorporating carbon value into investment decisions. From a policy perspective, the study offers evidence to support the development of mining electrification through shared charging infrastructure, long-term electricity supply arrangements, preferential electricity tariffs, and carbon market incentives, thereby contributing to Indonesia's commitment to achieving its Net Zero Emissions targets.

METHOD

This study adopts a quantitative comparative case-study design to evaluate the feasibility of replacing diesel-based hauling with an electric vehicle dump truck (EV DT) system in the Pongkeru Block nickel mining concession, East Luwu Regency, South Sulawesi, Indonesia. The study area covers approximately 2,365 hectares. The financial model uses a 15-year project horizon and a scenario-based reserve reconciliation, with mineable reserve estimates of approximately 49.13 million WMT, 54.28 million WMT, and 62.02 million WMT under Conservative, Base Case, and Optimistic scenarios, respectively. Discounted Cash Flow (DCF) analysis is used to assess project cash flows through NPV, IRR, and PBP.

In addition to the financial dimension, this study integrates energy-efficiency analysis and carbon emission assessment as part of the sustainability evaluation. The ESG-integrated DCF model incorporates the potential economic value of avoided or reduced carbon emissions under three carbon-price scenarios (USD 4, USD 10, and USD 25 per tCO₂e), while the financial risk analysis evaluates Conservative, Base Case, and Optimistic operating environments.

This study employed a combination of primary and secondary data collection methods. Primary data included operational assumptions, hauling distances, equipment specifications, electricity consumption estimates, and technical and cost information relevant to diesel and EV hauling. Secondary data included reserve and resource estimates, fuel and electricity assumptions, carbon-emission factors, nickel-price projections, regulatory information, and peer-reviewed literature.

Charging infrastructure costs and technical parameters were incorporated into the project assumptions. Secondary sources included nickel-price projections, carbon-emission factors, Indonesian regulatory documents, and academic literature relevant to mining electrification, DCF valuation, carbon accounting, and ESG-oriented investment assessment.

The data analysis proceeded through four stages. First, parallel DCF models were constructed for EV and diesel hauling, incorporating CAPEX, OPEX, revenue, energy costs, maintenance, labor, tax, and risk-adjusted discount rates. Second, three integrated financial scenarios were developed using Conservative, Base Case, and Optimistic assumptions, and probability-weighted expected NPV was calculated using scenario probabilities of 30%, 50%, and 20%, respectively. Third, one-way sensitivity analysis was conducted on key project variables, particularly ore price, production volume, and royalty rate. Fourth, activity-based carbon accounting, ESG valuation, and energy-efficiency analysis were used to compare the environmental and strategic implications of EV and diesel hauling.

The difference between ANTAM and LAPI reserve estimates reflects their different geological modelling approaches. ANTAM's landform analysis provides a broader regional potential estimate, while LAPI ITB's 3D geological modelling provides a more conservative, grade-constrained technical basis. The final project therefore uses a bridge/scenario approach to capture geological uncertainty rather than relying on a single reserve estimate.

For financial risk assessment, three reserve-realization scenarios are used: Conservative, Base Case, and Optimistic. The associated geological confidence factors are 25%, 35%, and 50%, producing mineable reserve assumptions of approximately 49.13 million WMT, 54.28 million WMT, and 62.02 million WMT, respectively. These confidence factors are scenario-development parameters, not statistical probabilities.

The scenario framework is complemented by assumed scenario probabilities of 30% for Conservative, 50% for Base Case, and 20% for Optimistic conditions. These probabilities are used only for the probability-weighted expected-value calculation and are distinct from the 25%/35%/50% geological confidence factors used to derive reserve scenarios.

$$\begin{aligned}\text{Cadangan Bridge } (\chi) &= \text{LAPI Max} + \alpha \times (\text{ANTAM Min} - \text{LAPI Max}) \\ (\chi) &= 36.235.460 + 35\% \times (102.480.000 - 36.235.460) \\ (\chi) &= 59.421.049\end{aligned}$$

The selling price was determined by averaging the nickel price projections from Wood Mackenzie, Bloomberg, and market consensus. Based on this average projected selling price, adjustments were made to account for nickel content, CF saprolite, and moisture levels.

According to the Decree of the Minister of Energy and Mineral Resources of the Republic

of Indonesia Number 2946 K/30/MEM/2017, the formula for calculating the benchmark price for nickel ore was as follows:

$$\text{Saprolite Price: Ni Price} \times \text{Ni Grade} \times \text{CF} \times (1 - \text{Moisture})$$

The research design used in this study was a quantitative comparative case study methodology for assessing the viability of adopting electric vehicle (EV)-based hauling systems in nickel mining, particularly at the Pongkeru Block, located in East Luwu Regency, South Sulawesi. The study aimed to assess not only the economic but also the environmental consequences of transitioning from traditional diesel-powered dump trucks to EV DTs under simulated and analyzed real-world operating conditions. The study undertook a rigorous approach to provide a comprehensive evaluation that integrated financial value and sustainability indicators by incorporating factors intended to facilitate feasible decision-making within the mining sector.

