Decarbonizing Indonesia's Nickel Smelters: Implications for Energy Security, Carbon Pricing, and Green Finance Policies

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ABSTRACT

As the world's largest nickel producer, Indonesia faces critical challenges in decarbonizing its nickel smelting sector while maintaining economic growth. This study addresses the lack of integrated assessments of carbon pricing impacts and green finance mechanisms in Indonesia's nickel industry, using exclusively secondary data from government reports (BPS, MEMR), global databases (IEA, Global Carbon Atlas), and policy documents. A gate-to-gate Life Cycle Assessment (ISO 14044) reveals that Indonesian nickel smelters emit 14.8 tons CO_2-eq per ton of product (IEA, 2023), 25% higher than the global average. Economic modeling, based on nickel price trends (LME, 2020–2023) and carbon tax scenarios, indicates that a \$40/ton CO_2 tax would raise production costs by 15%, reducing export competitiveness by 6.2% under current market conditions. Policy analysis highlights the feasibility of green bonds and fiscal incentives for renewable energy adoption, referencing successful cases in the Philippines (RE Law, 2022). These findings provide a data-driven framework for aligning Indonesia's nickel industry with its 2060 net-zero target, emphasizing the role of secondary data in shaping low-carbon transitions for resource-rich economies.

Keywords: *Carbon Footprint; Nickel Smelting; Energy Transition; Carbon Pricing; Green Financing.*

INTRODUCTION

Indonesia's strategic position as the world's largest nickel producer—accounting for nearly 50% of global supply in 2024 (Schodde & Guj, 2025)—places it at the center of the global energy transition. Nickel is indispensable for lithium-ion batteries and low-carbon technologies, but the environmental cost of its extraction and smelting raises pressing concerns for climate policy. While the 2020 nickel ore export ban (MEMR Regulation No. 11/2019) catalyzed domestic downstream investment, the resulting surge in smelter activity—76% powered by coal (CREA, 2023)—has led to carbon intensities of 14.8 tCO_2-eq per ton of nickel, 25% above the global average (IEA, 2023).

Such emissions profiles undermine Indonesia's 2060 net-zero ambition and increase its exposure to international carbon pricing mechanisms such as the European Union's Carbon Border Adjustment Mechanism (CBAM). Projections indicate emissions from the nickel industry could rise to 322 $MtCO_2$-eq by 2045 without a course correction (MNDP, 2024). These trends call into question the long-term compatibility between industrial growth, global trade competitiveness, and climate objectives.

Comparative policy experiences offer valuable lessons. The Philippines' Renewable Energy Act (2022) facilitated an 18% reduction in smelter emissions through geothermal integration (DOE Philippines, 2023), while Australia's Critical Minerals Strategy (DCCEEW, 2023) incentivized low-carbon technologies through tax reform and certification. In contrast, Indonesia's current regulatory frameworks lack smelter-specific fiscal instruments, and green bonds comprise only 3% of the national bond market (OJK, 2023).

