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ORIGINAL ARTICLE

Green Extractivism, Customary Territory Dispossession, and Indigenous Counter-Mapping Around Critical Mineral and Geothermal Corridors in Indonesia

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ABSTRACT

Background: Decarbonization has accelerated extraction of battery minerals and volcanic geothermal power across tropical archipelagos. Does this 'green extractivism' improve rural welfare or deepen dispossession of customary territory (wilayah adat)? When does Indigenous counter-mapping halt encroachment?

Objective: To examine post-2014 mining deforestation, district welfare differences, and the configurations of counter-mapping and protection across mineral and geothermal corridors in Indonesia.

Methods: A four-tier mixed-methods design used 594,366 public records: satellite mine-polygon deforestation (2001–2019); power-plant and resource-rent data; a 2011–2020 panel of 514 districts (two-way fixed-effects, AIPW, and quantile regressions); and fuzzy-set Qualitative Comparative Analysis (fsQCA) with process tracing across 24 contested corridors.

Results: Indonesia ranked first in direct industrial-mining deforestation in the data analyzed (3,603.26 km^2). Mean annual forest loss in transition-mineral concessions was 23.5% higher in 2014–2019 than in 2001–2013. Corridor regencies had a mining GDP share of 17.92% but mining employment of only 3.39%. Their agrarian employment share was 8.12 percentage points (pp) lower than in non-corridor regencies (AIPW −2.04 pp, 95% CI −4.25 to +0.17). AIPW safe-water estimates were imprecise (+0.48 pp, p = 0.737). In fsQCA, counter-mapping (0.934), litigation (0.901), and translocal coalitions (1.000) were necessary for protection. Their conjunction with absent National Strategic Project lock-in was sufficient (consistency = 0.9057, PRI = 0.8838). Lock-in was near-necessary for dispossession (0.9529).

Conclusion: The findings are associations within contested corridors. They support pre-concession Indigenous cadastral screening, statutory Free, Prior and Informed Consent (FPIC), small-island and sacred-watershed no-go zones, and review of National Strategic Project judicial-override exemptions.

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1. Introduction

1.1. Decarbonization's material frontier and the paradox of green extractivism

Global climate-mitigation pledges have catalyzed a major reconfiguration of industrial resource extraction and energy infrastructure across the Global South. Electric-vehicle lithium-ion batteries, stainless-steel alloys, solar photovoltaics, transmission grids, and baseload low-carbon power systems all need large inputs of metallic minerals and dispatchable renewable electricity. So decarbonization has not dematerialized global capitalism. It has intensified what agrarian political economists term 'postfossil' and 'green extractivism'.[1,2] State planners and transnational consortia increasingly justify concession expansion, forest excision, and rural land acquisition in the name of planetary climate urgency, a pattern that spans Latin America, Sub-Saharan Africa, and Southeast Asia.[2,3] Yet the land is not empty. Green extractivism does not cross vacant terra nullius. It crosses densely inhabited customary territories, smallholder agroforests, coastal fishing commons, and sacred volcanic watersheds, where Indigenous and local communities hold long-standing vernacular tenure yet lack statutory cadastral deeds. Postcolonial states have reinforced that condition through 'dispossession by archive' and colonial forestry classifications.[4] Territories designated to supply low-carbon transition inputs often become 'green sacrifice zones'. Distributive asymmetries mark these places. Global decarbonization benefits flow one way, while localized socio-ecological dispossession falls on the communities that live there.[5,6]

State industrial policy and transnational green-capitalist alliances play important mediating roles in this global transformation.[7–9] Indonesia is the sharpest case. Remote-sensing assessments of pantropical industrial mining establish that the country holds the single largest national share of direct mining-induced tropical forest loss worldwide. Recent ecological modeling warns that unmitigated critical-mineral supply chains pose severe biodiversity and hydrological risks across biodiverse island ecosystems.[10,11] Canopy loss is just the start. Forest loss and landscape fragmentation across steep island catchments alter watershed storage, so that surface runoff accelerates, sediment loading rises, and young, unfiltered water reaches downstream agrarian and coastal settlements.[12] Geothermal resources add a second pressure. Indonesia possesses roughly two-fifths of global volcanogenic geothermal resources,[13] which lie overwhelmingly inside upland protection and conservation forests. The archipelago is a uniquely revealing laboratory. Subsoil

transition-mineral extraction and renewable baseload power generation collide there with Indigenous customary territories (*wilayah adat*).

1.2. Critical minerals, geothermal materiality, and customary resistance in comparative perspective

International scholarship increasingly recognizes that the 'criticality' of transition minerals is never a purely geological attribute. It is a politically contested classification that governments deploy to fast-track permitting and compress environmental review.[14,15] Indonesia illustrates the point. Its 2014 raw-ore export ban and mandatory domestic smelter downstreaming (*hilirisasi*) policy triggered massive capital inflows into Rotary Kiln-Electric Furnace (RKEF) ferronickel and High-Pressure Acid Leach (HPAL) battery-grade nickel-cobalt complexes across Sulawesi and North Maluku, which generated extensive laterite strip-mining footprints.[16–18] Contestation persists elsewhere. Socio-legal disputes continue in legacy tin and bauxite belts such as Bangka–Belitung and West Kalimantan.[19,20] Do extractive booms improve local living standards? Development economics still debates this fiercely. Mineral fiscal windfalls and corporate social responsibility (CSR) outlays can lower aggregate monetary poverty metrics. Enclave capital intensity, migrant labor segmentation, and environmental externalities, however, frequently displace traditional agrarian livelihoods and provoke community conflict.[21–23]

Existing research has mostly treated metallic mining apart from utility-scale geothermal energy, a separation that hides the territorial and institutional mechanics the two share. Recent energy-justice scholarship reports distinct material hazards from geothermal drilling in Indonesia's Dieng plateau and across agrarian uplands in Western Turkey: wellhead blowouts, hydrogen sulfide emissions, induced micro-seismicity, spring depletion, and agrarian land enclosure. These hazards have sparked intersectional mobilization. Smallholders and women lead it.[24–26] Decentralized, community-governed micro-hydro initiatives can match rural electrification with Indigenous village autonomy. Top-down state energy corridors routinely reproduce procedural and recognition injustices. Only Indigenous-led territorial defense confronts them.[27] In Indonesia and comparable Latin American frontiers, environmental and climate-justice movements face narrowing civic space and executive security overrides. They also meet corporate strategies of fragmented compensation.[28,29]