Economic valuation was the first fundamental element of this study and was conducted using Discounted Cash Flow (DCF) analysis (Uzma et al., 2010). Two types of DCF models were used: the standard DCF model and an ESG-integrated DCF model. The standard model focused on conventional financial indicators, such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period, while considering capital expenditures (CAPEX), operating expenditures (OPEX), and revenue forecasts. The analysis assisted in evaluating the economic feasibility of investing in EV trucks over the life of the investment.

The estimation of carbon emissions uses an activity-based approach focused on hauling energy use. Diesel Scope 1 emissions are estimated from diesel consumption, calorific value, and the applicable emission factor, while EV charging emissions are considered as Scope 2 and depend on the electricity generation mix. The analysis therefore distinguishes gross direct diesel emissions from net emission reduction after accounting for electricity-related emissions.

The analytical approach integrated several areas of study, including financial modeling, environmental impact assessment, and business model evaluation. In this way, the study was able to replicate the realistic business environment and provide evidence regarding the viability of conducting nickel mining using EV-based hauling systems. The relevance to industry practice was ensured by the case study approach, which was based on data collected from a real mining site, while the ESG elements incorporated into the analysis created additional value for stakeholders interested in aligning operational strategies with sustainability objectives.

RESULTS AND DISCUSSION

Results

The feasibility of the business model and the use of EV DTs in the Pongkeru project were assessed using NPV, IRR, PBP, and supporting cost-efficiency indicators. The scenario-based results show that EV hauling has stronger financial performance than diesel hauling under Conservative, Base Case, and Optimistic conditions, with the largest absolute value advantage occurring under more favorable operating conditions.

Furthermore, after the economic feasibility assessment, the study estimates direct diesel-related greenhouse-gas emissions from hauling and evaluates the potential carbon value associated with emissions reduction. The carbon analysis distinguishes Scope 1 diesel emissions from Scope 2 emissions associated with electricity used for EV charging.

Analysis

The business feasibility analysis for implementing EV DTs in the Pongkeru Block involved several analytical steps, starting with the identification of variable factors that could potentially be optimized through EV DT implementation. The financial feasibility assessment was then conducted using a discounted financial model to determine and evaluate the IRR, NPV, ROI, and payback period. Sensitivity analysis was conducted within the financial feasibility model (Kleijnen, 1997). Finally, the total carbon emissions savings were calculated.

Total Ownership Calculation (CAPEX)

Based on the business model assumptions above, all project financing will be funded through shareholder contributions; therefore, there are no loan interest costs in the Pongkeru

Block financial model. The capital expenditure calculations for this financial model also assume that the hauling activities are carried out directly by the company. The breakdown of the total ownership costs for VKTR's EV DTs and Hino's DT units, each with a 30-ton capacity and a 10-wheel configuration, is in Table 1.

Table 1*Total Ownership Cost EV vs Diesel*

Number	Description	EV (IDR)	Diesel (IDR)
Unit Price			
1	MSRP on the road JAKARTA	2,245,945,946	1,170,743,482
2	Additional Flatbed Towing EV Cost	-	-
Charging			
3	DC CCS2 x 120 kW	500,000,000	-
4	Charging device cost per unit	25,000,000	-
Tax and Retribution			
5	Motor Vehicle Tax (PKB)		19,434,342
6	Motor Vehicle Ownership Transfer Fee		136,040,393
7	VAT	247,054,054	128,781,783
TCO per unit		2,518,000,000	1,455,000,000
Total TCO (32 unit)		80,576,000,000	46,560,000,000

Based on the TCO calculation above, additional costs are associated with the construction of the charging station for the EV DT unit. Furthermore, based on Minister of Home Affairs Regulation No. 6 of 2023, battery-based electric vehicles, including electric goods vehicles such as electric dump trucks, are subject to a 0% Motor Vehicle Tax (PKB) and a 0% Motor Vehicle Ownership Transfer Fee (BBNKB).

Regarding maintenance costs, EV DTs have lower maintenance costs than Diesel DTs because several engine components, such as fuel filters and other components associated with conventional diesel powertrains, do not require routine replacement. The comparison of maintenance costs between EV DTs and Diesel DTs is presented as follows.

