

Indonesia's Nickel Downstreaming: Contained-Metal Transformation, Rent Distribution, National Value Retention and Carbon Exposure

Juan Ignacio Guzmán

jguzmanb@uc.cl

Pontificia Universidad Católica de Chile

José Joaquín Jara

Pontificia Universidad Católica de Chile

Vicente Arriagada

Pontificia Universidad Católica de Chile

Jorge Bravo

Pontificia Universidad Católica de Chile

Felipe Mora

Pontificia Universidad Católica de Chile

Research Article

Keywords: carbon intensity, contained nickel, downstreaming, export restrictions, mineral rents, nickel

Posted Date: October 23rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11119762/v1>

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Additional Declarations: No competing interests reported.

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Abstract

Indonesia's nickel-ore export restrictions are often evaluated through the growth of processed exports. This paper asks a more demanding mineral-economics question: how did the policy change the physical form of nickel production, the distribution of mineral rents, and the value ultimately retained in Indonesia? The analysis combines a 2010-2024 panel of Indonesia and 11 comparison countries with contained-nickel production evidence, official benchmark-price rules, public-company financial and emissions data, and route-specific life-cycle evidence. Poisson pseudo-maximum likelihood (PPML) is the baseline trade specification. Log-one-plus estimates, event-time diagnostics, treated-unit permutations, and a synthetic control method (SCM) exercise provide complementary checks. The strict 2014-2016 and 2020-2024 regimes are associated with a near-complete contraction in recorded nickel-ore exports, while downstream products expand substantially but are harder to attribute to the ban alone because investment, Chinese demand, and spillovers changed simultaneously. The paper's main contribution is to separate four objects often conflated in downstreaming debates: control of ore exports, physical stage transformation, territorial value added, and nationally retained mineral income after ownership, fiscal, environmental, and depletion adjustments. Indonesia achieved a major industrial transformation, but its economic success depends on rent retention, capacity discipline, and lower-impact processing rather than gross processed exports alone.

Keywords: carbon intensity; contained nickel; downstreaming; export restrictions; mineral rents; nickel

JEL classifications: F13; O14; O25; Q31; Q38; L72

1. Introduction

Export restrictions on unprocessed minerals have returned to the center of industrial-policy debate. The attraction is straightforward. A resource-rich country may possess geological rents but capture only a narrow part of the value chain when ore is exported and transformed elsewhere. Restricting ore exports can enlarge domestic ore supply, lower the price paid by local processors, attract investment, create employment, stimulate supplier development, and shift bargaining power toward the producing state. The countervailing risks are equally important. A restriction can transfer rent from miners to processors without increasing

national income, attract inefficient capacity, encourage evasion, trigger trade diversion, concentrate ownership in foreign firms, accelerate depletion, and lock the economy into energy- and pollution-intensive production.

Indonesia is the defining contemporary case. Mining Law No. 4/2009 established a domestic-processing objective. A strict nickel-ore export prohibition entered into force in January 2014, exports of some low-grade ore were conditionally reopened in 2017, an accelerated reinstatement was announced in 2019, and the strict prohibition resumed in January 2020. The policy coincided with large investment in rotary kiln-electric furnace processing, nickel pig iron, ferronickel, matte, high-pressure acid leaching, mixed hydroxide precipitate, stainless steel, and battery intermediates. By the mid-2020s, Indonesia had become the dominant source of mined nickel and a major location of processing capacity. Its policies were no longer marginal domestic interventions. They affected the world nickel balance, the investment decisions of foreign processors, and the pricing environment faced by competing producers.

The industrial transformation is not in doubt. The harder question is how it should be evaluated in mineral economics terms. An increase in processed-export value can arise because more nickel is mined, because the product is sold at a later processing stage, because world prices change, or because the product mix shifts. It does not by itself reveal how much mineral income is retained by Indonesian residents and government after imported equipment and services, foreign primary income, tax concessions, public infrastructure, environmental damages, and resource depletion are considered. Nor does a rising number of smelters prove that the policy improved allocative efficiency. A processing facility can increase gross domestic product while generating limited nationally retained income if profit is largely foreign-owned, energy is subsidized, and local environmental costs are high.

The existing literature raises the novelty threshold for a new contribution. Policy, trade, and institutional studies establish the chronology and core mechanisms of Indonesia's export restrictions (Östensson 2019; Guberman et al. 2024; World Trade Organization 2022).

Political-economy work highlights the role of foreign capital, Chinese demand, and the electric-vehicle supply chain. Recent firm-, district-, and input-output evidence finds domestic value-added and employment gains, while also identifying allocative losses, uneven commodity responses, and environmental risks (Kee and Xie 2025). The contribution here is therefore not another claim that ore exports fell and processed exports rose. The contribution is to integrate four mineral-specific dimensions that must be jointly considered: physical

contained-metal transformation, rent incidence through the domestic ore-price wedge, national value retention, and carbon/resource adjustments.

This paper asks three related questions. First, how strongly did the phased policy regimes alter Indonesia's recorded trade at different stages of the nickel chain? Second, how should gross upgrading be evaluated once contained metal, rent distribution, ownership, fiscal capture, environmental costs, and depletion are distinguished from gross export value? Third, how should the post-build-out shift toward ore-price regulation, higher royalties, production management, and decarbonization be interpreted within that mineral-economics framework? The study's central contribution is an integrated framework for evaluating downstreaming beyond gross processed exports. First, contained nickel is used as the common physical accounting unit, so that successive intermediate stages are not double counted. Second, the phased 2014-2016, 2017-2019, and 2020-2024 trade design is combined with mine-production and route-level evidence to separate direct trade effects from broader industrial transformation. Third, a rent-distribution and national value-retention framework distinguishes the domestic ore-price wedge, territorial value added, and income retained by residents and government. Fourth, route- and company-level emissions and life-cycle evidence are used to illustrate carbon exposure and the need to evaluate processing industrialization relative to an explicit counterfactual.

The remainder of the paper is organized as follows. Section 2 describes nickel-processing technology, the policy sequence, and the related empirical and methodological literature. Section 3 develops the contained-metal, rent-incidence, national-value-retention, environmental, and depletion framework. Section 4 presents the data and empirical strategy, including PPML, event-time diagnostics, permutation inference, and SCM. Section 5 reports the trade and physical-transformation evidence. Section 6 examines ore-price regulation, ownership, fiscal capture, and carbon exposure. Section 7 interprets the transition from forced processing to supply management, and Section 8 derives policy implications and conditions for international replicability. Section 9 discusses limitations, and Section 10 concludes.

2. Nickel Technology, Policy Sequence, and Related Literature

The appropriate economic unit depends on the technology. Indonesia's nickel resources are predominantly lateritic. Saprolite is generally better suited to pyrometallurgical rotary kiln-electric furnace (RKEF) processing, which produces nickel pig iron (NPI) or ferronickel for stainless steel. Part of this material can be converted into nickel matte and then refined toward nickel sulfate. Limonite is generally better suited to hydrometallurgical high-pressure acid

leaching (HPAL), which produces mixed hydroxide precipitate (MHP) containing nickel and cobalt and can be refined into battery-grade sulfate. These routes differ in ore grade, moisture, energy use, reagents, capital intensity, recovery, coproducts, waste streams, and market destination.

The distinction between product stages is central. Gross ore tonnage, ferronickel tonnage, matte tonnage, and MHP tonnage cannot be added as if each were independent final output. A tonne of ore may contain only a small percentage of nickel, while an intermediate contains a much larger share. Moreover, the same nickel unit can appear successively as ore, nickel pig iron, matte, sulfate, and cathode material. The common unit must therefore be contained nickel, and the system boundary must distinguish throughput from final availability. This follows the mineral-economics principle that economic models must be adapted to the geological, technological, and institutional characteristics of the commodity under study (Tilton and Guzmán 2016).