Comparative geospatial and forest-policy studies point the other way on the forest side. Legally secure Indigenous lands curb deforestation considerably in tropical hotspots, while unbridled mining threatens isolated forest-dwelling Indigenous peoples.[30,31] Indonesia's record is mixed. Two decades of post-authoritarian decentralization have passed, and the post-2012 Constitutional Court mandates for customary forest recognition remain hindered by bureaucratic fragmentation, unratified district ordinances (*Perda Masyarakat Adat*), and competing statutory land claims.[32–35] Against state cartographic erasure, Indigenous movements from the Niger Delta to Mesoamerica and Indonesia have adopted participatory counter-mapping. They assemble vernacular socio-territorial boundaries into georeferenced polygons, which are used to contest concession overlaps and to assert alternative resource governance.[36–38] What remains missing is systematic cross-corridor evidence. Why does counter-mapping successfully halt mining or geothermal concessions in some Indonesian landscapes, yet fail to prevent dispossession in others?

1.3. Multi-scale methodological integration and research objectives

Answering it means bridging two traditions. One is macro-spatial econometrics. The other is configurational case-comparative methodology. Recent advances in panel Difference-in-Differences (DiD) and unconditional quantile decomposition show that aggregate treatment averages frequently mask sharp distributional divergence across rural and vulnerable population strata.[39,40] Methodological advances in Qualitative Comparative Analysis (QCA) stress four safeguards against positive-results bias: conservative Boolean minimization, transparent fuzzy-set calibration, Proportional Reduction in Inconsistency (PRI) screening, and explicit modeling of causal asymmetry.[41–43] The two strands can be joined. Regression-based causal inference can be formally integrated with counterfactual within-case process tracing and structured mixed-methods research questions, and scholars can then estimate macro structural effects and, at the same time, identify the precise institutional conjunctures through which collective agency succeeds or fails.[44–46]

Guided by this integrative methodological agenda, the study addresses three interconnected research questions. Each is stated below. (RQ1 – Geospatial Scale) How has Indonesia's post-2014 domestic smelter-downstreaming policy reshaped 30-meter satellite industrial-mining deforestation, relative to global peers, across critical-mineral versus non-transition commodity classes and biodiverse island bioregions? Utility geothermal expansion is examined alongside. (RQ2 – Subnational Distributional Scale) Take all 514 Indonesian districts. Take, in particular, the 416 rural regencies (*Kabupaten*). Do extractive and geothermal corridors deliver inclusive livelihood, safe-water, and health gains? Or do they exhibit 'Fiscal Rent–Ecological Welfare Decoupling'? (RQ3 – Configurational & Process-Tracing Scale) Consider 24 contested Indonesian customary corridors, split into critical-mineral (n = 12) and geothermal (n = 12) cases. Which necessary and conjuncturally sufficient combinations of Indigenous counter-mapping, legal-constitutional mobilization, translocal coalitions, National Strategic Project (PSN) security status, and visible ecological disruption produce protective territorial outcomes? Which produce unchecked customary dispossession?

2. Methods

2.1. Statutory architecture of Indonesian downstreaming, geothermal forest access, and *adat* tenure

Indonesia's contemporary green-extractive regime rests on a sequence of intersecting statutory reforms enacted between 2009 and 2023. First, Law No. 4/2009 on Mineral and Coal Mining mandated domestic mineral processing. It banned unprocessed ore exports effective January 2014.[47] The 2014 ban did not curtail extraction. It reoriented Indonesian mining toward capital-intensive pyrometallurgical (RKEF) and hydrometallurgical (HPAL) smelter industrial parks, most prominently Indonesia Morowali Industrial Park (IMIP) in Central Sulawesi, Virtue Dragon/Obsidian Stainless Steel (VDNI/OSS) in Southeast Sulawesi, Indonesia Weda Bay Industrial Park (IWIP) in Central Halmahera, Harita's Obi Island HPAL complex in South Halmahera, and smelter-grade alumina refineries in West Kalimantan.[16,48,49] Second, in the renewable power

sector, Law No. 21/2014 on Geothermal legally reclassified geothermal utilization.[50] Exploratory and production activities were no longer defined as 'mining' (*pertambangan*). This authorized geothermal Working Areas (*Wilayah Kerja Panas Bumi* [WKP]) inside state Protection Forests (*Hutan Lindung*) and Conservation Forests through environmental-services permits.[24,51]

Third, Constitutional Court Ruling MK No. 35/PUU-X/2012 affirmed that Indigenous customary forests (*Hutan Adat*) are constitutionally distinct from state forests (*Hutan Negara*).[52] In practice, one step must come first. The Ministry of Environment and Forestry issues formal *Hutan Adat* decrees only after pre-existing district-level statutory recognition (*Peraturan Daerah* [*Perda*] *Masyarakat Adat*) is in place.[32,33,53] As a result, millions of hectares mapped by the Indigenous Territory Registration Agency (*Badan Registrasi Wilayah Adat* [BRWA]) stay outside Indonesia's central 'One Map Policy' (*Kebijakan Satu Peta*) licensing layers.[54,55] Fourth, Mining Law Revision No. 3/2020 and Job Creation Law No. 6/2023 recentralized mining permits to Jakarta.[56,57] They also expanded executive National Strategic Project (*Proyek Strategis Nasional* [PSN]) and Vital National Object (*Objek Vital Nasional*) designations. Land procurement and security deployment sped up.[58,59] One statute pulls the other way. Law No. 1/2014 on the Management of Coastal Zones and Small Islands, as upheld by Constitutional Court Ruling MK No. 35/PUU-XXI/2023, prohibits mineral mining that degrades ecological or social sustainability on small islands (≤2,000 km^2).[60,61] For archipelagic communities, it is an important statutory lever against the centralizing laws.