Table 2*Maintenance Cost Per Year*

Description	Total (IDR)
Diesel Haulage	
Periodic/Scheduled	34,077,044
Unscheduled	51,115,566
Total Maintenance	85,192,610
Electric Haulage	
Periodic/Scheduled	18,617,152
Unscheduled	27,925,727
Total Maintenance	46,542,879

Source: Author

Hauling Cost Calculation

The hauling cost calculation was performed using a formula adapted from historical data from Antam. Based on these assumptions and formulations, the total hauling costs for using EV DT compared with Diesel DT are as follows:

Table 3*O&M Cost Calculation Diesel Truck*

Number	OPEX	Total (IDR)		
1	HE, DT, LV & Mine Support	IDR /mt	1,293	323,228,311
2	HSE (APD & Rambu K3LH)	IDR /mt	70	17,465,000
3	Salary Driver and Support	IDR /mt	1,120	280,012,069

Number	OPEX			Total (IDR)
4	ATK	IDR /mt	54	13,525,000
5	Others	IDR /mt	20	5,000,000
	Total	IDR /mt	2,556.92	

Source: Author

Table 4

Hauling Cost Calculation Diesel Truck

Number	Hauling Cost Per Month			Amount (IDR)	Amount (USD)
1	COGS	IDR /mt		2,557	0.2
2	Diesel Fuel	IDR /mt		29,757	1.8
3	Estimated Price (HPS)	IDR /mt		32,314	2.0
		IDR /mt/km		1,539	0.1
Total Hauling Cost		IDR		8,078,480,379	489,605

Source: Author

Table 5

O&M Cost Calculation EV Truck

Number	OPEX			Amount
1	HE, DT, LV & Mine Support	IDR /mt	1,983	495,732,068
2	HSE (APD & Rambu K3LH)	IDR /mt	70	17,465,000
3	Salary Driver and Support	IDR /mt	1,120	280,012,069
4	ATK	IDR /mt	54	13,525,000
5	Others	IDR /mt	20	5,000,000
	Total	IDR /mt	3,246.94	

Source: Author

Table 6

Hauling Cost Calculation EV Truck

Number	Hauling Cost Per Month			Amount (IDR)	Amount (USD)
1	COGS	IDR /mt		3,247	0.2
2	Electricity	kWh/mt		2,703	0.2
3	Estimated Price (HPS)	IDR /mt		5,950	0.4
		IDR /mt/km		283	0.0
Total Hauling Cost		IDR		1,487,409,137	90,146

Source: Author

Based on the total hauling-cost calculations, EV DTs provide a substantially lower operating cost than diesel DTs, primarily because of lower energy costs and reduced maintenance requirements. Although EV units require higher initial capital expenditure, the operating-cost advantage contributes to stronger long-term project economics and supports the investment case for electrification.

Table 7

Potential Efficiency Using EV Truck

Total Potential Efficiency			
I.	Δ from purchasing price	1,075,202,463	34,406,478,831.58
	Total		34,406,478,831.58
II.	Fuel Efficiency		82,197,504,000
III.	Maintenance Efficiency		618,395,693
IV.	Tax and Retribution		11,247,499,926
	Total Potential Efficiency (IDR)		94,063,399,619

Source: Author

Project Feasibility Assessment

The economic feasibility assessment compares EV and diesel hauling using a scenario-based financial risk framework. The Conservative, Base Case, and Optimistic scenarios jointly vary reserve realization, production, fuel price, exchange rate, inflation, battery replacement cost, electricity-related assumptions, and the risk-adjusted discount rate. NPV, IRR, and PBP are the principal financial indicators.

The scenario results indicate that both alternatives are financially feasible under the modeled conditions; however, EV hauling produces higher NPV and IRR and a shorter or comparable payback period in each of the three scenarios.

Table 8

Scenario-Based Financial Feasibility Results

Economic Indicator	Conservative EV	Conservative Diesel	Base EV	Base Diesel	Optimistic EV	Optimistic Diesel
Production period (years)	15	15	15	15	15	15
Total reserve (WMT)	49,126,595	49,126,595	54,283,049	54,283,049	62,017,730	62,017,730
Geological confidence factor	25%	25%	35%	35%	50%	50%
Avg. production (WMT/month)	333,333	333,333	375,000	375,000	416,667	416,667
Battery replacement cost	50%	50%	40%	40%	30%	30%
Fuel price (IDR /L)	27,000	27,000	21,900	21,900	18,500	18,500
Risk-adjusted discount rate	20%	20%	16%	16%	12%	12%
IRR	47.11%	25.50%	57.33%	35.18%	61.73%	44.47%
NPV (USD)	87,850,961	25,153,390	116,990,708	52,565,368	138,700,847	85,181,231
Payback period (years)	3	5	2	4	2	3
ESG value (USD)	1,079,924	0	3,351,206	0	11,004,492	0

Source: Author

Sensitivity Analysis

One-way sensitivity analysis was conducted to identify the variables with the greatest influence on project NPV. The analysis varies key project assumptions while holding the other variables constant.

Table 9

Key One-Way Sensitivity Results

Key Variable	EV – Lower Bound NPV (USD m)	EV – Upper Bound NPV (USD m)	Relative Ranking
Ore price	-200.39	400.1	1 – highest influence
Production volume	-10.92	210.62	2
Royalty rate	50.98	137.07	3

Source: Author

The sensitivity analysis indicates that project value is driven primarily by commodity price and production performance, with royalty rates also materially affecting NPV. The EV alternative is less exposed to adverse operating-cost changes because its cost structure contains less dependence on diesel fuel.