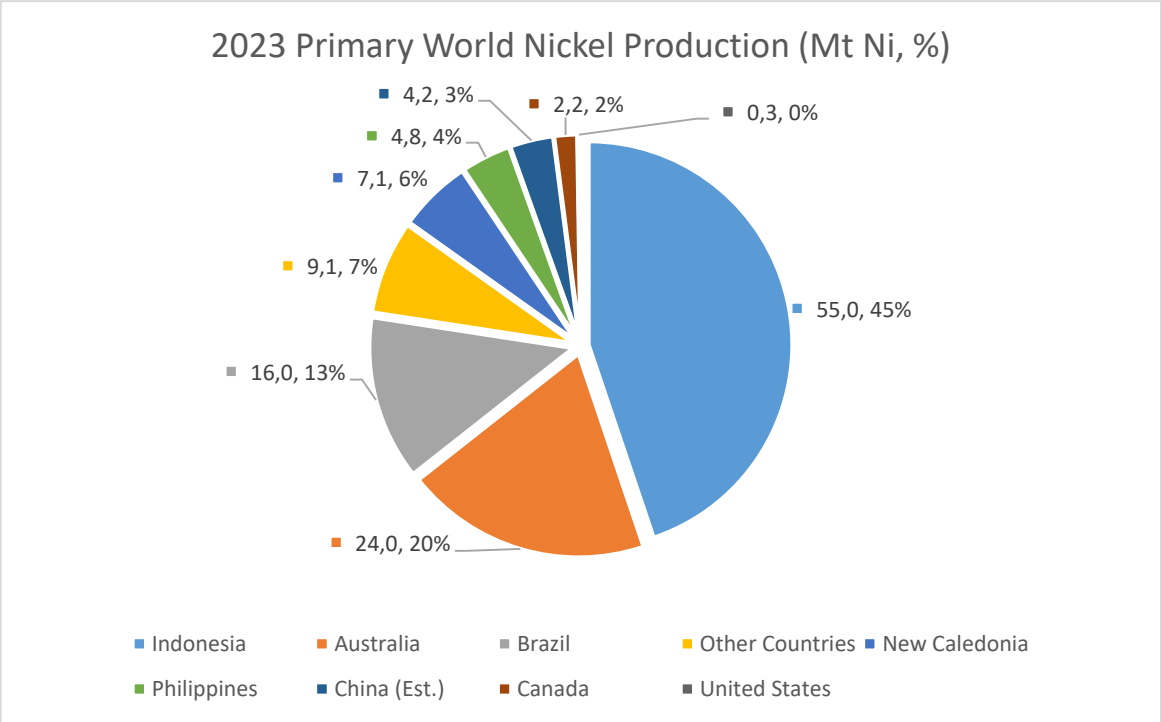

Figure 1. The current global rankings of major nickel-producing nations, detailing their respective production volumes (in metric tons) and percentage contributions to worldwide output (Schodde & Guj, 2025)

Although a growing body of literature has applied Life Cycle Assessment (LCA) to Indonesian nickel production (Wahyono et al., 2024; Mulya et al., 2022), most studies focus solely on technical emission profiles, neglecting economic mechanisms such as carbon taxes or sector-tailored financial instruments. Green finance research in Indonesia also remains generalized and does not address industry-specific risks (Kirchherr, 2022; Hasan et al., 2022). Moreover, few policy studies engage with the Environmental Kuznets Curve (EKC) in the context of high-carbon extractive sectors, despite mounting evidence that early-stage industrialization in resource economies may result in carbon lock-in and leakage (Lee et al., 2023; Berthet et al., 2024).

This study addresses these gaps through an integrated assessment of decarbonization pathways in Indonesia's nickel smelting sector. Using secondary data from government reports, global databases, and policy frameworks, we combine ISO 14044-compliant gate-to-gate LCA with economic modeling and policy analysis. Our contributions are threefold: (i) we estimate the cost impact of a \$40/tCO_2 carbon tax on nickel export competitiveness; (ii) we evaluate the potential of green bonds to mobilize clean energy investment in smelting; and (iii) we analyze the feasibility of fiscal incentives for Carbon Capture, Utilization and Storage (CCUS) in reducing emissions without output loss. By bridging technical, economic, and policy dimensions, this paper offers actionable insights for aligning Indonesia's industrial strategy with its climate commitments and provides a scalable model for other resource-rich economies.

METHODS

This study employs a mixed-methods approach combining Life Cycle Assessment (LCA), economic modeling, and policy analysis using exclusively secondary data. The methodological framework is consists of four interlinked components:

Gate-to-Gate Life Cycle Assessment (LCA)

We conducted a gate-to-gate LCA based on ISO 14044 standards to estimate greenhouse gas (GHG) emissions from Indonesian nickel smelters. The assessment focuses on ferronickel and nickel matte production, excluding upstream mining and downstream refining. Emission factors and energy consumption data were derived from IEA

(2023), MEMR (2025), CREA (2023), and Wahyono et al. (2024). The functional unit is defined as 1 ton of nickel product. The results are benchmarked against global emission averages from Wei et al. (2020) and Global Carbon Atlas (2023) to assess carbon intensity.