2.2. Multi-tier public data architecture (594,366 records)

To support reproducibility, we assembled 5 public datasets and checked file integrity with SHA-256 checksums. No synthetic or simulated observations were used. Together they hold 594,366 raw records (147.7 MB), listed in a SHA-256 manifest (Figure 1A). Tier 1 is the global 30-meter satellite industrial-mining deforestation panel archived on Zenodo[62] and analyzed by Giljum et al.[10] (DOI: 10.5281/zenodo.7307210). It contains 416,412 raw polygon-year rows. Of these, 297,689 are dated polygon-year observations from 2001 to 2019 (112.08 MB). The dataset intersects verified global industrial mine polygons and spatial clusters (id_hcluster) with Hansen Global Forest Change v1.7 annual tree-cover loss, WWF terrestrial ecoregions, and World Database on Protected Areas (WDPA) IUCN Categories Ia–VI, across direct concession footprints (area_forest_loss_000) and across 25-km and 50-km surrounding spatial buffers (measured in km^2). For Indonesia (ISO3: IDN; 1,590 mine polygons across 220 clusters), commodity strings were sorted into three mutually exclusive classes. Critical Transition Minerals cover nickel, cobalt, copper, bauxite/alumina, tin, manganese, and zinc-lead (389 polygons in 43 clusters). Coal has 865 polygons in 58 clusters. Precious and Other Minerals are gold-silver without base/battery metals plus industrial stone (336 polygons in 119 clusters). The Zenodo v1.7 series ends in 2019. Our post-2014 downstreaming estimates therefore capture only the initial 2014–2019 RKEF smelter wave. They form a conservative pre-HPAL baseline.[16,63]

Tier 2 draws on two global open repositories. Tier 2A is the World Resources Institute (WRI) Global Power Plant Database v1.3.0 (11.97 MB), which lists 34,936 georeferenced power facilities worldwide, among them 178 Indonesian utility plants totaling 48,751.4 MW across coal, gas, hydro, geothermal, and oil. Tier 2B is the World Bank World Development Indicators (WDI). It holds 30,453 sovereign country-year observations covering mineral rents [NY.GDP.MINR.RT.ZS], forest rents [NY.GDP.FRST.RT.ZS], forest land share and area [AG.LND.FRST.ZS, AG.LND.FRST.K2], terrestrial protected areas [ER.LND.PTLD.ZS], and non-hydro renewable electricity [EG.ELC.RNWX.ZS]. WRI v1.3.0 records Indonesia's 10 major operating utility geothermal complexes (1,342.0 MW). Newer modular units are absent. So are exploratory geothermal Working Areas such as Wae Sano, Poco Leok, Gunung Talang, Gunung Lawu, and Baturraden, and all of these enter directly into Tier 4's georeferenced contestation matrix.

Tier 3 uses the World Bank Indonesia Database for Policy and Economic Research (INDO-DAPOER). It provides 112,541 official subnational observations sourced from Statistics Indonesia (*Badan Pusat Statistik* [BPS]), the National Socioeconomic Survey (SUSENAS), the Village Potential Census (PODES), and Ministry of Finance fiscal ledgers. Coverage spans all 514 Indonesian second-tier jurisdictions (416 rural regencies [*Kabupaten*] and 98 urban municipalities [*Kota*]) and 34 provinces. Harmonizing the 2011–2020 panel leaves 5,131 district-year records. They track mining and quarrying GDP share (NA.GDP.MINQ.SNA08.KR / NA.GDP.INC.OG.SNA08.KR, bounded strictly within 0% to 100% to eliminate denominator reporting glitches). Direct mining employment share (SL.EMP.MINQ / SL.EMP.TOTL) is included. So is agrarian/forestry/fishery employment share (SL.EMP.AGR.FRST.FSH / SL.EMP.TOTL). Fiscal variables are central-to-district mineral revenue sharing (DBH *Pertambangan*, NRRV.SHR.MIN.CR) and geothermal revenue sharing (DBH *Panas Bumi*, NRRV.SHR.GEOT.CR). Welfare measures are household safe drinking water deprivation (100 - HOU.H2O.ACSN.ZS), population morbidity (SH.MORB.ZS), unpaved village road isolation (ROD.VILG.DIRT.ZS), poverty headcount (SI.POV.NAPR.ZS), poverty gap (SI.POV.NGAP), and the poorest-20% relative household expenditure share. The final one is within-district Gini inequality (SI.POV.GINI).

