

Online Resource 1: Supplementary Information

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

This Online Resource documents the comparison-country panel, trade variables, product codes, PPML baseline estimates, log-one-plus robustness checks, event-time and synthetic-control diagnostics, partial material-flow and reserve-life diagnostics, HPM benchmark calculations, and the public-source ledger supporting the manuscript.

S1. Country panel and comparison set

Table S1. Comparison-country panel and SCM donor candidates

Country	Role in analysis	Nickel-chain rationale
Indonesia	Treated country	Laterite nickel producer and policy jurisdiction
Philippines	Comparison country; SCM donor candidate	Major laterite ore exporter to China; directly exposed to trade diversion
New Caledonia	Comparison country; SCM donor candidate	Laterite producer and ferronickel exporter; dominant synthetic-control weight
Australia	Comparison country; SCM donor candidate	Large diversified nickel producer and processor
Russia	Comparison country; SCM donor candidate	Large integrated nickel producer/refiner; dominant alternative SCM donor when laterite comparators are excluded
Canada	Comparison country; SCM donor candidate	Integrated sulfide nickel producer and refiner
Brazil	Comparison country; SCM donor candidate	Nickel producer with laterite and ferronickel exposure
Cuba	Comparison country; SCM donor candidate	Laterite nickel/cobalt producer with hydrometallurgical route
South Africa	Comparison country; SCM donor candidate	Nickel-chain comparator with refined/intermediate exports
Madagascar	Comparison country; SCM donor candidate	Ambatovy laterite/HPAL producer
Guatemala	Comparison country; SCM donor candidate	Laterite/ferronickel comparator
Dominican Republic	Comparison country; SCM donor candidate	Ferronickel/laterite comparator

Membership in the comparison set does not imply absence of spillovers. The term donor pool is reserved for the weighted set used in the synthetic control method (SCM). The Philippines, New Caledonia and, to a lesser extent, Russia are economically exposed to Indonesia's policy through trade diversion, Chinese procurement, processing investment, and price responses. Results are therefore reported with donor-pool sensitivity rather than treating these countries as unaffected controls.

S2. Variables, sources and transformations

Table S2. Variables, sources, units, and transformations

Variable	Source	Raw unit	Transformation	Deflator	Missing / comparability rule
Export value	UN Comtrade	Current USD	Deflated to 2024 USD	CPI-U CUUR0000SA0 annual average, rebased to 2024	Missing row = zero in balanced baseline only after reporter/product/year coverage check; reporting flags retained

Variable	Source	Raw unit	Transformation	Deflator	Missing / comparability rule
Net weight / quantity	UN Comtrade	Reported mass/quantity	Converted to tonnes when unit is consistent	Not applicable	Used only when physical units are sufficiently comparable; residual shipments excluded from unit-value calculations
Unit value	Derived	USD per tonne	Export value divided by reported tonnes	Same 2024 USD deflator for numerator	Interpreted as composition-dependent trade unit value, not pure price
Policy phases	Indonesian regulations; WTO materials; official decrees	Dates/regimes	Ban 1 2014-2016; relaxation 2017-2019; Ban 2 2020-2024	Not applicable	2009 mandate and 2019 announcement treated as anticipation risks
Mine and route output	USGS Indonesia Minerals Yearbook; INSG	Contained nickel	Thousand tonnes of contained Ni	Not applicable	Route series overlap and are not summed without a material balance
Nickel reserves	USGS Mineral Commodity Summaries	Contained nickel	Thousand tonnes Ni	Not applicable	Used only for depletion diagnostics; reserves are endogenous economic stocks
Mirror trade	WITS / UN Comtrade	Value and gross weight	Reporter-partner comparison	Not applicable	Used to diagnose timing, reclassification, evasion and reporting discrepancies
HPM and HMA	ESDM decrees	USD per dry metric tonne and formula factors	Nickel-only floor component calculated under fixed price and moisture assumptions	Not applicable	HPM is a regulated benchmark floor, not realized mine price or export parity
Company financial and emissions sample	Public company disclosures compiled in prior research	Revenue, profit, emissions, contained Ni	Per tonne of contained nickel	Not applicable	Diagnostic only; product mix and boundaries vary across firms