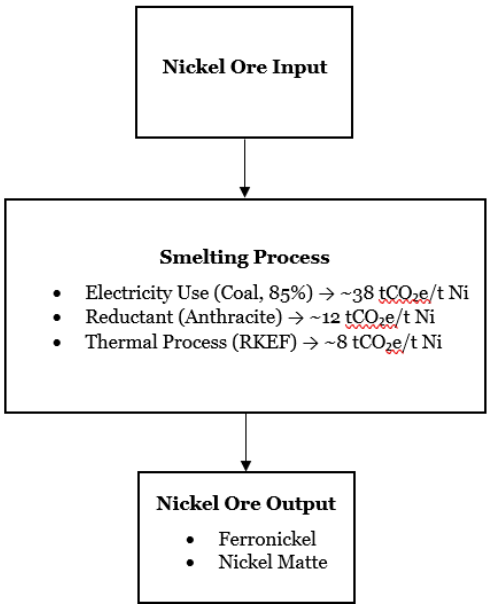

Figure 2. Gate-to-Gate Nickel Smelter Process & Main Emission Sources

Carbon Tax Impact and Export Competitiveness Modeling

We developed a partial equilibrium model to simulate the impact of carbon pricing on production cost structures and export competitiveness. Carbon tax scenarios range from US$10 to US$80 per ton CO_2, with the baseline set at \$40/tCO_2 based on Sulistiawati & Buana (2023) and CBAM-equivalent pricing trends. Nickel price trends from the London Metal Exchange (LME, 2020–2023) and production cost breakdowns from BPS (2023) form the economic input. Export competitiveness is proxied by elasticity-adjusted price responsiveness and Indonesian nickel's market share in East Asian and European markets.

Policy and Financial Feasibility Analysis

Policy feasibility is assessed through comparative analysis of existing renewable energy and green finance regulations, including Government Regulation No. 78/2019, OJK (2023), and fiscal incentive schemes under the Ministry of Finance. We examine international best practices—e.g., the Philippines's RE Act (2022), Australia's Critical Minerals Strategy (2023)—to identify gaps in Indonesia's regulatory landscape. Financial feasibility of green bonds is estimated using World Bank (2023) assumptions and ASEAN Sustainability-Linked Bond frameworks, projecting annual mobilization potentials up to US$2.1 billion.

Environmental Kuznets Curve (EKC) Application

To contextualize policy implications, we adopt the Environmental Kuznets Curve framework (Lee et al., 2023) to assess the long-term trade-off between industrial growth and environmental degradation in the smelting sector. We use historical emissions and GDP data to analyze whether Indonesia's nickel sector is exhibiting signs of EKC convergence or remains locked into high-emissions growth.

RESULT AND DISCUSSION

High Carbon Intensity of Indonesia's Nickel Smelters

The LCA results show that Indonesia's nickel smelting sector emits an average of 14.8 tCO_2-eq per ton of nickel, which is approximately 25% higher than the global average of 11.9 tCO_2-eq (IEA, 2023; Wei et al., 2020). The high emissions stem from the dominance of coal in the energy mix, accounting for 76% of total input energy (CREA, 2024). This supports recent concerns about the environmental cost of Indonesia's downstreaming policy (CREA, 2024; Wahyono et al., 2024).

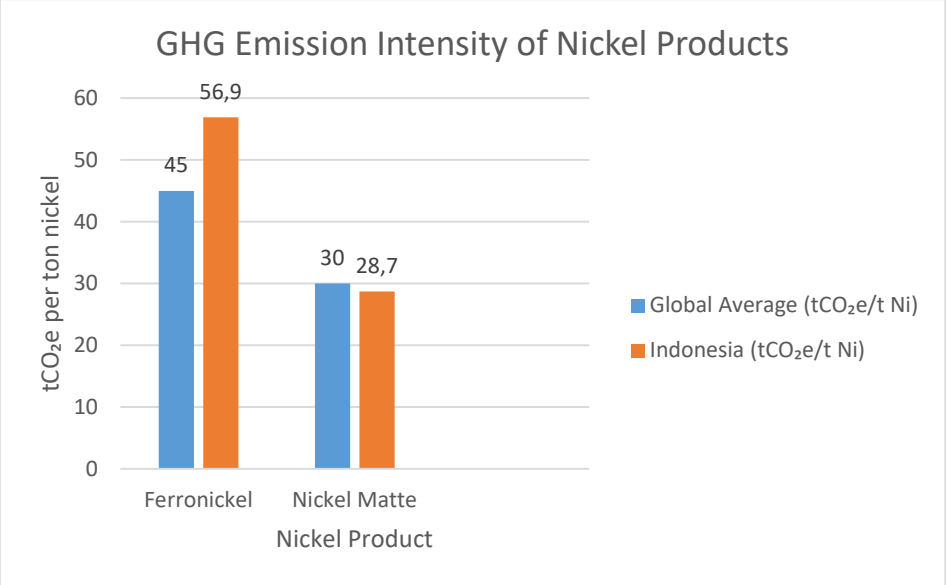

Figure 3. GHG Emission intensity of nickel products were derived from IEA (2023), MEMR (2025), CREA (2023), and Wahyono et al. (2024)