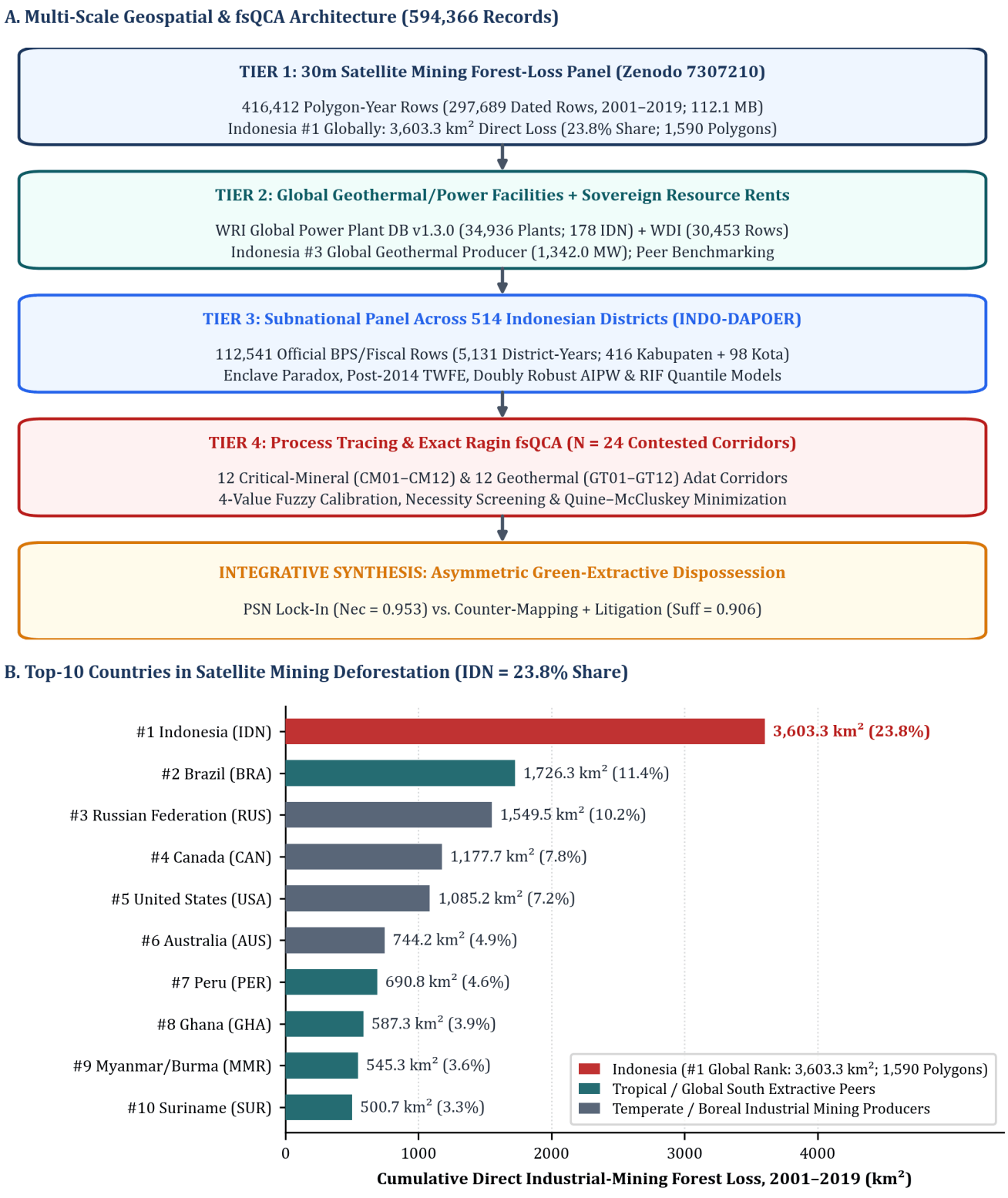


Figure 1. Multi-scale geospatial, econometric, and set-theoretic research architecture and global satellite industrial-mining deforestation ranking. (A) Four-tier empirical design integrating 594,366 public records (file integrity checked with SHA-256) (147.7 MB) across 30-meter satellite mine-polygon deforestation (Zenodo 7307210), WRI global power plants and World Bank WDI series, 514 Indonesian districts (INDO-DAPOER, 2011–2020), and 24 contested critical-mineral and geothermal customary corridors. (B) Cumulative direct industrial-mining forest loss (2001–2019, km²) across the top-10 countries globally, placing Indonesia first among the countries shown (3,603.3 km²; 23.8% global share across 1,590 mine polygons).

2.3. Satellite cluster TWFE, subnational doubly robust AIPW, and RIF quantile econometrics

Tier 1 starts with comparisons of annual commodity deforestation before 2014 (2001–2013) and after 2014 (2014–2019). Next comes a balanced 19-year panel. It spans all 220 Indonesian mining clusters (N = 4,180 cluster-years) and, separately, the 162 non-coal metallic clusters (N = 3,078 cluster-years). On this panel we estimate Two-Way Fixed-Effects (TWFE) Difference-in-Differences models of direct and 50-km spillover deforestation, with standard errors clustered at the cluster level. Tier 3 differs. We build a composite standardized District Extractive–Geothermal Endowment Index (Z_Ext). Its weights are 0.60 for district mining GDP share, 0.25 for log per-capita mineral DBH, and

0.15 for log per-capita geothermal DBH. Districts in the top quartile of mining GDP share, or with above-median positive geothermal DBH transfers, are classed as Green-Extractive Corridors (n = 212 rural *Kabupaten* vs. 204 non-corridor *Kabupaten*).

Geological siting is non-random.[39,40] That matters when distributional impacts across Indonesian districts are compared. Tier 3 therefore estimates three econometric models. Model (1) is a TWFE regression with district and year fixed effects, interacting Post_2014 with Z_Ext across N = 508 districts. Controls are log per-capita government expenditure, household electrification, and adult literacy. Standard errors are clustered by district, with small-sample degrees-of-freedom adjustments. Model (2) applies Doubly Robust Augmented Inverse Probability Weighting (AIPW) to post-2014 rural regencies (N = 415 *Kabupaten* with complete covariates), pairing Newton–Raphson logistic propensity scores with treatment-specific outcome regressions on literacy, electrification, urbanization, and log per-capita fiscal spending. Inference rests on 400 nonparametric bootstrap replications. VanderWeele E-values and Cinelli–Hazlett omitted-variable Robustness Values RV_q accompany them. Model (3) is the Firpo–Fortin–Lemieux Recentered Influence Function (RIF) unconditional quantile regression, run at the 10th, 25th, 50th, 75th, and 90th percentiles of rural safe-water deprivation and poverty gap index. It uses Gaussian kernel density estimation and HC3 heteroskedasticity-robust inference.