For the EV model, the sensitivity analysis identifies ore price as the most influential variable, followed by production volume and royalty rate. The project NPV ranges from

approximately negative USD 200.39 million to USD 400.10 million across the analyzed ore-price bounds, while the production-volume sensitivity ranges from approximately negative USD 10.92 million to USD 210.62 million. Royalty-rate sensitivity has a smaller range, with NPV remaining approximately between USD 50.98 million and USD 137.07 million.

The sensitivity results also show that the EV model retains positive project value under the adverse combined conditions reported in the final project, while the diesel alternative experiences substantially greater downside exposure. The diesel model is particularly vulnerable to fuel-cost increases because fuel represents a larger component of its operating cost.

Across the combined sensitivity analysis, EV hauling demonstrates greater downside protection than diesel hauling. This supports the interpretation that electrification can function as a long-term risk-management tool in addition to being an operating-cost strategy.

The one-way sensitivity results should be distinguished from the three integrated financial scenarios. The scenario analysis compares complete business environments, whereas the one-way sensitivity analysis isolates individual drivers of project value.

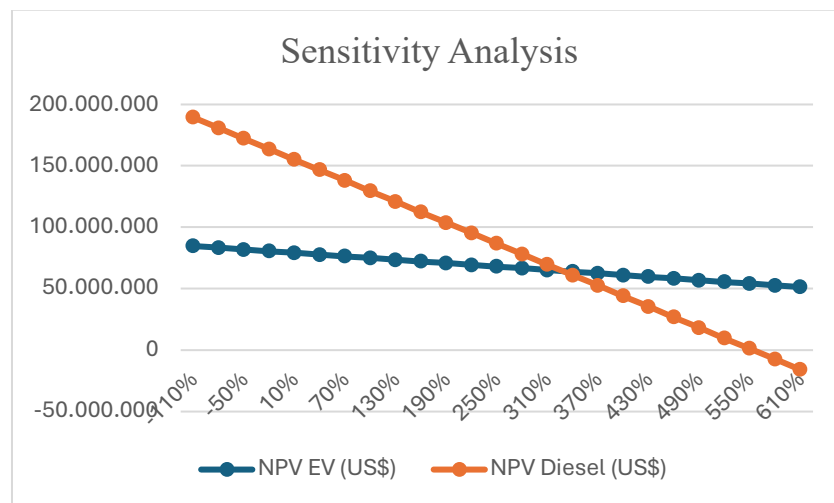


Figure 1. Sensitivity Analysis

Source: Author

The sensitivity analysis highlights that the two hauling systems are exposed to the same commodity and production uncertainties because both generate revenue from the same mine, but their operating-cost structures respond differently to energy-price changes. Diesel hauling has greater direct exposure to fuel-price volatility, while EV hauling is more dependent on electricity availability, charging infrastructure, and power pricing.

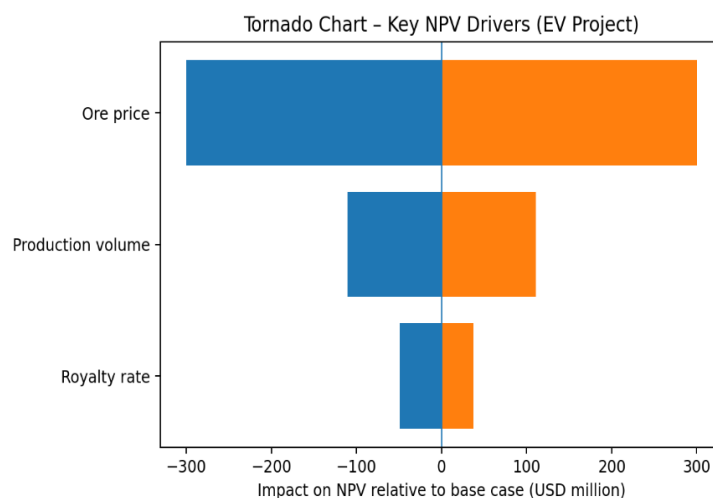


Figure 2. Tornado Chart – Key NPV Drivers (EV Project)

Source: Author

From a risk management perspective, these findings suggest that the EV system is more resilient to energy price volatility than the diesel system. The diesel system's reliance on global fuel prices creates structural risks that are challenging to control, whereas the EV system offers greater cost stability, particularly with support from a long-term electricity supply agreement or integrated energy sources.

Based on the tornado analysis in the final project, the factor that most influences project NPV is ore price, followed by production volume and royalty rate. This indicates that the principal value drivers are market and production performance rather than the incremental cost of electrification.

Overall, the sensitivity analysis strengthens the case for EV DTs as a resilient hauling option, while also showing that the underlying mining project remains fundamentally exposed to commodity-price and production uncertainty. Electrification should therefore be evaluated as a risk-management and value-creation strategy within the broader mine plan.

Carbon Emission

Based on the estimated diesel consumption used in the hauling model, the diesel-based hauling system produces approximately 914,727 kg CO₂ per month, or 10,976,729 kg CO₂ per year. Over the modeled life of the mine, the direct diesel-related emissions are estimated at approximately 142,697,482 kg CO₂, equivalent to 142,697.48 tCO₂e.