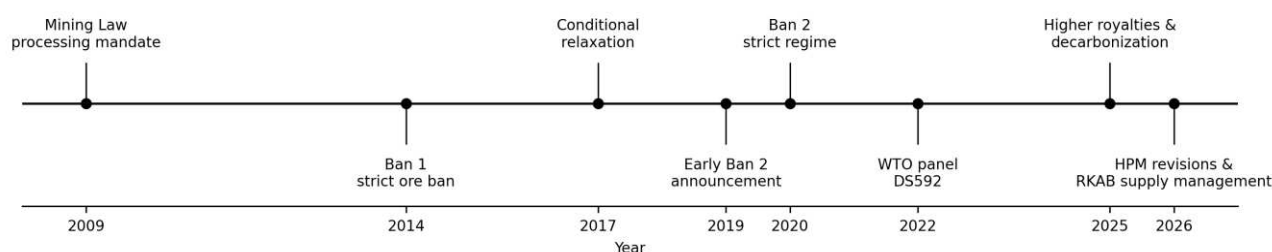


Fig. 1 Indonesia nickel-policy sequence, 2009–2026 (sources: Indonesian legislation, World Trade Organization 2022, and Ministry of Energy and Mineral Resources regulations)

The policy sequence is shown in Figure 1. The 2009 Mining Law created a five-year adjustment horizon for domestic processing. Regulation intensified before the 2014 prohibition, so investment and trade could respond before the formal treatment date. The 2014–2016 regime sharply restricted ore exports. The 2017 relaxation allowed conditional exports of low-grade ore linked to processing commitments, creating a distinct regime rather than a simple removal of policy. The 2019 announcement accelerated the return of the strict ban to January 2020, again creating anticipation. In 2022 the World Trade Organization (WTO) panel found the export prohibition and domestic processing requirement inconsistent with Article XI:1 of the General Agreement on Tariffs and Trade. Indonesia appealed. Legal uncertainty remains economically relevant because it affects durability and international replicability.

After the processing base expanded, policy began to change character. In 2020 the government made the Harga Patokan Mineral (HPM), or mineral benchmark price, a

compulsory reference for domestic nickel-ore transactions. Royalties became more progressive in 2025 and a national decarbonization roadmap placed processing emissions at the center of industrial strategy (World Resources Institute Indonesia and Bappenas 2025). In April 2026 the government revised the HPM formula (Ministry of Energy and Mineral Resources 2026a) to raise the benchmark share of nickel value for standard ore grades and to recognize associated minerals. In September 2026 it recalibrated the formula (Ministry of Energy and Mineral Resources 2026c) for low-grade limonite, sharply reducing the correction factors applied at 1.2% Ni and below while preserving the April schedule above that threshold. Annual mining work-plan approvals (Rencana Kerja dan Anggaran Biaya, RKAB) were also tightened to better align ore supply with demand. Together these changes indicate a transition from a policy designed primarily to create domestic processing capacity toward one concerned with rent allocation, feedstock economics, capacity discipline, and resource management.

The literature on downstreaming has moved well beyond the legal chronology. Östensson (2019) frames coercive downstream processing as an industrial-policy problem in which lost upstream exports must be weighed against any gains in processing, while Guberman et al. (2024) document the nickel ban's trade and institutional mechanisms. Camba (2021) shows that regulation also changes bargaining relations among large-scale miners, small-scale producers, and processing consortia. More recent evidence raises the empirical bar further: Kee and Xie (2025) find higher domestic value added alongside allocative-efficiency losses; Bosker et al. (2025) identify employment and structural-change effects in nickel districts; Soamole and Mokodompit (2025) emphasize the coexistence of upgrading and foreign dependence; Vivoda et al. (2026) place Indonesia's model in the wider ASEAN critical-minerals context and emphasize environmental and strategic-dependence constraints; Azhari and Adrison (2026) document trade discrepancies and evasion incentives; and Firmanto et al. (2025, 2026) show that competitiveness, resource quality, capacity constraints, and sustainability condition the desirability of downstreaming.

The paper also builds on empirical methods used to evaluate policy shocks when treatment is concentrated in one jurisdiction. Poisson pseudo-maximum likelihood is preferred for non-negative trade outcomes with zeros and heteroskedasticity (Santos Silva and Tenreyro 2006), with high-dimensional fixed effects and separation diagnostics implemented following Correia et al. (2020). The synthetic control method (SCM) was developed for comparative case studies in which a treated unit is reconstructed as a weighted combination of untreated units (Abadie et al. 2010; Abadie 2021). Applications span sanctions, export outcomes,

environmental regulation, and sectoral policy (Gharehgozli 2017; Mohan 2017; Peng et al. 2020; Kang et al. 2022). These applications are relevant to Indonesia because there is one treated country, but the method is credible only when pre-treatment fit is strong and comparison units are not themselves materially affected by treatment.

This literature motivates the paper's narrower contribution. It does not claim that Indonesia's export ban uniquely caused the entire downstream build-out. Instead, it combines phased trade evidence with contained-nickel accounting and a mineral-rent framework to distinguish the directly controlled export flow from subsequent physical transformation, and then asks who captures the value generated at later stages and at what environmental and depletion cost. Lim et al. (2021) provide complementary evidence that policy announcements can affect nickel prices before formal implementation, which is why anticipation is treated explicitly in the empirical design.

Industrial policy provides one justification for temporary protection when learning, coordination failures, or agglomeration externalities prevent a country from developing activities in which it can eventually become competitive (Rodrik 2008; Cherif and Hasanov 2019). Mineral downstreaming adds three commodity-specific features. First, the raw input is location-specific and exhaustible. Second, a ban can create a domestic input-price discount that transfers rent even before productivity changes. Third, processing is highly capital- and energy-intensive, so the technology and ownership of induced capacity determine whether local activity becomes national income.

The policy can be successful at one level and unsuccessful at another. Four claims must therefore be separated. The first is physical transformation: more nickel is processed domestically. The second is gross commercial upgrading: exported products have a higher unit value. The third is domestic value addition: output net of intermediate consumption is generated in Indonesia, regardless of who ultimately receives the associated income. The fourth is national value retention: residents and government retain enough income and dynamic benefit to justify fiscal support and compensate for environmental damage, allocative loss, and any incremental depletion cost. Evidence for the first claim does not establish the fourth.

The bauxite comparison reinforces the need for commodity-specific analysis. Indonesia applied restrictions to both nickel and bauxite, yet investment and employment responded much more strongly in nickel. Nickel possessed a combination of laterite resources, rapidly expanding Chinese stainless-steel and battery demand, replicable RKEF technology, integrated industrial parks, and access to large-scale foreign finance. Bauxite processing

required a different infrastructure, energy, and market configuration. The contrast is not an exception to a general downstreaming rule; it is evidence that no universal rule exists.

3. Analytical Framework

The analytical framework begins with a physical identity. Let M_t denote contained nickel recovered from mining in year t , B_{t-1} beginning inventory, O_t contained nickel exported in ore, $D_{r,t}$ nickel entering domestic processing route r , B_t ending inventory, and L_t losses, unrecorded flows, or statistical discrepancy. The contained-metal balance is

$$M_t + B_{t-1} = O_t + \sum_r D_{r,t} + B_t + L_t \quad (1)$$

A strict ore-export prohibition imposes $O_t = 0$ for legal exports, but it does not determine M_t . Mine output can fall, remain unchanged, or increase depending on domestic processing demand, ore prices, recovery, capacity, and investment. This distinction is essential because an export ban is not mechanically a conservation policy.

Customs quantities must be converted to contained nickel. Let $W_{p,t}$ be gross product weight and $\theta_{p,t}$ the nickel-content factor for product p . Then

$$N_{p,t} = W_{p,t} \theta_{p,t} \quad (2)$$

The factor $\theta_{p,t}$ is product- and sometimes facility-specific. Uncertainty in $\theta_{p,t}$ should be represented by low, central, and high values when customs classifications combine products with different grades. Equation (2) prevents the double counting that occurs when successive stages are aggregated in gross tonnes.