2.4. Comparative process tracing and fsQCA calibration (N = 24 contested corridors)

District aggregates cannot observe village-level customary resistance or judicial permit revocations. Tier 4 therefore compiles a structured comparative archive of N = 24 prominent contested green-extractive corridors across Indonesia. The archive has two sets. Of these, 12 are critical-mineral corridors (CM01 Morowali IMIP, CM02 North Konawe–Morosi, CM03 Weda Bay IWIP, CM04 East Halmahera Buli–Maba, CM05 Obi Island Kawasi, CM06 Wawonii Island, CM07 Sangihe Island, CM08 Dairi Prima Mineral, CM09 Tumpang Pitu Banyuwangi, CM10 Mimika Highland–Estuary, CM11 Ketapang–Sanggau Bauxite, and CM12 Bangka–Belitung Tin). The other 12 are volcanic geothermal corridors (GT01 Poco Leok Manggarai, GT02 Wae Sano West Manggarai, GT03 Mataloko Ngada, GT04 Sorik Marapi Mandailing Natal, GT05 Sarulla North Tapanuli, GT06 Gunung Talang Solok, GT07 Gunung Lawu Central/East Java, GT08 Baturraden Mount Slamet, GT09 Dieng Plateau, GT10 Rantau Dedap South Sumatra, GT11 Muara Laboh Solok Selatan, and GT12 Lahendong–Tompaso Minahasa). Case coding triangulates Supreme Court (*Mahkamah Agung* [MA]) and State Administrative Court (PTUN) decisions. Constitutional Court rulings are also used. So are multilateral lender accountability dockets (IFC CAO and World Bank Inspection Panel/exit records), BRWA customary territory registries, and peer-reviewed field monographs.

Following Rutten[42,64] and Rohlfing,[42,64] we calibrate five causal conditions and the territorial outcome on a transparent four-value fuzzy scale: 0.00 (fully out), 0.33 (more out than in), 0.67 (more in than out), and 1.00 (fully in). Ambiguous 0.50 crossover scores are avoided (full anchor rules in Supplementary Codebook). Condition (1) is National Strategic Project Security Lock-In (PSN_LOCK). A score of 1.00 means active PSN or Vital National Object status with central security backing, and 0.67 means national grid/priority concession without full industrial-park exemption. A score of 0.33 means an ordinary regional/ministerial permit. A score of 0.00 means exclusion from national strategic lists. Condition (2) is Indigenous Participatory Counter-Mapping (CMAP). Here 1.00 means a formal BRWA/community GIS polygon boundary integrated into village/litigation dossiers, and 0.67 means participatory territory/watershed mapping under mobilization. A score of 0.33 means informal plot claims only. A score of 0.00 means no spatial counter-mapping. Condition (3) is Legal-Constitutional & Safeguard Mobilization (LEGAL). A score of 1.00 means Supreme Court/PTUN/MK judicial review or a multilateral lender safeguard complaint, and 0.67 means a formal ministerial/gubernatorial administrative appeal. A score of 0.33 means localized petitions/protests without litigation. A score of 0.00 means none. Condition (4) is Translocal Environmental–Indigenous Coalition (COALITION). Scoring 1.00 requires a sustained local *adat* alliance with national/transnational legal-environmental networks [AMAN, WALHI, JATAM, Trend Asia, Save Sangihe/Wawonii]. Scoring 0.67 reflects episodic NGO advocacy. A score of 0.33 means isolated village protest. A score of 0.00 means fragmented/co-opted. Condition (5) is Acute Visible Ecological–Hydrological Disruption (ECOL_VIS). A score of 1.00 means severe spring/karst/coastal sedimentation, H2S blowouts, or seismic fault-dam risk, and 0.67 means moderate exploratory clearing/turbidity. A score of 0.33 means the pre-drilling stage. A score of 0.00 means minimal disruption. Item (6), the outcome, is Protective Territorial Outcome (OUTCOME_PROTECT). A score of 1.00 means binding judicial permit revocation, lender withdrawal/project cancellation, or auction delisting. A score of 0.67 means a formal moratorium, concession excision, or protected enclave carve-out, and 0.33 means a symbolic non-binding buffer pledge while core extraction proceeds. A score of 0.00 means unabated extraction and customary dispossession. We test single-condition necessity at consistency ≥ 0.90 and report coverage and Relevance of Necessity [RoN]. Exact 2^5 = 32 truth tables are then constructed for both OUTCOME_PROTECT and ~OUTCOME_PROTECT, using raw consistency ≥ 0.80 and PRI ≥ 0.65. Exact Quine–McCluskey Boolean minimization is applied strictly over observed rows (conservative solution). This prevents speculative remainder bias.[43,65] Reporting followed the Mixed Methods Appraisal Tool (MMAT), the Ragin and Schneider–Wagemann standards for fsQCA, and the STROBE items applicable to the observational panels.

3. Results

3.1. Tier 1 and Tier 2: global deforestation epicenter, post-2014 critical-mineral clearing, and geothermal scale

Tier 1 satellite analysis covers 297,689 dated global mine-polygon observations (2001–2019). Indonesia leads. It is the world's single largest contributor to direct industrial-mining deforestation, having cleared 3,603.26 km^2 (360,326 hectares) across 1,590 mine polygons in 220 spatial clusters, which is 23.77% of all direct industrial-mining forest loss globally (Table 1, Panel A; Figure 1B). The next two are #2 Brazil (1,726.32 km^2; 11.39%) and #3 Russian Federation (1,549.46 km^2; 10.22%). Indonesia's loss is more than twofold either figure. It also exceeds the combined totals of Canada (1,177.72 km^2), the United States (1,085.25 km^2), and Australia (744.17 km^2), a gap that stands out for a single country. Beyond concession

boundaries, mining corridors added 43.37 km² of forest loss within 25-km buffers and 90.65 km² within 50-km buffers. These figures derive from the global Zenodo polygon dataset, which covers all biomes, and are not directly comparable with the 1,901 km² (58.2% of 3,264 km² in 26 tropical countries, 2000–2019) reported by Giljum et al..[10]

Split Indonesia's 1,590 mine polygons by commodity class and a structural shift appears. It follows the January 2014 raw-ore export ban and mandatory domestic smelter downstreaming policy (Table 1, Panel B; Figure 2A). Thermal and metallurgical coal holds the largest cumulative 19-year volume (2,025.03 km² across 865 polygons). Yet its mean annual clearing rose by only 7.1% after 2014, from 98.81 to 105.78 km²/yr. Mean annual clearing in Precious/Other non-transition minerals was 10.2% lower (from 26.90 to 24.15 km²/yr). Clearing inside Critical Transition Mineral concessions (389 polygons across 43 clusters, totaling 1,059.49 km²) behaved differently. Mean annual direct forest clearing there was 23.5% higher after 2014, rising from 48.96 km²/yr (2001–2013) to 60.44 km²/yr (2014–2019), and peaked at 91.93 km² in 2016 as Sulawesi and Halmahera RKEF smelter parks came online. Encroachment tells the same story. Within 50-km corridors, these minerals produced the highest absolute intrusion into designated protected and community conservation areas: 0.84 km², against 0.75 km² for coal and 0.30 km² for precious minerals.