S3. HS-code mapping and physical comparability

Table S3. HS-code mapping and physical comparability

HS category	Product interpretation	Chain stage	Principal limitation	Physical treatment
260400	Nickel ore and concentrates	Upstream	Grade and moisture vary; gross tonnes are not contained nickel	Use value and net weight; convert only under explicit grade/moisture scenarios
720260	Ferronickel, often including NPI-like material	Pyrometallurgical intermediate	Customs code does not cleanly separate NPI from ferronickel	Treat as processed-stage trade; avoid interpreting as homogeneous NPI
750110	Nickel matte	Intermediate	Quality and payability vary	Use value; physical conversion needs product assay
750120	Sintered oxides and other intermediates	Intermediate	Can include materially different products; not a unique MHP code	Use as broad intermediate category; triangulate with plant/route data
283324	Nickel sulfate	Refined chemical	Nickel content and solution/crystal form vary	Convert only with explicit product form assumption
750210	Unwrought unalloyed nickel	Refined metal	May not be battery-grade; LME deliverability varies	Treat as refined metal trade

HS category	Product interpretation	Chain stage	Principal limitation	Physical treatment
750220	Unwrought nickel alloys	Refined/alloy stage	Broad product composition	Use cautiously; not a single nickel-content factor

S4. PPML baseline results and archive requirement

Table S4. PPML baseline point estimates

Product	Outcome	Phase	PPML coefficient	Inference status	Interpretation
Ore	Real value	Ban 1	-3.81	Point estimate only	Large decline in recorded ore exports
Ore	Real value	Relaxation	-0.05	Point estimate only	Relaxation weakens the strict-ban effect
Ore	Real value	Ban 2	-12.98	Point estimate only; separation diagnostics required	Near-zero recorded exports
Ore	Volume	Ban 1	-3.71	Point estimate only	Large decline in recorded ore quantity
Ore	Volume	Relaxation	-0.87	Point estimate only	Partial return of ore exports
Ore	Volume	Ban 2	-17.93	Point estimate only; possible quasi/complete separation	Boundary-like collapse in recorded ore quantity
Ferronickel	Real value	Ban 1	0.21	Point estimate only	Limited immediate downstream response
Ferronickel	Real value	Relaxation	1.89	Point estimate only	Positive processed-export expansion
Ferronickel	Real value	Ban 2	3.36	Point estimate only	Stronger downstream expansion after 2020
Ferronickel	Volume	Ban 1	0.85	Point estimate only	Limited immediate response
Ferronickel	Volume	Relaxation	2.66	Point estimate only	Positive processed-volume expansion
Ferronickel	Volume	Ban 2	4.30	Point estimate only	Strong processed-volume expansion

Poisson pseudo-maximum likelihood (PPML) is the manuscript's baseline functional form for non-negative trade outcomes with zeros. The point estimates below are those available from the underlying analysis. The current research package does not contain the original variance-covariance matrix, convergence log, or separation diagnostics; these must be regenerated from the raw panel before journal submission. The Ban-2 ore coefficient is boundary-like and should be interpreted as a near-complete collapse in recorded exports rather than as a stable semi-elasticity. Final estimation should use a separation-aware high-dimensional fixed-effects implementation such as `ppmlhdfe` (Correia et al. 2020).