The first incidence channel is the domestic ore-price wedge. Let $P_{g,t}^{XP}$ denote the export-parity or alternative-market value of ore with nickel grade g , adjusted to a common delivery point, moisture, payability, and transport basis, and let $P_{g,t}^D$ be the realized domestic price on the same basis. The wedge is

$$\omega_{g,t} = P_{g,t}^{XP} - P_{g,t}^D \quad (3)$$

For wet ore with moisture share m_t , the wedge per tonne of contained nickel is

$$\Omega_{g,t} = \frac{\omega_{g,t}}{g(1-m_t)} \quad (4)$$

A positive $\Omega_{g,t}$ transfers quasi-rent from ore sellers toward domestic processors or other buyers. It is not, by itself, value creation. The national effect depends on who owns the upstream and downstream activities, how the wedge is taxed, and whether processing creates productivity or capability gains.

Indonesia's benchmark price provides a regulated floor rather than an observed market wedge. Under the 2026 rule, the nickel-ore benchmark can be represented as

$$HPM_{i,t} = [HMA_t^{Ni} g_i c^{Ni}(g_i) + HMA_t^{Fe} q_i^{Fe} c^{Fe} + HMA_t^{Co} q_i^{Co} c^{Co} + HMA_t^{Cr} q_i^{Cr} c^{Cr}] (1 - m_i) \quad (5)$$

where HMA is the official mineral reference price, g_i is nickel grade, q_i denotes associated-mineral content, c denotes correction factors, and m_i is moisture. Because the benchmark constrains the domestic transaction range, a higher correction factor reallocates part of the policy-created margin toward miners, all else equal.

The second channel is value retention. Let $Y_{r,t}$ be gross output of route r , $IC_{r,t}$ intermediate consumption, and $CFC_{r,t}$ consumption of fixed capital. Gross and net value added are

$$GVA_{r,t} = Y_{r,t} - IC_{r,t}, \quad NVA_{r,t} = GVA_{r,t} - CFC_{r,t} \quad (6)$$

Territorial value added includes income accruing to foreign owners. Let $W_{r,t}^{res}$ be compensation of resident employees, $T_{r,t}^{net}$ taxes and royalties net of subsidies, $\Pi_{r,t}^{res}$ resident-owned net operating surplus, and $FPI_{r,t}$ foreign primary income remitted or accrued abroad. Nationally retained mineral income can be represented as

$$NRI_{r,t} = W_{r,t}^{res} + T_{r,t}^{net} + \Pi_{r,t}^{res} \quad (7)$$

Equation (7) avoids treating foreign-owned profit as nationally retained mineral income while preserving resident wages, domestic capital income, and government capture. Reinvested foreign earnings require separate treatment because they remain in the domestic capital stock but remain claims of foreign owners.

A useful ownership sensitivity starts with distributable operating surplus $\Pi_{r,t}$, foreign ownership share $f_{r,t}$, and effective domestic capture of foreign-owned profit through taxes, royalties, state participation, or retained local income $\tau_{r,t}$. The retained fraction of distributable profit is

$$\rho_{r,t}^{\pi} = 1 - f_{r,t}(1 - \tau_{r,t}) \quad (8)$$

This expression does not imply that foreign investment is undesirable. It identifies the wedge between domestic production and national income and shows why fiscal design, local ownership, and domestic suppliers matter.

The third channel is environmental. Carbon is the implemented metric in this paper, but the same accounting structure can incorporate sulfur dioxide, particulates, acidification, eutrophication, water use, residue and tailings impacts, land conversion, and local damages when comparable data exist. Let $e_{r,t}^B$ denote emissions per tonne of contained nickel from processing in Indonesia through route r , and let $e_{r,t}^{CF}$ denote emissions under the relevant counterfactual route and location. Incremental emissions are

$$\Delta e_{r,t} = e_{r,t}^B - e_{r,t}^{CF} \quad (9)$$

Let p_t^C be the social carbon price and $D_{r,t}^{local}$ monetized local environmental and social damage. Carbon- and environment-adjusted nationally retained (CANRI) mineral income is

$$CANRI_{r,t} = NRI_{r,t} - p_t^C \Delta e_{r,t} D_{r,t} - D_{r,t}^{local} \quad (10)$$

The relevant comparison is incremental. Charging the full emissions of Indonesian processing without deducting emissions from the displaced foreign route would overstate the carbon cost of relocation. Conversely, comparing only plant emissions while ignoring captive power, mining, reagents, residues, and land-use change would understate it.

Resource depletion enters only through a differential user cost. Let u_t^B and M_t^B denote the user cost and extraction quantity under the ban, and let u_t^{CF} and M_t^{CF} denote the corresponding counterfactual values. The policy-relevant depletion adjustment is

$$\Delta U_t = u_t^B M_t^B - u_t^{CF} M_t^{CF} \quad (11)$$

If the same quantity is extracted at the same date under both regimes, the user-cost term cancels. It becomes material when downstreaming changes extraction timing, recovery, cut-off decisions, mine sequencing, depletion of lower-quality ore, or the probability that ore remains unextracted.

Combining the channels, a route creates positive national value relative to ore export or alternative processing only when

$$NRI_{r,t} + TOT_{r,t} + \Psi_{r,t} > \omega_{g,t} O_t + Ineff_{r,t} + S_{r,t} + p_t^C \Delta e_{r,t} D_{r,t} + D_{r,t}^{local} + \Delta U_t \quad (12)$$

where $TOT_{r,t}$ captures terms-of-trade gains, $\Psi_{r,t}$ verified dynamic spillovers, $Ineff_{r,t}$ processing inefficiency, and $S_{r,t}$ fiscal or infrastructure support not already netted from taxes. Equation (12) is the study's accounting discipline for welfare evaluation. Higher processed-export value is neither necessary nor sufficient for the inequality to hold.

Finally, capacity creation changes the subsequent policy problem. Let K_t be installed processing capacity, Q_t ore throughput, $P_t^{Ni}(Q_t)$ the world nickel-product price that may depend on Indonesian supply, ρ_t the national retention rate from downstream revenue, $C(Q_t, K_t)$ private processing cost, $E(Q_t)$ environmental cost, and $A(K_t - Q_t)$ the economic and political cost of idle induced capacity. A stylized national flow objective is

$$\max_{Q_t} \rho_t P_t^{Ni}(Q_t) Q_t - C(Q_t, K_t) - E(Q_t) - A(K_t - Q_t) \quad (13)$$

Once K_t is large and sunk, a high marginal idle-capacity cost can sustain ore demand even when world prices or national margins fall. The second-stage response may therefore involve production quotas, higher royalties, stricter benchmark prices, closure of non-compliant capacity, or accelerated decarbonization rather than another expansion incentive. In empirical

interpretation, Equation (13) requires care because Indonesia may influence the nickel price in some product segments but cannot treat every nickel-chain price as a fully controlled domestic variable.

4. Data and Empirical Strategy

The trade panel covers Indonesia and 11 comparison countries, seven nickel-chain product categories, and annual observations from 2010 through 2024. The comparison countries are the Philippines, New Caledonia, Australia, Russia, Canada, Brazil, Cuba, South Africa, Madagascar, Guatemala, and the Dominican Republic. They were selected because they produced or exported nickel ore, ferronickel, intermediate products, or refined nickel during the study period and therefore provide economically relevant counterfactual information. The term donor pool is used only for the subset and weights employed in the SCM exercise. The comparison group is not assumed to be unaffected by Indonesia’s policy: the Philippines and New Caledonia are particularly exposed to trade diversion and Chinese procurement, while Russia becomes influential when laterite comparators are excluded. Sensitivity to these cases is therefore reported in Online Resource 1, which contains the comparison-country panel, variable and source definitions, PPML and robustness diagnostics, event-time and SCM diagnostics, material-flow and reserve-life tables, HPM calculations, and the source ledger. The product categories are nickel ore and concentrates, ferronickel or nickel pig iron-like material, nickel matte, sintered oxides and other intermediate products, nickel sulfate, unwrought unalloyed nickel, and unwrought nickel alloys. Trade data are from UN Comtrade (United Nations Statistics Division 2026). Export value is deflated to 2024 U.S. dollars using the U.S. CPI-U, All Items, U.S. city average, annual average, series CUUR0000SA0 (U.S. Bureau of Labor Statistics 2026). Quantities are used only when the reported unit is physically comparable. Unit values are interpreted as composition-dependent trade unit values, not as pure prices. Online Resource 1 reports countries, product codes, transformations, missing-data rules, zero-trade rules, and the source ledger.