Bioregional decomposition explains why balanced within-cluster TWFE averages across all 220 historical mining clusters look diffuse (+0.225 km²/cluster-yr overall, p = 0.561; +0.338 km²/cluster-yr versus non-critical metallic clusters, p = 0.377). Geography is the reason. Post-2014 downstreaming deforestation was intensely concentrated in specific ultramafic and bauxite/tin island bioregions. Legacy concessions did not share it evenly (Table 1, Panel C; Figure 2B). Critical transition minerals account for 88.6% (126.87 of 143.13 km²) of all mining deforestation in Sulawesi lowland rain forests. The share is 88.9% (35.06 of 39.42 km²) in Sulawesi montane rain forests and 96.6% (106.15 of 109.93 km²) in Southwest Borneo freshwater swamp forests. Sundaland heath forests (Bangka–Belitung and West Kalimantan) show 43.5% (445.73 of 1,023.87 km²). Power data add context. Tier 2 WRI power-infrastructure benchmarking adds a second picture. Indonesia operates 1,342.0 MW of utility geothermal capacity across 10 major volcanic complexes, which ranks #3 globally behind the United States (3,889.2 MW) and the Philippines (1,848.2 MW), while hydropower stands at 4,559.6 MW and coal at 29,333.0 MW (Table 2; Figure 3A). Among tropical peers, Indonesia is the only one pairing #1 global mining deforestation with top-tier volcanic geothermal expansion. Protection lags. Just 12.2% of its terrestrial land is protected, less than half the share of Brazil (30.6%) and well below Peru (22.5%) and Chile (21.0%). The TWFE estimates therefore do not isolate an effect of the 2014 mandate; the post-2014 difference in critical-mineral clearing is descriptive, and it is a comparison of mean annual clearing in 2014–2019 with 2001–2013, not an annual growth rate. National and industry sources report Indonesia second in installed geothermal capacity, at about 2.6 GW at the end of 2024;[66] the third rank above therefore reflects the coverage of the WRI database.

Table 1. Global Satellite Industrial-Mining Deforestation Ranking (2001–2019), Indonesian Post-2014 Smelter Downstreaming Surge, and Bioregional Encroachment (Tier 1: Zenodo 7307210; N = 297,689 Dated Polygon-Years).

Country / Indonesian Commodity Class / Bioregion	Georeferenced Polygons (Clusters)	Cumulative Direct Loss (km²)	50-km Buffer Spillover (km²)	Global Share / Critical Share (%)	Pre-2014 vs. Post-2014 Mean (km²/yr)
Panel A: Global Top-6 Industrial-Mining Deforestation Countries (2001–2019)					
#1 Indonesia (IDN)	1,590 (220)	3,603.26	90.65	23.77% Global	Epicenter (#1 Global)
#2 Brazil (BRA)	4,166 (723)	1,726.32	53.44	11.39% Global	Comparator Sovereign
#3 Russian Federation (RUS)	6,107 (1,833)	1,549.46	252.95	10.22% Global	Comparator Sovereign
#4 Canada (CAN)	6,194 (1,054)	1,177.72	93.60	7.77% Global	Comparator Sovereign
#5 United States (USA)	6,578 (2,117)	1,085.25	66.47	7.16% Global	Comparator Sovereign
#6 Australia (AUS)	2,264 (674)	744.17	278.96	4.91% Global	Comparator Sovereign
Panel B: Indonesian Mining Deforestation by Commodity Class & Post-2014 Smelter Mandate					
Critical Transition Minerals (Ni, Co, Cu, Al/Bauxite, Sn, Zn-Pb)	389 (43)	1,059.49	17.00 (Prot: 0.84)	29.40% of IDN Loss	48.96 → 60.44 (+23.5%)
Thermal & Metallurgical Coal	865 (58)	2,025.03	56.80 (Prot: 0.75)	56.20% of IDN Loss	98.81 → 105.78 (+7.1%)
Precious & Other Non-Transition Minerals	336 (119)	518.74	16.85 (Prot: 0.30)	14.40% of IDN Loss	26.90 → 24.15 (−10.2%)
Panel C: Key Threatened Indonesian Bioregions & Critical-Mineral Dominance					
Borneo lowland rain forests	520 polygons	1,918.43	45.72 (Prot: 0.10)	15.4% Critical (294.62 km²)	Coal-Dominated Belt
Sundaland heath forests	374 polygons	1,023.87	32.81 (Prot: 1.27)	43.5% Critical (445.73 km²)	Nickel/Bauxite/Tin Belt
Sulawesi lowland rain forests	149 polygons	143.13	2.14 (Prot: 0.14)	88.6% Critical (126.87 km²)	Nickel/Bauxite/Tin Belt

Country / Indonesian Commodity Class / Bioregion	Georeferenced Polygons (Clusters)	Cumulative Direct Loss (km^2)	50-km Buffer Spillover (km^2)	Global Share / Critical Share (%)	Pre-2014 vs. Post-2014 Mean (km^2/yr)
Southwest Borneo freshwater swamp forests	13 polygons	109.93	1.08 (Prot: 0.14)	96.6% Critical (106.15 km^2)	Nickel/Bauxite/Tin Belt
Sulawesi montane rain forests	11 polygons	39.42	0.80 (Prot: 0.00)	88.9% Critical (35.06 km^2)	Nickel/Bauxite/Tin Belt

Note: Computed directly from Zenodo Archive DOI: 10.5281/zenodo.7307210 (Giljum et al., 2022;[10] file integrity checked with SHA-256, 416,412 raw rows; 297,689 dated polygon-year rows intersecting Hansen Global Forest Change v1.7 at 30m resolution). Protected loss denotes IUCN Categories Ia–VI and designated protected polygons within 50-km mine buffers. Percent changes in Panel B compare period means (2001–2013 vs. 2014–2019), not annual growth rates.