S5. Log-one-plus robustness and treated-unit permutation inference

Table S5. Log-one-plus robustness and treated-unit permutation results

Product	Outcome	Phase	Coefficient	Clustered SE	Permutation p	Rank
Ore	Volume	Ban 1	-13.10	1.07	0.083	1/12
Ore	Volume	Relaxation	0.45	1.95	1.000	12/12
Ore	Volume	Ban 2	-14.96	1.84	0.083	1/12
Ferronickel	Volume	Ban 1	0.36	1.36	0.917	11/12
Ferronickel	Volume	Relaxation	2.86	1.83	0.667	8/12
Ferronickel	Volume	Ban 2	5.27	1.74	0.333	4/12

Product	Outcome	Phase	Coefficient	Clustered SE	Permutation p	Rank
Ore	Real value	Ban 1	-15.78	1.20	0.083	1/12
Ore	Real value	Relaxation	1.03	2.50	0.917	11/12
Ore	Real value	Ban 2	-13.38	2.42	0.167	2/12
Ferronickel	Real value	Ban 1	-0.53	2.34	0.833	10/12
Ferronickel	Real value	Relaxation	2.60	3.26	0.667	8/12
Ferronickel	Real value	Ban 2	5.26	3.23	0.417	5/12

The smallest attainable simple treated-unit permutation probability with 12 countries is $1/12 = 0.083$. These estimates therefore provide robustness and comparative ranking rather than conventional many-cluster inference.

S6. Event-study diagnostics

Table S6. Event-time pre-treatment diagnostics

Outcome	Base year	Pre-treatment diagnostic	Interpretation
Nickel ore export volume	2013	Joint pre-treatment test p = 0.784	Pre-treatment pattern does not reject parallel movement in the underlying event-time diagnostic
Ferronickel export volume	2013	Joint pre-treatment test p = 0.087	Pre-period is borderline; downstream causal interpretation should be cautious

Event-time evidence should be read as timing diagnostics rather than a conventional once-treated event study because the treatment is announced in 2009, implemented in 2014, relaxed in 2017, announced again in 2019, and reinstated in 2020.

S7. Synthetic-control diagnostics

Table S7. Synthetic-control fit and donor-pool sensitivity

Donor pool	Pre RMSPE	Post RMSPE	Post/pre ratio	Principal donor	Weight	2023 gap
Full donor pool	0.003	19.95	6556.2	New Caledonia	95.8%	USD 15.74 bn
Excluding Philippines	0.014	19.40	1397.2	New Caledonia	90.4%	USD 15.74 bn
Excluding Philippines and New Caledonia	1.209	13.30	11.0	Russia	99.9%	USD 15.74 bn

The synthetic control method (SCM) is retained as a complementary diagnostic, not as the primary causal estimator. The full donor pool places 95.8% of the weight on New Caledonia; excluding the Philippines still leaves 90.4% on New Caledonia; excluding both the Philippines and New Caledonia shifts 99.9% of the weight to Russia and materially worsens pre-treatment fit. The large and persistent post-treatment gap is therefore evidence that Indonesia diverged sharply from feasible comparison paths, but the concentration of weights and treatment-related exposure of key donors limit a literal no-policy interpretation. This follows the diagnostic logic emphasized in Abadie et al. (2010) and Abadie (2021).

S8. Partial contained-nickel and ore-trade diagnostic

Table S8. Partial contained-nickel and ore-trade diagnostic

Year	Policy state	Mine output (kt Ni)	Ore exports (Mt gross)	Ore imports (Mt gross)	NPI (kt Ni)	Matte (kt Ni)	Ferronickel (kt Ni)	MHP (kt Ni)
2013	Pre-ban	440	c. 60-65	n.a.	n.a.	n.a.	n.a.	0

Year	Policy state	Mine output (kt Ni)	Ore exports (Mt gross)	Ore imports (Mt gross)	NPI (kt Ni)	Matte (kt Ni)	Ferronickel (kt Ni)	MHP (kt Ni)
2019	Relaxation	853	32,3801	0.052	179	71.0	25.7	0
2023	Ban 2	2,030	near zero; mirror larger	0.374468	1,390	265	21.5	180

Interpretation: 2013 is the pre-ban export-oriented baseline; 2019 is the relaxation regime in which ore exports and expanded processing coexist; 2023 combines near-zero official ore exports with large domestic processing. Gross ore cannot be converted to contained nickel without grade and moisture assumptions. Route outputs overlap and cannot be summed as final output. This is a partial diagnostic, not a closed national material balance. A complete balance requires plant-level ore feed, grades, moisture, recovery, inventories, and intermediate-to-intermediate transfers.