Table 1. Nickel-chain customs categories and measurement limits

HS category	Product interpretation	Chain stage	Main limitation
260400	Nickel ore and concentrates	Upstream	Grade and moisture vary. Gross tonnes are not contained nickel
720260	Ferronickel, often including NPI-like material	Pyrometallurgical intermediate	Customs code does not clearly separate NPI from ferronickel
750110	Nickel matte	Intermediate	Quality and payability vary

750120	Sintered oxides and other intermediates	Intermediate	Can combine materially different products; not a unique MHP code
283324	Nickel sulfate	Refined chemical	Nickel content and solution or crystal form vary
750210	Unwrought unalloyed nickel	Refined metal	May not represent battery-grade material
750220	Unwrought nickel alloys	Refined/alloy stage	Broad product composition

The treatment is phased: Ban 1 covers 2014-2016, the conditional relaxation covers 2017-2019, and Ban 2 covers 2020-2024. The baseline estimator is Poisson pseudo-maximum likelihood (PPML), which accommodates zero trade observations without transforming the dependent variable. For each country-product-year observation, the pooled specification allows treatment effects to differ by product:

$$E[y_{cpt} | X_{cpt}] = \exp\{\alpha_{cp} + \lambda_{pt} + \sum_{k=1}^3 \beta_{kp} D_{kt} I_c + X'_{cpt} \gamma_p\} \quad (14)$$

The dependent variable is non-negative export value or quantity. Country-product fixed effects absorb time-invariant country-product characteristics, product-year fixed effects absorb shocks common to each nickel-chain product, and the three phase indicators identify Ban 1, the conditional relaxation, and Ban 2. Their interactions with Indonesia are allowed to vary by product. PPML is preferred because log-linearization can be biased under heteroskedasticity and because deleting zero trade is inappropriate for a policy that intentionally drives some recorded flows toward zero (Santos Silva and Tenreyro 2006). The Ban-2 ore estimate is close to a boundary solution, so final inference requires convergence and separation diagnostics using a separation-aware implementation such as `ppmlhdfc` (Correia et al. 2020). The log-one-plus transformation is retained only as a robustness specification. Large coefficients from that transformation are not interpreted as exact percentage changes.

The phased design improves on a single post-2014 indicator because the legal regimes changed materially, but it does not eliminate anticipation. The 2009 law and pre-2014 implementation measures could affect investment and trade before Ban 1, while the 2019 announcement could affect outcomes before Ban 2. Event-time coefficients are therefore used as diagnostics of timing and pre-treatment behavior, not as a separate source of identification. The annual frequency and short pre-2014 window limit power; full coefficients and joint pre-treatment tests are reported in Online Resource 1.

Inference is difficult because there is one treated country and only 11 comparison countries. Conventional country-clustered standard errors rely on asymptotics that are weak with so few

clusters, so the paper emphasizes point estimates, transparent robustness checks, and treated-unit permutation ranks. With 12 possible treated countries, the smallest simple placebo probability is

$$p_{min} = \frac{1}{12} = 0.083 \quad (15)$$

This discreteness means that a rank of first among 12 is strong comparative evidence but does not cross a conventional 5% threshold. The statistical language used below reflects that limitation.

The synthetic control method (SCM) is used as a complementary counterfactual design rather than as the sole identification strategy. SCM is attractive in a single-treated-country setting because it constructs a data-driven counterfactual from a weighted combination of comparison countries (Abadie et al. 2010; Abadie 2021), and related applications have used it to study sanctions, exports, environmental policy, and sector-specific regulation (Gharehgozli 2017; Mohan 2017; Peng et al. 2020; Kang et al. 2022). In the Indonesian nickel case, however, donor contamination is economically important and downstream scale is difficult to reproduce. The synthetic-control results are therefore used to assess whether Indonesia departs from the pre-policy path that can be reconstructed from the comparison countries; donor weights, pre- and post-treatment root mean squared prediction errors, leave-one-donor-out sensitivity, and placebo diagnostics are reported in Online Resource 1.

Spillovers further complicate identification. The Philippines increased ore exports to China after Indonesian restrictions; Chinese firms shifted capital and procurement; competing producers reacted to nickel prices; and world processing investment changed. Such countries are economically affected controls. The empirical strategy therefore treats the upstream coefficient as evidence on the direct effect on recorded Indonesian ore exports, while interpreting downstream coefficients as comparative evidence on transformation under the policy and investment environment rather than as isolated causal effects of the ban.

Physical validation uses mine production in contained nickel, route-level output, smelter and HPAL capacity, and public-company disclosures. The mine series is preferable to adding customs product stages because it measures primary nickel once. Route data describe transformation but are not summed without a material balance. The present application provides a partial material-flow diagnostic for 2013, 2019, and 2023 rather than a fully closed contained-nickel account. Employment and domestic-value evidence is drawn from the district- and firm-level literature. Ownership, fiscal, price-floor, and emissions information is used as diagnostic evidence for the value-retention mechanisms in Equations (3)-(13).

Use of generative AI and AI-assisted technologies. OpenAI ChatGPT was used to assist with language editing, manuscript organization, equation and figure formatting, and bibliographic cross-checking. All substantive analyses, numerical results, interpretations, and final text were reviewed and verified by the authors, who take full responsibility for the manuscript.

5. Trade and Physical Transformation Results

The strongest empirical result is the contraction in recorded nickel-ore exports. Table 2 reports the principal PPML point estimates for ore and ferronickel. The log-one-plus estimates, standard errors, event-time diagnostics, and treated-unit permutation results are reported in Online Resource 1. The strict-ban coefficients for ore are large and negative, while the relaxation sharply reduces the estimated effect. In the treated-unit permutation exercise applied to the log-one-plus model, Indonesia ranks first in absolute effect among the 12 countries in both strict regimes, which corresponds to the minimum attainable simple placebo probability of 0.083. The same discreteness means that these ranks should be read as strong comparative evidence rather than as conventional 5% significance tests.

Table 2. Key trade-regime estimates for nickel ore and ferronickel exports

Product and outcome	Ban 1, 2014-2016	Relaxation, 2017-2019	Ban 2, 2020-2024	Interpretation
Ore volume, PPML	-3.71	-0.87	-17.93	Near-complete recorded export collapse. Ban 2 requires separation diagnostics
Ore real value, PPML	-3.81	-0.05	-12.98	Directionally consistent with volume collapse
Ferronickel volume, PPML	0.85	2.66	4.30	Positive downstream expansion. Attribution remains mixed
Ferronickel real value, PPML	0.21	1.89	3.36	Consistent with processed-export expansion

The event-time and synthetic-control diagnostics point in the same direction but also delimit the causal claim. The joint pre-treatment test has a reported p-value of 0.784 for ore exports, providing no evidence of a systematic pre-trend in that outcome, whereas the corresponding ferronickel test has a p-value of 0.087 and therefore warrants more caution. In the full synthetic-control donor pool, New Caledonia receives 95.8% of the weight and the post/pre root mean squared prediction-error ratio is very large; after excluding both the Philippines and New Caledonia, Russia receives 99.9% of the weight and pre-treatment fit deteriorates materially. The 2023 gap remains large across these specifications. SCM therefore supports the conclusion that Indonesia diverged sharply from feasible comparison paths, but the concentration of donor weights and exposure of key donors to Indonesia's policy make it a diagnostic of uniqueness rather than the paper's primary causal estimator; full weights, fit statistics, gaps, and sensitivity results are reported in Online Resource 1.

The pattern is internally coherent with the legal sequence. The strict bans suppress recorded ore exports; the relaxation permits their return; and the second strict regime suppresses them again. This is the study's most clearly identified result because the intervention directly governs the observed flow. Even here, mirror trade matters. Azhari and Adrison (2026) estimate material discrepancies under Indonesian mineral restrictions, consistent with evasion, reclassification, timing, or reporting differences. The coefficient should therefore be interpreted as an effect on recorded official exports, not proof that all physical ore shipments ceased.