Table 2. Indonesian Power Generation Infrastructure by Fuel (WRI v1.3.0; n = 178 Plants) and Cross-National Resource-Ecology Peer Benchmarks Across Tropical & Critical-Mineral Frontiers (Tier 2).

Fuel fleet (Indonesia)	—	Installed capacity (MW)	Mean MW per plant	Primary use	Operating mode
Panel A: Indonesian Utility Power Infrastructure Structure (WRI Global Power Plant DB, n = 178)					
Indonesia — Coal Fleet (70 plants)	—	29,333.0 MW (Coal)	Mean 419.0 MW/plant	Grid/Captive Smelter Power	Baseload / Peaking
Indonesia — Gas Fleet (41 plants)	—	12,810.0 MW (Gas)	Mean 312.4 MW/plant	Grid/Captive Smelter Power	Baseload / Peaking
Indonesia — Hydro Fleet (41 plants)	—	4,559.6 MW (Hydro)	Mean 111.2 MW/plant	Grid/Captive Smelter Power	Baseload / Peaking
Indonesia — Geothermal Fleet (10 plants)	—	1,342.0 MW	Mean 134.2 MW/plant	Volcanic Upland Forests	#3 Global Geothermal Rank
Indonesia — Oil Fleet (16 plants)	—	706.8 MW (Oil)	Mean 44.2 MW/plant	Grid/Captive Smelter Power	Baseload / Peaking
Panel B: Resource-Rich & Geothermal Global South Sovereign Benchmarks (World Bank WDI + Zenodo + WRI)					
Country / Indonesian Power Sector	**Mining Forest Loss (km^2)**	**Utility Geothermal (MW)**	**Mineral Rents (% GDP)**	**Forest Area (% Land)**	**Protected Land (% Total)**
Indonesia (IDN)	3,603.3	1,342.0	1.91%	50.6%	12.2%
Brazil (BRA)	1,726.3	0.0	4.49%	58.9%	30.6%
Congo, Dem. Rep. (COD)	171.6	0.0	28.81%	61.6%	13.9%
Philippines (PHL)	54.0	1,848.2	1.52%	24.7%	15.9%
Kenya (KEN)	7.7	754.0	0.01%	6.5%	12.2%
Mexico (MEX)	33.1	903.6	1.36%	34.2%	14.6%
Chile (CHL)	4.0	0.0	16.23%	24.5%	21.0%
Peru (PER)	690.7	0.0	12.10%	52.9%	22.5%

Note: WRI Global Power Plant Database v1.3.0 (34,936 global plants; file integrity checked with SHA-256) and World Bank World Development Indicators (WDI, 30,453 sovereign observations; latest post-2018 values). Indonesia combines the largest direct mining deforestation (3,603.3 km^2) with the third-largest installed geothermal capacity in the data analyzed (1,342.0 MW; after USA 3,889.2 MW and Philippines 1,848.2 MW). WRI v1.3.0 lists ten Indonesian geothermal complexes; national sources report about 2.6 GW and a second rank for Indonesia (see text).