Table 10

Direct Diesel Emissions and Indicative Carbon Value

Indicator	Value	Unit / Interpretation
Diesel consumption	325,000	L/month
Direct diesel emissions	914,727	kg CO ₂ /month
Direct diesel emissions	10,976,729	kg CO ₂ /year
Direct diesel emissions over modeled mine life	142,697.48	tCO ₂ e – gross Scope 1 baseline
Indicative carbon value	8.56	IDR billion at IDR 60,000/tCO ₂ e; undiscounted, not guaranteed revenue

Source: Author

The estimated 142,697.48 tCO₂e represents the direct diesel-related emissions that could be avoided from the hauling activity if the diesel fleet were fully replaced by EV DTs. This is a gross Scope 1 reduction estimate; the net environmental benefit is lower to the extent that EV charging electricity produces Scope 2 emissions.

The avoided emissions also have potential economic relevance under carbon-pricing mechanisms. Using the supplementary valuation assumption of IDR 60,000 per tCO₂e, the undiscounted indicative value of 142,697.48 tCO₂e is approximately IDR 8.56 billion. This benchmark is not treated as guaranteed project revenue.

Strategically, the reduction is significant for the mine's decarbonization pathway. The magnitude of the net reduction depends on the electricity generation mix, making lower-carbon electricity an important complement to fleet electrification.

These results address the carbon-emission dimension of the study by quantifying the direct diesel-related emissions associated with hauling and identifying the conditions under which electrification can deliver a larger net carbon benefit.

Carbon Value

To improve the financial evaluation, this study incorporates carbon value into an ESG-integrated DCF framework. The analysis uses carbon-price scenarios of USD 4, USD 10, and USD 25 per tCO₂e, consistent with the scenario structure in the final project.

The carbon valuation is treated as a supplementary source of project value rather than as a guaranteed cash inflow. The scenario analysis indicates that higher carbon prices increase the economic value of emissions reductions and therefore improve the relative attractiveness of lower-carbon hauling.

$$\begin{aligned}\text{Carbon Value} &= 142,697.48 \times \text{IDR } 60,000 \\ &= \text{IDR } 8,561,820,000\end{aligned}$$

The ESG-adjusted results show that internalizing carbon-related value adds to the financial attractiveness of EV hauling, although the direct monetary contribution is smaller than the core mining cash flows. The broader ESG value lies in regulatory preparedness, reduced transition risk, sustainable-finance access, and the long-term competitiveness of low-carbon nickel production.

ESG Integrated Valuation

To enhance the financial evaluation, this study incorporates the economic value of carbon emission reductions into the Discounted Cash Flow model. Based on the emission analysis, the implementation of EVDT results in a total emission reduction of approximately 142,697.48 tons of CO₂e over the life of the mine.

To assess the impact of carbon pricing on project valuation, this study employs three carbon price scenarios: USD 4, USD 10, and USD 25 per tCO₂e. These values are selected to represent a range of current market conditions and future policy-aligned trajectories.

The USD 4/tCO₂e scenario reflects the current carbon market price in Indonesia, where carbon trading remains in its early stages of development, with relatively low liquidity and pricing. This scenario serves as a conservative baseline, capturing the present economic value of carbon under existing regulatory and market conditions.

The USD 10/tCO₂e scenario represents a moderate and forward-looking estimate aligned with global carbon pricing trends and recommendations from international institutions such as the World Bank and the High-Level Commission on Carbon Prices. This level is often cited as a minimum threshold required to incentivize meaningful emissions reductions and low-carbon investment decisions.

The USD 25/tCO₂e scenario reflects a progressive and policy-aligned outlook consistent with the long-term decarbonization pathways required to meet the targets of the Paris Agreement. Many developed carbon markets and policy frameworks indicate that carbon prices may reach or exceed this level in the coming decades, particularly in high-emission sectors such as mining and energy.

By incorporating these three scenarios, the analysis captures a comprehensive range of potential carbon pricing environments, enabling a robust evaluation of the project's financial sensitivity to ESG factors and highlighting the strategic value of low-emission technologies under future regulatory developments.

Table 11

ESG-Integrated Carbon Value by Scenario

Scenario	Net Emission Reduction (tCO ₂ e)	Carbon Price (USD/tCO ₂ e)	Additional Carbon Value (USD)	Additional Value (IDR)
Conservative	112,312	4	449,248.35	7,861,846,138
Base Case	139,410	10	1,394,101.80	23,002,679,700
Optimistic	183,115	25	4,577,868.75	70,956,965,625