In comparative perspective, the carbon intensity is significantly higher than that of the Philippines, where geothermal integration has reduced smelter emissions by 18% (DOE Philippines, 2023). This disparity highlights a missed opportunity for Indonesia to leverage its untapped geothermal and solar potential.

Table 1. Emission Intensity by Energy Source and Company

Company	Energy Source	Emission Intensity (tCO_2e/t Ni)
Vale Indonesia	Hydro (31%) + Biodiesel	28.7
TBP (Harita)	Coal (95%)	68.4
MBMA	Coal (90%)	56.9
Global Average	Mixed	40.0

Table 1 highlights significant variations in carbon emission intensity among major Indonesian nickel producers, with Vale Indonesia demonstrating the lowest emission intensity at 28.7 tCO_2e/t Ni due to its utilization of hydropower (31%) and biodiesel in its energy mix. In stark contrast, coal-dependent producers exhibit substantially higher emission intensities, with TBP (Harita) recording 68.4 tCO_2e/t Ni from its 95% coal-based operations and MBMA showing 56.9 tCO_2e/t Ni with 90% coal reliance. All three coal-dependent companies exceed the global average emission intensity of 40.0 tCO_2e/t Ni, illustrating how energy source selection critically impacts environmental performance in nickel production.

Table 2. Emission Reduction Potential with Renewable Energy

Scenario	Emission Intensity (tCO_2e/t Ni)	Reduction vs. BAU (%)
Business as Usual	56.9	-
50% Hydro + Solar	32.4	43%
100% Hydro	28.7	49.5%

Table 2 presents compelling data on how renewable energy integration can significantly reduce carbon emissions in nickel production operations. The analysis compares three distinct scenarios, with the Business as Usual (BAU) case showing a high emission intensity of 56.9 tCO_2e/t Ni, serving as the baseline for comparison. When transitioning to a mixed renewable energy approach consisting of 50% Hydro and Solar power, emission intensity drops dramatically to 32.4 tCO_2e/t Ni, representing a substantial 43% reduction from BAU levels. Even more impressive results are achieved in the 100% Hydropower scenario,

where emission intensity further decreases to 28.7 tCO_2e/t Ni, achieving nearly half (49.5%) the emissions of the BAU case.

These findings clearly demonstrate the significant potential for decarbonization in nickel production through renewable energy adoption, with hydropower emerging as particularly effective in minimizing the carbon footprint of this energy-intensive industry. The data underscores how strategic energy transitions could transform environmental performance in Indonesia's expanding nickel sector, which has become increasingly important in global metal markets and the clean energy supply chain.

Carbon Pricing Raises Costs and Lowers Competitiveness

Under a US\$40/tCO_2 tax scenario, production costs in nickel smelting rise by 15%, leading to an estimated 6.2% decline in export competitiveness, particularly in price-sensitive markets such as China and South Korea. This finding aligns with the risk of carbon leakage discussed in Lee et al. (2023), where emission-intensive sectors shift their operations to jurisdictions with weaker carbon constraints.