The downstream evidence is positive but less sharp. Ferronickel expands most strongly after 2020, while matte, other intermediates, and nickel sulfate also record positive Ban-2 coefficients in the broader analysis. Several estimates are large but do not rank first in the comparison-country distribution. This difference is economically meaningful. The policy can stop an official ore export immediately, but a smelter requires capital, technology, electricity, infrastructure, construction, and commissioning. Chinese stainless-steel demand, foreign financing, industrial-park integration, and global nickel prices changed at the same time. The ban was a central component of the investment environment, but the annual panel does not identify the full downstream expansion as its isolated effect. The downstream coefficients are therefore interpreted as comparative evidence of transformation under the policy regime rather than as standalone causal estimates.

Trade diversion is visible in the Philippines. The rise in Philippine ore exports offsets a material share of Indonesia’s recorded decline, especially during the later strict regime. This reduces the world-supply effect of the restriction and contaminates a natural donor. It also explains why a national policy can transform domestic industrial location while producing a smaller change in global primary nickel availability.

Physical evidence establishes that industrial transformation occurred even where causal attribution is incomplete. Figure 2 reports Indonesian mine output in contained nickel. Production was approximately 440 thousand tonnes in 2013, fell after the first ban, then rose rapidly as domestic processing capacity expanded. It reached about 853 thousand tonnes in 2019, 2.03 million tonnes in 2023, and roughly 2.2 million tonnes in 2024. Relative to the pre-ban 2013 level, mine output increased approximately fivefold.

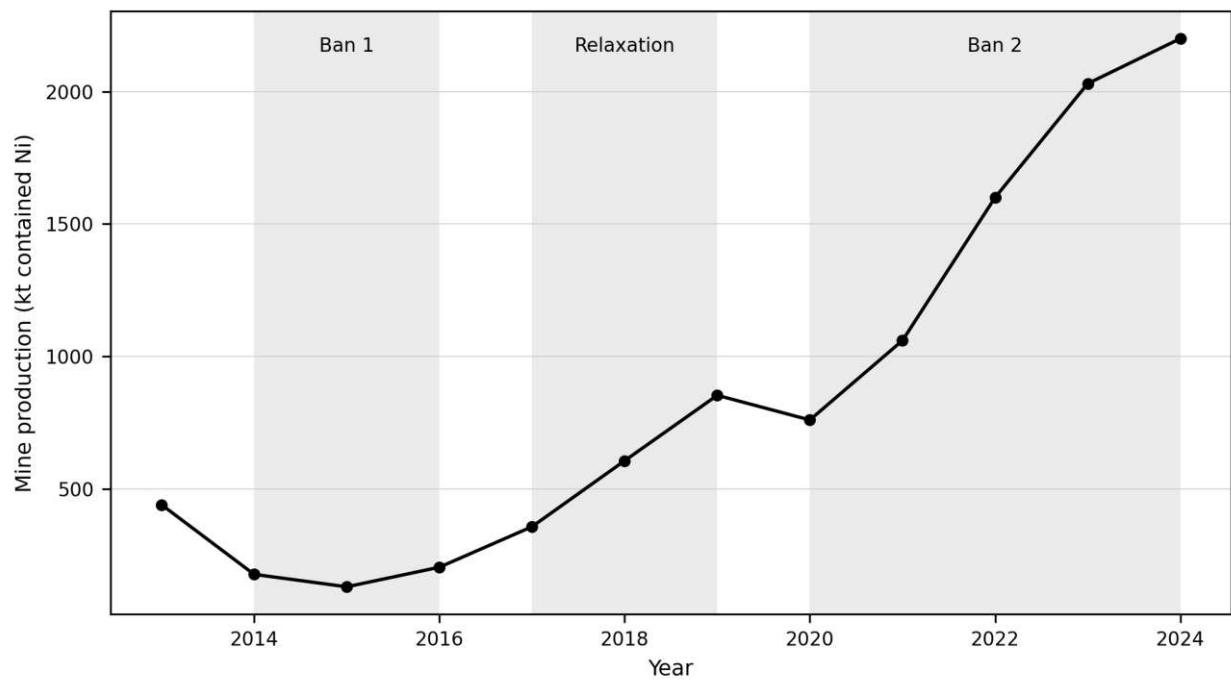


Fig. 2 Indonesian mine nickel production, 2013–2024, with policy phases (sources: U.S. Geological Survey 2024, 2025; International Nickel Study Group 2024)

The route-level evidence is similarly striking but must be read as flows through a chain. Nickel pig iron output reportedly increased from approximately 27 thousand tonnes of contained nickel in 2015 to about 1.39 million tonnes in 2023. Matte increased from approximately 79 thousand tonnes in 2014 to 265 thousand tonnes in 2023. MHP emerged at scale after 2021. Ferronickel grew more slowly because NPI and integrated stainless-steel capacity became the dominant pyrometallurgical route. These series overlap: NPI can be

converted into matte, and matte or MHP can become sulfate. Therefore, Figure 3 presents the route structure rather than adding the series.

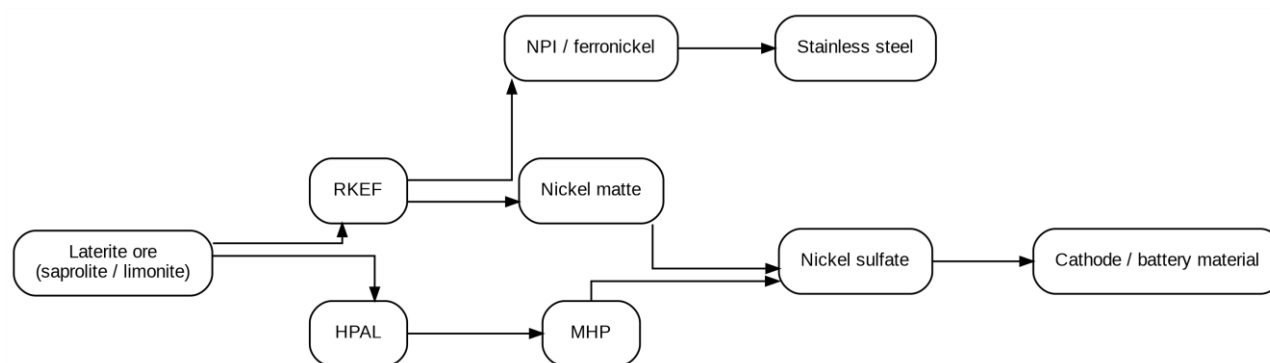


Fig. 3 Principal Indonesian laterite-nickel processing routes from ore to stainless-steel and battery-material products

The partial material-flow diagnostic in Online Resource 1 uses 2013, 2019, and 2023. It deliberately reports unexplained residuals rather than forcing closure. The benchmark years show three distinct states: pre-ban ore-export orientation in 2013, relaxation-era coexistence of ore exports and domestic processing in 2019, and near-zero official ore exports with large domestic processing in 2023. This is sufficient to support the physical-transformation claim, but not yet a complete national contained-nickel balance.

The physical transformation generated employment and local economic activity. Recent district-level and firm-level studies report positive effects on employment and domestic value added in nickel-exposed areas, while also finding allocative costs and weaker outcomes for bauxite. These results are compatible: a policy can create jobs and value added while still using capital, energy, or ore less efficiently than the counterfactual. The bauxite contrast supports the view that nickel's outcome depended on a specific conjunction of geology, technology, demand, foreign investment, and industrial parks.

6. Rent Distribution, Ownership, Fiscal Capture, and Carbon Exposure

The first measurable distributional mechanism is the price paid for ore. Indonesia's HPM is a regulated domestic benchmark rather than an observed export-parity price. The 2020 framework made the benchmark compulsory (Ministry of Energy and Mineral Resources 2020) for domestic nickel-ore transactions and allowed only limited downward deviations for specified quotation-period or quality differences. Under the earlier schedule, 1.9% Ni ore used a 20% correction factor, implying 17% at 1.6% Ni. Decree 144.K/MB.01/MEM.B/2026 (Ministry of Energy and Mineral Resources 2026a), effective in April 2026, raised the factor to 30% at 1.6% Ni, with one percentage-point changes for each 0.1 percentage-point change

in grade, and added explicit treatment of associated iron (Fe), cobalt (Co), and chromium (Cr). Decree 363.K/MB.01/MEM.B/2026 (Ministry of Energy and Mineral Resources 2026c), effective 15 September 2026, preserved the schedule above 1.2% Ni but introduced a separate low-grade rule: the factor at 1.2% Ni fell from 26% to 14%, with the cobalt factor also reduced for ore at or below this threshold. The two 2026 revisions therefore illustrate that rent allocation is now being calibrated by ore quality and processing route rather than moving uniformly in favor of either miners or processors.