Source: Author

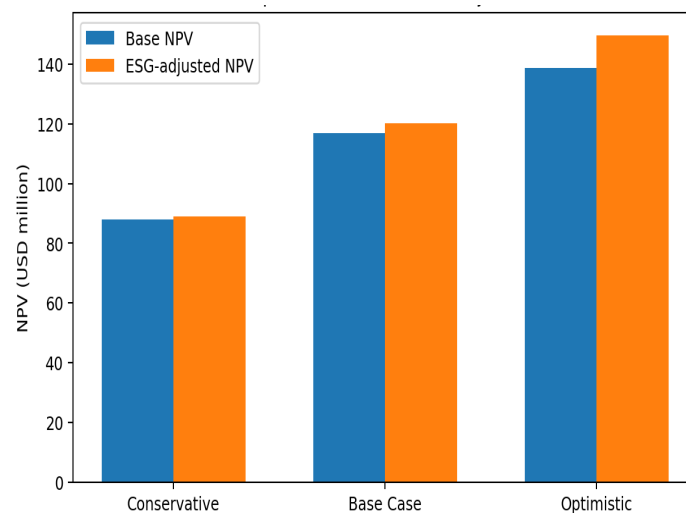


Figure 3. NPV Comparison – Base vs ESG-Adjusted Model
Source: Author

This result demonstrates that when environmental externalities are internalized, EV adoption is not only environmentally sustainable but also financially superior.

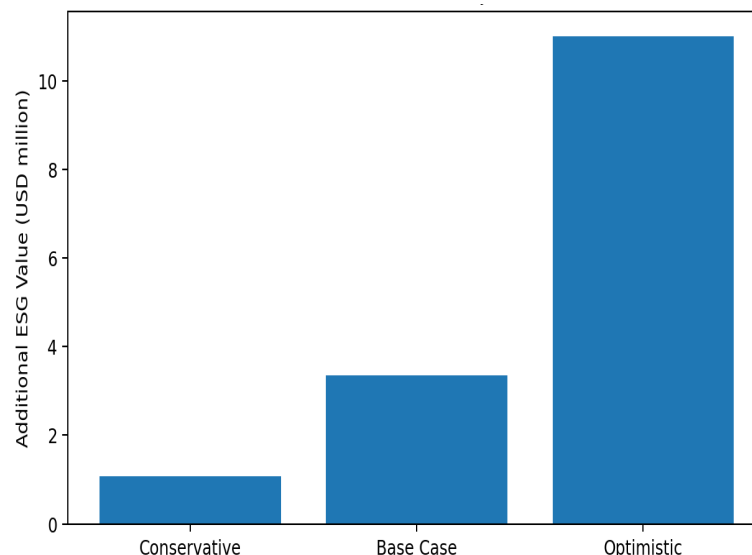


Figure 4. ESG Contribution to Project Value
Source: Author

The ESG-adjusted framework therefore complements rather than replaces conventional financial valuation. Its value is most relevant when carbon prices, regulatory expectations, financing conditions, and stakeholder requirements change over the life of the mine.

Energy Efficiency

To explain the increased energy efficiency of electric vehicle (EV) dump trucks compared with diesel-powered dump trucks, a mathematical simulation can be performed based on the monthly energy consumption and energy conversion efficiency of each system.

In a diesel system, most of the fuel's energy is lost as heat, friction, and other losses. Conversely, in an EV system, the electric motor has a much higher conversion efficiency, resulting in a greater proportion of the input energy being converted into motive power.

The diesel system requires approximately 8.14 million MJ of energy input per month, with assumed system efficiency of 30%–40%. The EV system requires approximately 2.88–4.14 million MJ per month, with assumed system efficiency of 85%–95%. The resulting conversion-efficiency ratio is approximately 2.1–3.2 times in favor of EV hauling, while total input-energy requirements are reduced by approximately 49%–65%.

The resulting conversion-efficiency ratio indicates that the EV system is approximately 2.1–3.2 times more efficient than the diesel system. In addition, total input-energy requirements are reduced by approximately 49%–65%, indicating that electrification improves both conversion efficiency and overall energy utilization.

This advantage is further enhanced by regenerative braking, which allows some kinetic energy to be recovered during operation, particularly on downhill roads or during deceleration. Although not all the benefits of regenerative braking are explicitly included in this basic simulation, this feature can technically further enhance the efficiency advantage of EV systems over conventional diesel vehicles.

Thus, from a thermodynamic and operational energy consumption perspective, the use of EV dump trucks for hauling activities is a superior alternative because it can produce greater mechanical work with lower input energy. Further implications include increased operational cost efficiency, reduced fossil fuel consumption, and substantial reductions in carbon emissions.

Discussion

What is the economic feasibility of replacing conventional diesel dump trucks with EV-based hauling systems in the Pongkeru Block nickel mining operation?

The scenario-based financial results indicate that the EV hauling system is economically favorable relative to the diesel alternative. Under the Base Case, EV hauling generates an NPV of approximately USD 116.99 million and an IRR of 57.33%, compared with USD 52.57 million and 35.18% for diesel. Across the Conservative and Optimistic scenarios, the same direction is maintained, with EV NPV of approximately USD 87.85 million and USD 138.70 million versus USD 25.15 million and USD 85.18 million for diesel, respectively.

The economic advantage is supported by lower energy and maintenance costs and the tax-related assumptions embedded in the model. The analysis indicates that the higher upfront EV investment can be offset by lower operating costs over the modeled project life.