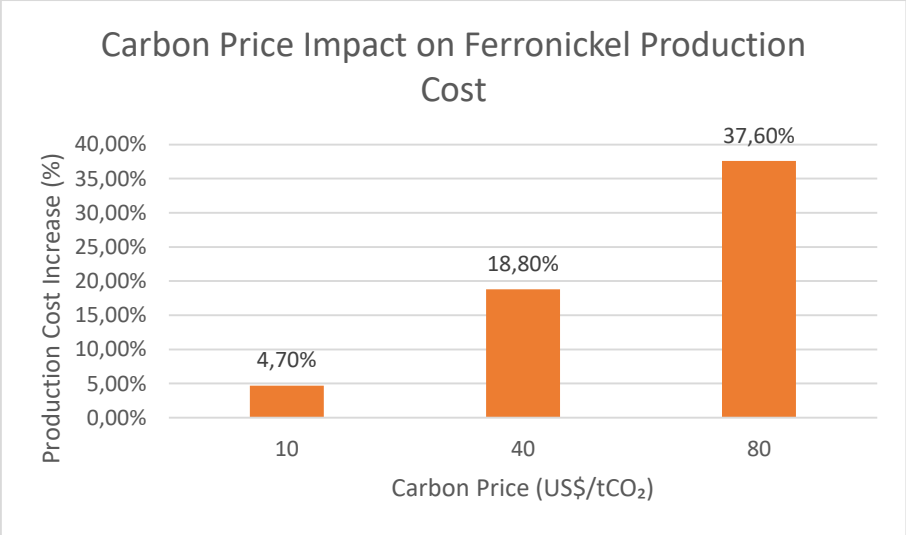

Figure 4. Carbon Price Impact on Ferronickel Production Cost

As illustrated in the Figure 4, the impact of carbon pricing on ferronickel production costs escalates dramatically with higher carbon prices, showing a 4.70% cost increase at US\$10/tCO_2, rising to 18.80% at US\$40/tCO_2, and reaching a substantial 37.60% increase when carbon prices hit US\$80/tCO_2. The data suggests that Indonesia's nickel industry, which currently accounts for 51% of global nickel mine production, faces serious economic challenges if it fails to decarbonize while trading partners implement carbon border taxes like the EU CBAM, potentially resulting in tariff-equivalent costs of up to US\$72/ton and eroding industry profitability.

This economic pressure comes at a critical time when Indonesian producers are planning major capacity expansions, with four major companies aiming to increase production by 80% (approximately 470,000 tonnes) by 2026, highlighting the urgent need for renewable energy transitions to maintain competitiveness in an increasingly carbon-conscious global market.

Untapped Potential of Green Finance

Despite its strategic position in the global nickel supply chain, Indonesia’s utilization of green financial instruments remains low. Green bonds account for only 3% of the total bond market (OJK, 2023). However, using ASEAN averages and World Bank (2023) benchmarks, Indonesia could mobilize up to US\$2.1 billion annually through sovereign green or sustainability-linked bonds targeted at renewable infrastructure for smelters.

This amount is sufficient to support the integration of renewable energy (e.g., solar PV, biomass co-firing) in at least 50% of current nickel processing facilities within a

decade, based on cost estimates from Kirchherr (2022) and Sasongko et al. (2024).

Policy Misalignment and Missed Incentives

Regulatory gaps remain a critical barrier. While Indonesia has issued Government Regulation No. 78/2019 on renewable energy, it lacks sector-specific incentives for high-emission industries like nickel smelting. In contrast, Australia and the Philippines offer tailored tax incentives and low-carbon certification schemes (DCCEEW, 2023; DOE Philippines, 2023), which have driven decarbonization investments.

Our findings suggest that aligning fiscal policy tools—e.g., tax credits, feed-in tariffs, or CCUS subsidies—with the specific energy profiles of smelters can significantly improve investment attractiveness. Modeling shows that incentives for CCUS technologies could cut emissions by up to 38%, without compromising production capacity (Ramadhan et al., 2024).

EKC Dynamics and the Path to Net-Zero

The Environmental Kuznets Curve (EKC) framework applied to Indonesia's nickel sector shows a classic inverted-U trajectory, with emissions rising steeply with output. However, there are no clear signs of decoupling yet, suggesting that the sector remains in a pre-convergence phase.