Figure 4 isolates the nickel component of the benchmark under the pre-2026, April 2026, and September 2026 correction-factor schedules, holding the reference nickel price at USD 17,802.14 per dry metric tonne (Ministry of Energy and Mineral Resources 2026b) and moisture at 30% to isolate the effect of the formula itself. Associated iron, cobalt, and chromium credits are excluded.

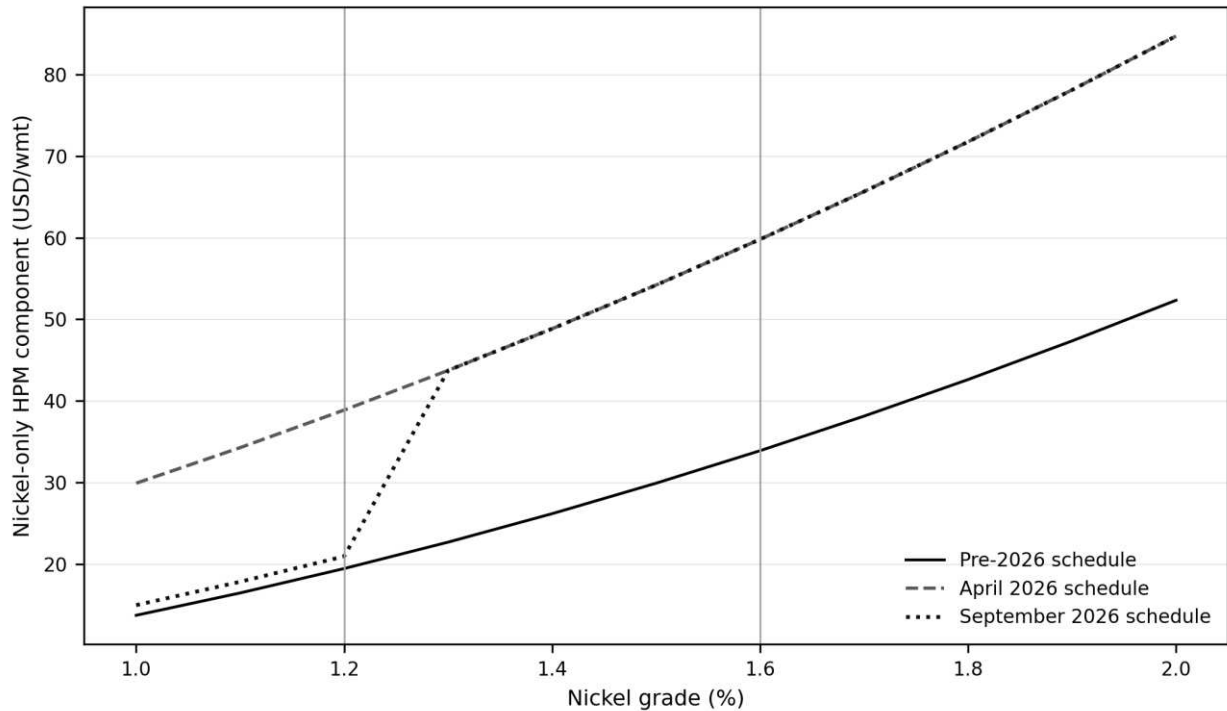


Fig. 4 Nickel-only HPM component under the pre-2026, April 2026, and September 2026 correction-factor schedules at a fixed reference price and 30% moisture

At 1.6% nickel, the earlier schedule produces

$$HPM_{Ni}^{old} = 17802.14 \times 0.016 \times 0.17 \times 0.70 = 33.90 \text{ USD/wmt} \quad (16)$$

The 2026 schedule produces

$$HPM_{Ni}^{2026} = 17802.14 \times 0.016 \times 0.30 \times 0.70 = 59.82 \text{ USD/wmt} \quad (17)$$

Holding the reference price and moisture fixed, the nickel-only floor component rises by

$$\frac{59.82-33.90}{33.90} = 0.765 \quad (18)$$

At 1.6% Ni, the April 2026 revision raises the nickel-only benchmark component by approximately 76.5% relative to the earlier schedule under the fixed-price illustration above, and the September 2026 amendment leaves that grade unchanged. The September amendment is nevertheless economically important because it sharply lowers the benchmark for low-grade limonite at 1.2% Ni and below, which is particularly relevant for HPAL feed. These changes are regulatory rent-distribution diagnostics, not estimates of the realized domestic ore-price wedge. A full wedge requires realized domestic transaction prices and an alternative-market or export-parity comparator adjusted for grade, moisture, freight, impurity, and payability.

The second mechanism is ownership and fiscal capture. Indonesia can record high territorial value added while a substantial share of capital income accrues to foreign owners. At the same time, foreign-owned plants create resident wages, taxes, royalties, local procurement, infrastructure, and learning. The correct object is therefore not a binary foreign-versus-domestic classification but the decomposition in Equation (7). A plant-level nationally retained mineral-income account should identify resident labor compensation, domestic supplier margins, corporate and withholding taxes, royalties, state participation, tax holidays, imported services, depreciation, and remitted or reinvested earnings.

Public data allow a preliminary scale diagnostic rather than a national retained-income estimate. A public 2023 sample of Antam, Merdeka Battery Materials, Trimegah Bangun Persada/Harita, and Vale Indonesia reports approximately 353 thousand tonnes of contained nickel, USD 6.77 billion of revenue, USD 996 million of net profit, and 15.35 million tonnes of greenhouse-gas emissions expressed as carbon dioxide equivalent (CO₂e). The observations span ferronickel, matte, and MHP routes, so they are not a homogeneous production frontier. They nevertheless show the order of magnitude of carbon exposure relative to reported earnings.

Table 3. Four-company public nickel sample, 2023

Indicator	Sample value	Per tonne of contained nickel
Contained-nickel output	353 thousand tonnes	-
Revenue	USD 6.77 billion	USD 19,181
Net profit	USD 996 million	USD 2,822
Reported greenhouse-gas emissions	15.35 million tonnes CO ₂ e	43.5 tonnes CO ₂ e
Carbon price equal to sample net profit divided by emissions	-	USD 64.9 per tonne CO ₂ e

The profit-equivalent carbon price is

$$p_C^* = \frac{996 \text{ million USD}}{15.35 \text{ million tCO}_2\text{e}} = 64.9 \text{ USD/tCO}_2\text{e} \quad (19)$$

This ratio is not a carbon-adjusted value or the carbon price at which the companies become economically non-viable. Net profit already reflects taxes, financing, product prices, and accounting choices; emissions boundaries differ; and carbon costs may be passed through. It is a transparent carbon-exposure materiality indicator: at a carbon shadow price near USD 65 per tonne, the sample's reported emissions cost equals its reported net profit.

A facility-specific Indonesian life-cycle assessment provides a lower-emission benchmark for MHP. Kinanti et al. (2026) estimate 15.85 kilograms of carbon dioxide equivalent per kilogram of nickel in MHP from mining through HPAL, equivalent to 15.85 tonnes per tonne of contained nickel. The same study reports terrestrial acidification and freshwater eutrophication, showing why carbon alone is incomplete. Figure 5 compares the MHP intensity with the listed-company sample average.