The sensitivity analysis further demonstrates the resilience advantage of EV hauling. The principal project value drivers are ore price, production volume, and royalty rate, while diesel hauling has greater exposure to fuel-price volatility because of its higher dependence on diesel fuel.

At the regional level, coordinated electrification may provide additional benefits through shared charging infrastructure, long-term electricity procurement, and potential economies of scale. The final project also supports a hybrid transition approach in which existing diesel units continue to operate while EV units are introduced progressively, reducing technology, infrastructure, and energy-supply transition risks.

These findings are consistent with the broader literature on mining electrification and energy transition. The results support evaluating electrification as a lifecycle investment and as a mechanism for reducing structural dependence on fossil-fuel markets.

How much carbon emissions can be reduced by adopting an EV-based fleet?

The transition from diesel-powered hauling to EV dump trucks offers substantial environmental benefits. The direct diesel-related baseline is approximately 142,697.48 tCO₂e over the modeled mine life. Full electrification can eliminate these direct Scope 1 hauling emissions, but the net reduction depends on Scope 2 emissions from electricity used for charging.

Under full electrification, the direct diesel emissions associated with hauling are eliminated from Scope 1. However, electricity consumed for charging may generate Scope 2 emissions depending on the electricity-generation mix. The net carbon benefit should therefore be evaluated together with the source of electricity.

Using the supplementary valuation assumption of IDR 60,000 per tCO₂e, the undiscounted indicative value of the direct diesel-emission baseline is approximately IDR 8.56 billion. Separately, the ESG-integrated model uses carbon-price scenarios of USD 4, USD 10, and USD 25 per tCO₂e to evaluate the strategic effect of higher carbon values. These two calculations serve different purposes and should not be treated as the same cash-flow item.

The ESG sensitivity analysis considers carbon prices of USD 4, USD 10, and USD 25 per tCO₂e. As carbon prices increase, the economic value attributed to emissions reduction increases, strengthening the relative attractiveness of lower-carbon hauling technologies.

The results indicate that carbon reduction provides an additional economic value driver, but its direct monetary contribution remains small relative to total project NPV under current carbon-price assumptions. The more significant strategic benefits arise from lower transition risk, regulatory preparedness, and potential access to sustainable finance.

Moreover, the environmental impact of adopting EVDTs can be further enhanced by using cleaner electricity sources. While electric vehicle systems eliminate Scope 1 emissions, they may generate indirect emissions (Scope 2) depending on the electricity generation mix. Therefore, pairing electric vehicle operations with low-carbon power sources, such as hydropower or renewable energy, can significantly reduce Scope 2 emissions and maximize overall emissions reductions.

Collaboration among the mining company, regional government, PLN, and energy providers may therefore be important for developing reliable and lower-carbon electricity infrastructure that supports long-term electrification.

The estimated direct diesel-related emissions reduction demonstrates a substantial opportunity for operational decarbonization in open-pit nickel hauling. The result should be interpreted within the study's system boundary and distinguished from a full life-cycle assessment of batteries, electricity generation, and mine development.

What energy efficiency gains are achieved in the hauling process?

The transition from diesel-powered dump trucks to EV-based hauling systems in the Pongkeru Block produces a significant increase in energy efficiency because electric and internal-combustion powertrains have materially different energy-conversion characteristics.

The analysis indicates that the EV hauling system is approximately 2.1–3.2 times more energy-efficient than the diesel system, while total input-energy requirements are reduced by approximately 49%–65%.

Regenerative braking may provide additional energy savings by recovering part of the vehicle's kinetic energy during deceleration and downhill operation. This benefit is not separately quantified in the base simulation.

The energy-efficiency findings support the economic and environmental case for electrification because lower energy demand can reduce operating costs and fossil-fuel dependence while supporting emissions reduction.

The 2.1–3.2-fold efficiency improvement documented in this study is consistent with Feng et al. (2022), who reported 85%–95% energy-conversion efficiency for electric powertrains compared with 30%–40% for diesel internal-combustion engines. The efficiency advantage is primarily attributable to lower conversion losses in electric powertrains. Regenerative braking can provide an additional benefit during deceleration and downhill operation, although this effect is not separately quantified in the present base calculation. Feng et al. (2022)

The dominant drivers of project value remain commodity price, production performance, and reserve development. Management attention should therefore remain focused on reserve conversion, production optimization, and market and geological risk. Within this framework, electrification should be regarded as a long-term value-adding and risk-management strategy rather than as a standalone source of project risk. Implementation should be supported by reliable power supply, appropriate charging infrastructure, and a practical transition plan, including the option of a phased or hybrid fleet during the transition period.

The scenario and sensitivity analyses indicate that electrification can strengthen the project's resilience to changes in operating conditions. The principal project value drivers are ore price and production volume, followed by royalty rates. Diesel hauling has greater exposure to fuel-price volatility because fuel is a larger component of its operating cost, while EV hauling has a more stable cost structure but requires reliable electricity and charging infrastructure. ESG-integrated valuation therefore complements conventional financial analysis by incorporating transition and carbon-related considerations.