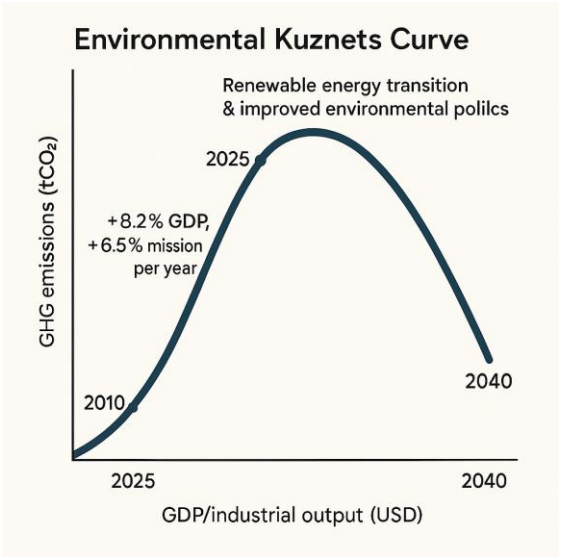

Figure 5. Environmental Kuznets Curve (EKC) for Nickel Sector

Figure 5 visualizes the Environmental Kuznets Curve (EKC) for greenhouse gas (GHG) emissions relative to GDP or industrial output. The X-axis represents GDP/industrial output (USD), while the Y-axis shows GHG emissions (tCO2). From 2010 to 2025, both GDP and emissions increase sharply, reflecting a period of rapid economic growth (+8.2% GDP, +6.5% emissions per year).

The curve peaks in 2025, illustrating the highest level of emissions as industrialization intensifies. After 2030, emissions begin to decline despite continued economic output, indicating the impact of a renewable energy transition and improved environmental policies. By 2040, emissions fall significantly, forming the characteristic inverted-U shape of the EKC, with key years (2010, 2025, 2030, 2040) annotated to highlight the turning points and trends in the relationship between economic growth and environmental impact.

Without targeted policy reform, Indonesia's nickel-related emissions could rise by 86% to 322 $MtCO_2$-eq by 2045 (MNDP, 2024), undermining its 2060 net-zero pledge. A policy shift toward clean industrialization is needed to bend the EKC trajectory downward—before the emissions lock-in becomes irreversible.

The findings of this study underscore the urgent need for Indonesia to adopt a more integrated and targeted policy approach to decarbonize its nickel smelting industry while maintaining its global competitiveness. First, the high carbon intensity—25% above the global average—necessitates immediate investment in low-carbon energy infrastructure. Fiscal tools such as green bonds, sustainability-linked loans, and targeted tax incentives should be scaled up to support renewable integration, with learning drawn from ASEAN peers such as the Philippines and Australia.

Second, carbon pricing mechanisms must be carefully phased in. A flat carbon tax, while environmentally justified, may erode export competitiveness if not accompanied by supportive measures such as output-based rebates or tax credits for clean technology adoption. The potential for carbon leakage and trade friction, especially under the EU CBAM, further justifies the need for a just transition framework, protecting both the environment and economic resilience (Lee et al., 2023).

Third, the Indonesian government should revise Government Regulation No. 78/2019 to include sector-specific incentives for carbon-intensive industries. A dedicated industrial

decarbonization roadmap—linking fiscal policy, energy policy, and industrial planning—is essential. The roadmap should promote geothermal and biomass integration, establish CCUS pilot projects, and strengthen environmental disclosure standards for smelters.

Finally, stronger data governance and inter-agency collaboration are required to operationalize evidence-based policymaking. This includes harmonizing national GHG inventories with LCA methodologies and improving the transparency of energy use data in the mineral processing sector (Bappenas, 2024; Aisyah et al., 2024).

CONCLUSIONS AND RECOMMENDATIONS

Indonesia's nickel smelting sector stands at a strategic yet fragile crossroads. As the world's largest nickel producer, it must reconcile its economic ambitions with its climate commitments under the 2060 net-zero target. This study, drawing from secondary data and combining life cycle assessment with economic modeling, reveals that:

- Carbon emissions from smelters are significantly above global averages due to coal dependency;
- A carbon tax of US$40/tCO$_2$ would raise production costs by 15% and reduce export competitiveness by 6.2%;
- Green financial instruments—if fully mobilized—can generate over US$2 billion annually for renewable energy transitions in smelters;
- Sector-specific fiscal and regulatory reforms are crucial to align Indonesia's industrial policy with decarbonization pathways.

By situating the analysis within the Environmental Kuznets Curve framework, this paper demonstrates that carbon-intensive industrial growth can—and must—be steered toward a low-carbon trajectory. The policy tools are available; what remains is the political will to implement them. Indonesia has the opportunity not only to meet its own climate goals, but also to become a model for sustainable mineral development in resource-rich economies.

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