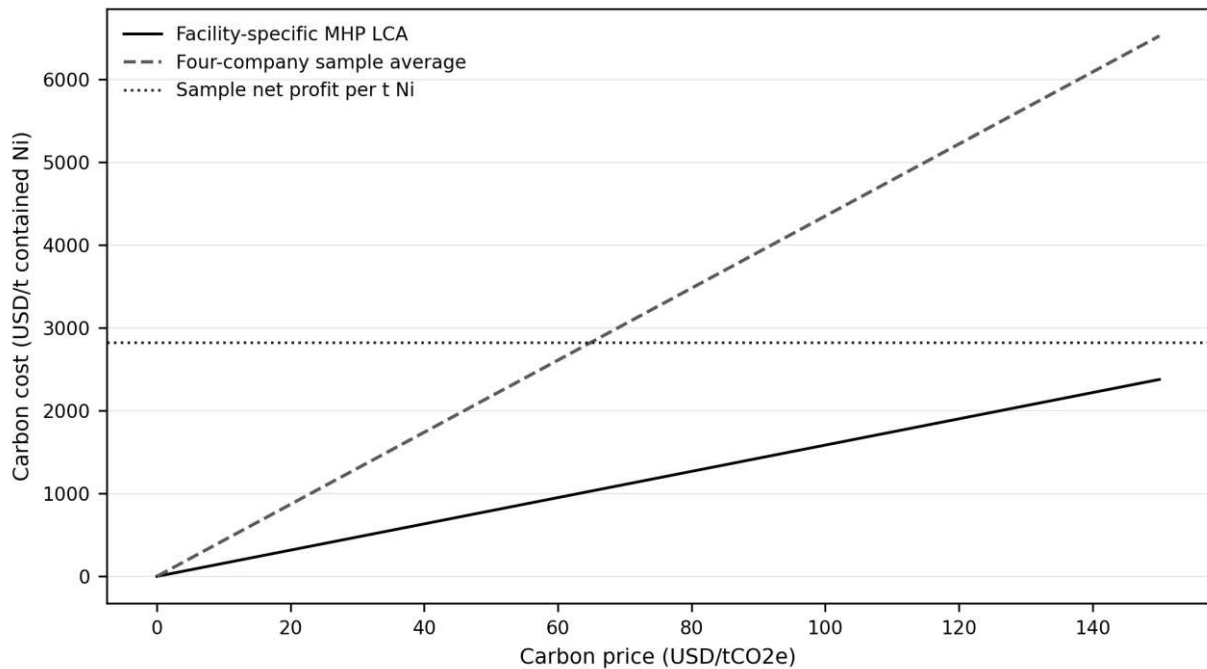


Fig. 5 Carbon-cost exposure under the facility-specific MHP life-cycle benchmark and the four-company listed-producer sample

At a carbon price of USD 50 per tonne, the implied carbon cost is approximately USD 793 per tonne of nickel for the facility-specific MHP estimate and USD 2,175 for the listed-company sample average. At USD 100 per tonne, the corresponding values are approximately USD 1,585 and USD 4,349. These scenarios illustrate how processing route and electricity source can materially alter carbon exposure relative to reported processing income. Since the

counterfactual route is not identified, these results should not be interpreted as incremental carbon-adjusted national values.

The carbon adjustment must use the correct counterfactual, not only carbon exposure measures. If Indonesian processing displaces equally carbon-intensive processing in another country, only the incremental difference belongs in Equation (10). If the policy induces output that would not otherwise have been processed, the full additional route may be relevant. The counterfactual also changes over time as importing countries decarbonize. A rigorous national account should therefore report route-specific Indonesian emissions and displaced-route emissions separately.

Local impacts remain outside the monetary calculation. They include land conversion, coastal water quality, sulfur dioxide, particulate matter, tailings and residues, water use, worker safety, and community disruption. These costs can be spatially concentrated even when national value added is positive. A nationally successful industrial policy may still require compensation, strict environmental standards, monitoring, and technological change to address local losses.

The combined evidence supports a sharper interpretation of downstreaming. Indonesia created domestic processing, employment, and fiscal bases. At the same time, the ban created a captive ore market, and foreign-owned, carbon-intensive capacity may retain only part of the resulting margin nationally. The 2026 HPM reform, higher royalties, production management, and decarbonization agenda can therefore be read as attempts to address rent-distribution and environmental problems that became more evident after the first-stage industrial objective was achieved.

7. From Forced Processing to Supply Management

The post-2024 policy sequence can be understood as a second-stage response to sunk capacity. During the first stage, the government sought to change industrial location by making ore unavailable to foreign processors and abundant to domestic plants. The restriction was designed to lower the domestic input price, attract investment, and generate a large installed industrial base. Once the base existed, continued rapid mine expansion coincided with global oversupply, lower nickel prices, pressure on smaller miners, and a growing captive-energy system. The marginal policy problem shifted from how to create processing capacity to how to manage the quantity, rent distribution, and environmental quality of that processing infrastructure.

Four policy developments illustrate the shift. First, progressive royalty rates introduced in 2025 increased the state's claim on ore and several processed products as prices rose. Second, the April 2026 HPM formula raised the regulated benchmark for standard saprolite grades and explicitly recognized associated minerals, reallocating part of the processing margin upstream. Third, the September 2026 amendment reduced the correction factors for low-grade limonite used in HPAL, easing feedstock costs for battery-material processors while preserving the higher-grade schedule. Fourth, the government tightened RKAB approvals and explicitly linked ore supply management to market balance and resource conservation. Taken together, these measures are more consistent with state-contingent supply and rent management than with a simple continuation of the original export-ban strategy.

Supply management does not necessarily mean cartel pricing. Indonesia is dominant in mine supply but still faces substitution, recycling, stainless-steel demand, battery-chemistry change, inventories, and responses from other producers. Moreover, mining approvals control wet ore, while the international market prices contained nickel in different product forms. A reduction in wet-tonne approvals may have a smaller or larger contained-nickel effect depending on grade, moisture, recovery, and route allocation.

The capacity constraint creates a domestic tension. An ore quota that is low relative to smelter demand can support ore and nickel prices but can also reduce utilization, increase ore imports, encourage lobbying for quota expansion, and strand capital. Indonesia already imports some ore from the Philippines despite being the world's largest mine producer, showing that the processing system and the resource policy are not automatically aligned. In the notation of Equation (13), the marginal cost of idle capacity competes with the resource and price benefits of lower throughput.

A state-contingent rule is preferable to a fixed target. The policy can condition approvals on verified ore inventories, contained-nickel demand, plant efficiency, taxes paid, environmental compliance, and progress toward decarbonization. High-emission or chronically underperforming facilities should not receive the same priority as efficient plants simply because both represent sunk capital. Production management should also be coordinated with the HPM floor. A quota that supports world prices but leaves domestic miners below a transparent benchmark would reproduce the original rent-transfer problem.

The WTO dispute limits international replicability. The panel concluded that the export prohibition and domestic processing requirement were inconsistent with Article XI:1 and were not justified by the exceptions invoked. Indonesia appealed, but the legal uncertainty raises the expected cost of policies that rely on indefinite quantitative export restrictions.

More durable alternatives may include transparent royalties, auctioned extraction rights, carbon and environmental standards, time-limited investment support, infrastructure, skills, and non-discriminatory incentives tied to measurable domestic externalities.

The policy objective should therefore be reframed. The relevant target is not the maximum quantity processed domestically. It is the highest sustainable nationally retained mineral value per tonne of depleted nickel, subject to environmental and social constraints. A smaller, more efficient, lower-carbon system can dominate a larger system whose margins depend on cheap ore, tax concessions, and coal-fired power.

8. Policy Implications and International Replicability

The results imply a hierarchy of policy evaluation. First, did the intervention alter the controlled flow? For nickel ore, the answer is clearly yes. Second, did it create domestic processing? The physical evidence also says yes. Third, did processing generate territorial value added and employment? Existing district- and firm-level evidence supports a positive answer, with heterogeneity and allocative costs. Fourth, did Indonesian residents and government retain enough mineral income to compensate for support, foreign profit income, environmental damage, and differential depletion? The available evidence is incomplete, and the present study provides a framework and diagnostics rather than a full national account. Fifth, is the industrial structure resilient to lower prices, higher carbon constraints, and technological change? The move toward supply management suggests that resilience is now the central issue.

Five practical measures follow. First, Indonesia should publish a contained-nickel material account. The account should reconcile mine production, imports, inventories, ore allocation, route throughput, intermediate production, exports, and losses. Product codes alone cannot do this. A physical account would also improve royalty control and reduce the scope for misclassification.