The ESG-integrated valuation demonstrates that carbon reduction can create additional economic value, with the modeled carbon-price scenarios of USD 4, USD 10, and USD 25 per tCO₂e producing additional carbon values of approximately USD 0.45 million, USD 1.39 million, and USD 4.58 million, respectively. The direct monetary contribution remains smaller than the core mining cash flows, but ESG integration provides broader strategic value through regulatory

preparedness, reduced transition risk, potential access to sustainable financing, and stronger long-term positioning for low-carbon nickel production.

The environmental assessment estimates approximately 142,697.48 tCO₂e of direct diesel-related emissions from hauling over the modeled mine life. Full replacement of the diesel hauling fleet can eliminate these direct Scope 1 hauling emissions; however, electricity used for EV charging creates Scope 2 emissions that depend on the electricity-generation mix. Accordingly, the net carbon benefit depends materially on the source of electricity. The final project also indicates scenario-based net emission reductions of approximately 112,312–183,115 tCO₂e under its ESG valuation framework, reinforcing the importance of lower-carbon electricity sources.

The study concludes that EV-based hauling is economically favorable across the Conservative, Base Case, and Optimistic scenarios. The Base Case produces an NPV of approximately USD 116.99 million and an IRR of 57.33% for EV hauling, compared with USD 52.57 million and 35.18% for diesel hauling. The Conservative scenario produces NPVs of approximately USD 87.85 million for EV and USD 25.15 million for diesel, while the Optimistic scenario produces approximately USD 138.70 million and USD 85.18 million, respectively. Using the assumed scenario probabilities of 30%, 50%, and 20%, the probability-weighted expected NPV is approximately USD 112.59 million for EV hauling and USD 50.86 million for diesel hauling. EV payback is two to three years across the scenarios, compared with three to five years for diesel. These results support EV adoption as a financially attractive alternative while recognizing that long-term commodity, production, and energy conditions remain important.

CONCLUSION

The study concludes that EV-based hauling is economically favorable across the Conservative, Base Case, and Optimistic scenarios. The Base Case produces an NPV of approximately USD 116.99 million and an IRR of 57.33% for EV hauling, compared with USD 52.57 million and 35.18% for diesel hauling. The Conservative scenario produces NPVs of approximately USD 87.85 million for EV and USD 25.15 million for diesel, while the Optimistic scenario produces approximately USD 138.70 million and USD 85.18 million, respectively. Using assumed scenario probabilities of 30%, 50%, and 20%, the probability-weighted expected NPV is approximately USD 112.59 million for EV hauling and USD 50.86 million for diesel hauling. EV payback is two to three years across the scenarios, compared with three to five years for diesel. These results support EV adoption as a financially attractive alternative while recognizing that commodity, production, and energy conditions remain important.

The environmental assessment estimates approximately 142,697.48 tCO₂e of direct diesel-related emissions from hauling over the modeled mine life. Full replacement of the diesel hauling fleet can eliminate these direct Scope 1 hauling emissions; however, electricity used for EV charging creates Scope 2 emissions that depend on the electricity-generation mix. Accordingly, the net carbon benefit depends materially on the source of electricity. The final project's ESG framework also reports scenario-based net emission reductions of approximately 112,312–183,115 tCO₂e, reinforcing the importance of lower-carbon electricity sources.

The ESG-integrated valuation demonstrates that carbon reduction can create additional economic value. Under carbon-price scenarios of USD 4, USD 10, and USD 25 per tCO₂e, the modeled additional carbon values are approximately USD 0.45 million, USD 1.39 million, and USD 4.58 million, respectively. The direct monetary contribution is smaller than the core mining cash flows, while the broader ESG value arises from regulatory preparedness, reduced transition risk, potential access to sustainable financing, and stronger long-term positioning for low-carbon nickel production.

The scenario and sensitivity analyses indicate that electrification can strengthen project resilience to changes in operating conditions. The principal project value drivers are ore price and production volume, followed by royalty rates. Diesel hauling has greater exposure to fuel-price volatility because fuel is a larger component of its operating cost, whereas EV hauling has a more stable operating-cost structure but requires reliable electricity and charging infrastructure. ESG-integrated valuation therefore complements conventional financial analysis by incorporating transition and carbon-related considerations.

The dominant drivers of project value remain commodity price, production performance, and reserve development. Management attention should therefore remain focused on reserve conversion, production optimization, and market and geological risk. Within this framework,

electrification should be regarded as a long-term value-adding and risk-management strategy rather than as a standalone source of project risk. Implementation should be supported by reliable power supply, appropriate charging infrastructure, and a practical transition plan, including the option of a phased or hybrid fleet during the transition period.

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AUTHOR CONTRIBUTION STATEMENT

Author 1: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Visualization, Writing – Original Draft Preparation. Author 2: Conceptualization, Validation, Supervision, Project Administration, Funding Acquisition. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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