S9. Nickel production, reserves and simple reserve-life diagnostic

Table S9. Nickel production, reserves, and simple reserve-life diagnostic

Year	Mine production (kt Ni)	Reserves (kt Ni)	Production / reserves	Simple reserve life (years)
2014	177	4,500	3.93%	25.4
2019	853	21,000	4.06%	24.6
2023	2,030	55,000	3.69%	27.1
2024	2,200	55,000	4.00%	25.0

Reserve-life ratios are diagnostics, not measures of scarcity rent or physical exhaustion. Reserve estimates change with prices, exploration, reporting standards, technology, and economic assumptions.

S10. HPM ore-price floor diagnostic

For the standard-grade illustration, the reference nickel price is held at USD 17,802.14 per dry metric tonne and moisture at 30%, with associated Fe, Co and Cr credits excluded. The September 2026 decree preserves the April 2026 schedule above 1.2% Ni but creates a lower correction factor for low-grade limonite at and below 1.2% Ni; the additional 1.2% rows below show the magnitude of that recalibration.

Table S10. HPM nickel-only benchmark diagnostics

Schedule / grade	Correction factor	Nickel-only component (USD/wmt)	Interpretation
Pre-2026, 1.6% Ni	17%	33.90	Earlier implied schedule
April 2026, 1.6% Ni	30%	59.82	Higher standard-grade benchmark
September 2026, 1.6% Ni	30%	59.82	Unchanged above 1.2% Ni
April 2026, 1.2% Ni	26%	38.88	April low-grade schedule
September 2026, 1.2% Ni	14%	20.94	Low-grade limonite recalibration

A full ore-price wedge would compare realized domestic ore prices with export parity or alternative-market prices adjusted for grade, moisture, freight, impurity and payability.

S11. Public-source ledger and reproducibility status

Table S11. Public-source ledger and reproducibility status

Source	Variables	Period	Access	URL / identifier	Role
UN Comtrade	Trade value, net weight, partner flows	2010-2024	Public	https://comtradeplus.un.org/	Core panel
U.S. Bureau of Labor Statistics	CPI-U CUUR0000SA0	2010-2024	Public	https://www.bls.gov/cpi/	Deflator

Source	Variables	Period	Access	URL / identifier	Role
USGS Mineral Commodity Summaries	Nickel production and reserves	2013, 2014, 2019, 2023, 2024 diagnostics	Public	https://pubs.usgs.gov/periodicals/mcs2025/	Depletion diagnostic
USGS Indonesia Minerals Yearbook / country page	Mine and route production	2014-2024	Public	https://www.usgs.gov/centers/national-minerals-information-center/indonesia	Physical validation
World Bank WITS / UN Comtrade	Reporter-partner mirror checks	Selected years	Public	https://wits.worldbank.org/	Mirror trade
International Nickel Study Group	Contained-nickel production series	2014-2023	Publication-based	World Nickel Factbook	Physical validation
ESDM Decree 144.K/MB.01/ME M.B/2026	HPM formula and correction factors	2026	Public official document	jdih.esdm.go.id	HPM formula
ESDM Decree 179.K/MB.01/ME M.B/2026	HMA nickel price	May 2026	Public official document	jdih.esdm.go.id	HPM numerical example
Public company disclosures	Revenue, net profit, output, emissions	2023	Public company reports compiled in research package	Company reports	Carbon materiality diagnostic
Kinanti et al. (2026)	Facility-specific MHP life-cycle emissions	2026	Published article	DOI 10.1016/j.hydromet.2026.106712	Route-specific LCA benchmark
ESDM Decree 363.K/MB.01/ME M.B/2026	Low-grade HPM correction factors	September 2026	Public official document	jdih.esdm.go.id	HPM low-grade recalibration