Second, the government should publish a domestic rent-distribution account. The HPM benchmark, realized mine prices, delivery terms, ore grade, moisture, processor payability, royalties, and taxes should be reported on a comparable basis. This would reveal whether miners, processors, workers, government, or foreign owners capture the policy-created margin.

Third, incentives should be conditional on measurable spillovers. Time-limited support can be tied to resident employment, verified domestic procurement, training, research, recovery improvement, infrastructure access, and emissions performance. A permanent input-price

discount is a weak capability policy because it can sustain inefficient capacity without learning.

Fourth, carbon and local environmental costs should be integrated into mineral policy rather than treated as a separate climate agenda. Captive power, process heat, sulfuric acid, residues, land use, and water should be monitored at facility level. Benchmarking in tonnes of carbon dioxide equivalent per tonne of contained nickel would allow processing rights and fiscal incentives to favor lower-impact routes.

Fifth, supply management should be transparent and state-contingent. Annual approvals can respond to market balance and resource conservation, but opaque discretionary reductions create investment risk and rent seeking. A published rule linking approvals to contained-nickel balance, environmental performance, tax compliance, and inventories would be more credible.

The Indonesian case also provides a basis for evaluating whether downstreaming can be replicated elsewhere, but the relevant question is not whether another country can legally copy an export ban. The Indonesian evidence shows that outcomes depend jointly on resource scale, ore characteristics, processing technology, downstream demand, infrastructure, finance, ownership, environmental capacity, fiscal administration, legal durability, and substitution risk. These dimensions follow directly from the mechanisms developed in Sections 2-7: they determine whether a restriction can redirect processing, whether the induced capacity can operate competitively, and whether the resulting rent is retained nationally rather than absorbed by inefficient production, foreign income, fiscal support, or environmental damage. Table 4 therefore converts the Indonesian case into a set of diagnostic questions for other mineral-producing economies rather than a checklist of conditions that automatically justifies downstreaming.

The table is part of the paper's contribution because it links the empirical case to a general mineral-economics decision rule. A country with a small market share and high processing costs may mainly divert trade and lose upstream rents, whereas a producer with scalable technology, infrastructure, and durable downstream demand may create genuine local capabilities. Even in the latter case, the policy should be judged against national value retained per unit of depleted resource, not against the gross value of processed exports.

Table 4. Conditions for assessing the international replicability of mineral downstreaming

Dimension	Question	Why it matters
Resource position	Is mine supply large enough to influence processing location or buyer behaviour?	A small producer mainly diverts trade and loses market access
Ore and technology	Can the domestic ore be processed with commercially mature, scalable technology?	Processing cost and learning differ by mineral and deposit type
Demand	Is there durable downstream demand near the proposed product stage?	Capacity without demand becomes stranded or subsidy-dependent
Infrastructure and energy	Are power, water, ports, roads, and industrial services available at competitive social cost?	Private plant economics can conceal public infrastructure cost
Finance and ownership	Can the country attract capital without surrendering nearly all capital income and control?	Territorial value added can exceed national retained income
Domestic capability	Can resident firms and workers supply skills, maintenance, engineering, and inputs?	Linkages determine dynamic spillovers
Environmental capacity	Can emissions, residues, land, and water impacts be managed and enforced?	High external costs can reverse national welfare gains
Fiscal and regulatory capacity	Can government measure ore, products, costs, related-party prices, and profits?	Weak administration reduces rent capture and encourages evasion
Legal durability	Is the instrument consistent with international obligations or credibly time-limited?	Legal uncertainty raises the investment threshold
Substitution risk	Can consumers switch products, chemistries, locations, or suppliers?	Persistent restrictions can destroy future demand

Nickel met more of these conditions than bauxite in Indonesia. Other countries may not. A policy package based on infrastructure, skills, carbon standards, competitive power, and transparent fiscal capture may create more national value than an export prohibition where market share is small or processing is structurally uncompetitive.

The market implication extends beyond Indonesia. By shifting a majority of mine supply into an integrated domestic chain, Indonesia changed the form in which nickel reaches the world market. Class II intermediates, matte conversion, MHP, and sulfate do not respond identically to the London Metal Exchange (LME) refined-nickel price. Market analysis must therefore distinguish mine supply, intermediate availability, refined Class I units, stainless-steel demand, and battery-material qualification. The same distinction applies to policy: controlling ore does not control all nickel availability one-for-one.

9. Limitations

The empirical results face several limitations. The trade panel contains one treated country and a small comparison set. Permutation probabilities are discrete, and several controls are affected by trade diversion, foreign investment, or price spillovers. The estimates therefore provide strong evidence for the direct suppression of official ore exports but more limited evidence for the isolated causal effect on downstream capacity.

Annual data are coarse relative to policy announcements and investment timing. The 2009 law, pre-2014 regulations, 2017 relaxation, 2019 announcement, and 2020 implementation create anticipation and overlapping regimes. Monthly partner-level data would improve event timing and absorb importer-product demand shocks.

Customs categories are imperfect measures of the physical chain. Ferronickel and NPI can share a code; MHP is not uniquely identified; grade, moisture, and payability vary; and mirror discrepancies can reflect freight, timing, classification, or evasion. A fully reconciled contained-nickel series therefore remains to be built from triangulated customs, mine, plant, inventory, and production data.

The nationally retained mineral-income account remains incomplete because plant-level ownership, imported inputs, fiscal concessions, related-party prices, reinvested earnings, and domestic procurement are not consistently public. The four-company sample is a carbon and financial materiality diagnostic, not a national retained-income estimate.

PPML is the preferred functional form for the non-negative trade outcomes because it retains zero observations and is robust to heteroskedasticity under correct conditional-mean specification. However, the archived materials available for this version contain PPML point estimates but not the full variance-covariance matrices, convergence logs, or separated-observation diagnostics. The extremely negative Ban-2 ore-volume estimate should therefore be interpreted as evidence that recorded exports approach zero rather than as a stable semi-elasticity. Final submission should regenerate PPML inference from the raw panel and archive the separation diagnostics.

The depletion diagnostic is deliberately simple. Reserve life remains around 25-27 years across the reported benchmark years because reserve estimates rose alongside production. This does not prove absence of scarcity, because reserves are endogenous to exploration, prices, technology, and reporting. Nor does it estimate user cost. It only cautions against a simplistic fixed-stock interpretation while highlighting the need to evaluate whether downstream changes extraction paths and ore-quality depletion.

Environmental effects are represented primarily through carbon because comparable route-level data are most available there. Local pollution, residues, tailings, land conversion, water use, marine effects, and community impacts require facility-level and site-specific evidence. These effects can alter national welfare even when carbon-adjusted value appears positive.

10. Conclusion

Indonesia's nickel downstreaming policy produced a genuine industrial transformation. The strict export bans sharply reduced recorded ore exports; domestic processing capacity expanded; mine output rose dramatically; and Indonesia became central to global stainless-steel and battery-material supply chains. In that sense, the policy changed the physical and institutional form in which Indonesian nickel reaches world markets.

The transformation is not the same as proof of national welfare improvement. Downstreaming shifts rents between miners, processors, workers, government, foreign owners, and affected communities. The relevant metric is not gross processed-export value. It is nationally retained mineral income per tonne of depleted nickel, adjusted for fiscal support, ownership, environmental damages, and the resource user cost when extraction paths differ.

The sequence of HPM revisions in 2026 is especially informative. The April formula increased the benchmark share of nickel value for standard ore grades and recognized associated minerals, while the September amendment preserved that schedule above 1.2% Ni but sharply reduced the correction factor for low-grade limonite. The policy problem has therefore evolved beyond simply forcing processing: the state is now adjusting how mineral rent is shared across ore qualities and processing routes while also managing production, fiscal capture, and decarbonization.

The Indonesian case is therefore neither a simple success story nor a cautionary tale against downstreaming. It is a mineral-specific industrial policy whose outcome depends on geology, processing technology, market share, ownership, fiscal capacity, environmental governance, and legal durability. The policy lesson for other mineral producers is not to copy an export ban. It is to ask whether domestic processing can generate retained national value after all resource, fiscal, ownership, and environmental adjustments are made.

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