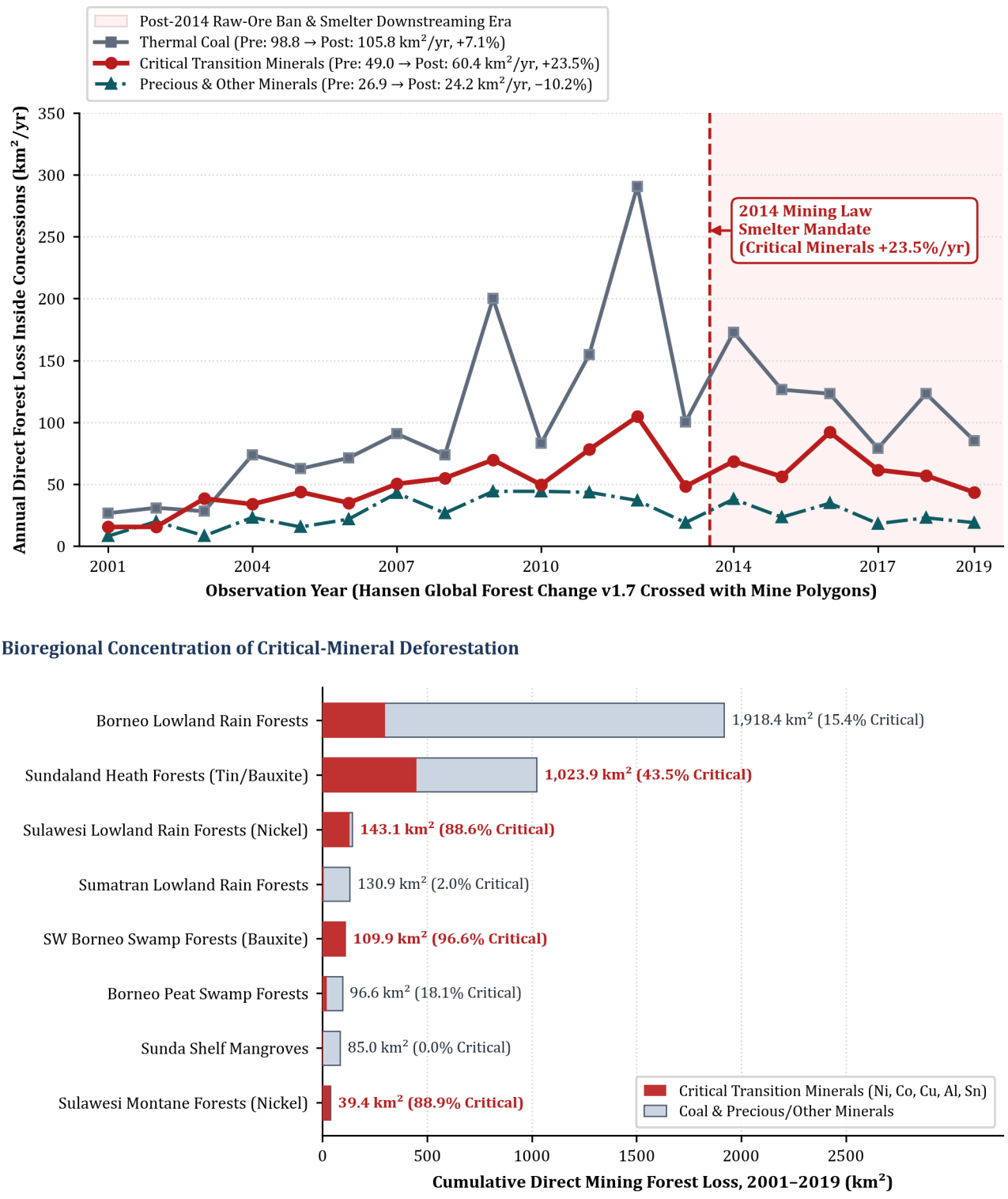


Figure 2. Post-2014 domestic smelter-downstreaming deforestation surge and bioregional concentration in Indonesia. (A) Annual direct forest loss inside Indonesian mining concessions by commodity class (2001–2019, km²/yr), showing 23.5% higher mean annual clearing in critical transition minerals (48.96 to 60.44 km²/yr) after the 2014 raw-ore export ban and mandatory smelter policy, versus 10.2% lower mean annual clearing in precious/other minerals. (B) Cumulative mining deforestation across Indonesia's top-8 threatened bioregions, highlighting critical-mineral dominance in Sulawesi lowland rain forests (88.6%), Sulawesi montane rain forests (88.9%), Southwest Borneo freshwater swamp forests (96.6%), and Sundaland heath forests (43.5%).

3.2. Tier 3: the rural enclave dispossession paradox across 416 Indonesian *Kabupaten*

Does extractive and geothermal expansion translate into inclusive rural development? To test this, Table 3 and Figure 3B compare all 212 extractive/geothermal corridor rural regencies with all 204 non-corridor rural regencies. The sample spans Indonesia's 416 *Kabupaten* (2011–2020) and excludes 98 urban *Kota*. Corridor regencies show very large resource-sector output and fiscal inflows. Mining and quarrying make up 17.92% of district GDP (SD = 20.46%) in corridor *Kabupaten*, against only 2.09% (SD = 1.83%) in

non-corridor *Kabupaten*, a +15.83 percentage-point premium (Welch t = 35.27, p = 6.40 × 10^{-215}). Corridor regencies also receive larger per-capita mineral revenue-sharing (log DBH *Pertambangan* 8.00 vs. 7.00, t = 7.43, p = 1.27 × 10^{-13}) and geothermal revenue-sharing transfers (log DBH *Panas Bumi* 2.81 vs. 1.34, t = 16.99, p = 3.08 × 10^{-62}).

Yet this macroeconomic and fiscal abundance coexists with a labor-absorption and morbidity paradox. Mining and quarrying generate nearly one-fifth of district GDP. They are capital-intensive, though, and employ just 3.39% of corridor workers (versus 1.45% in non-corridor regencies; +1.93 pp). Livelihoods suffer. The agrarian, forestry, and fishery employment share is 8.12 pp lower in corridor regencies (45.79% vs. 53.91%, t = −13.50, p = 1.56 × 10^{-40}), while unadjusted morbidity is significantly higher in extractive and geothermal corridor regencies, by +1.10 pp (28.65% vs. 27.55%, t = 4.11, p = 3.99 × 10^{-05}). Nearly two in five corridor households (39.45%) still lack safe drinking water. Fiscal transfers do help. They lower the headline monetary poverty headcount (12.08% vs. 16.71%) and dirt-road isolation (10.74% vs. 17.43%).

Table 3. The Rural Enclave Dispossession Paradox Across 416 Indonesian Rural Regencies (*Kabupaten*, 2011–2020): Extractive & Geothermal Corridor Regencies (n = 212) Versus Non-Corridor Regencies (n = 204).

District Structural, Fiscal, Livelihood & Ecological-Welfare Indicator	Extractive/Geothermal *Kabupaten* (Mean ± SD)	Non-Corridor *Kabupaten* (Mean ± SD)	Mean Difference (Corridor – Non)	Welch t-Statistic	Two-Sided p-Value
Mining & Quarrying Share of District GDP (%)	17.92 ± 20.46	2.09 ± 1.83	+15.83	35.27	6.40×10^{-215}
Direct Mining & Quarrying Share of District Employment (%)	3.39 ± 5.10	1.45 ± 2.09	+1.93	14.63	1.58×10^{-46}
Agrarian, Forestry & Fishery Livelihood Employment Share (%)	45.79 ± 16.17	53.91 ± 19.93	−8.12	−13.50	1.56×10^{-40}
Log Per-Capita Mineral Revenue Sharing (DBH *Pertambangan*)	8.00 ± 4.46	7.00 ± 4.20	+1.00	7.43	1.27×10^{-13}
Log Per-Capita Geothermal Revenue Sharing (DBH *Panas Bumi*)	2.81 ± 3.40	1.34 ± 2.00	+1.47	16.99	3.08×10^{-62}
Households Lacking Safe Drinking Water Access (%)	39.45 ± 17.16	45.22 ± 21.95	−5.77	−9.32	1.96×10^{-20}
Population Morbidity Rate (%)	28.65 ± 7.53	27.55 ± 9.38	+1.10	4.11	3.99×10^{-05}
Villages Accessible Only via Unpaved/Dirt Roads (%)	10.74 ± 14.90	17.43 ± 22.51	−6.69	−5.98	3.17×10^{-09}
District Poverty Headcount Rate (%)	12.08 ± 6.01	16.71 ± 9.62	−4.64	−18.41	3.20×10^{-72}
District Poverty Gap Index (P1)	1.95 ± 1.53	3.01 ± 2.61	−1.06	−15.78	4.18×10^{-54}
Poorest-20% Relative Household Expenditure Ratio (%)	44.02 ± 5.89	43.74 ± 7.45	+0.29	1.36	0.1750
Within-District Gini Inequality Index	0.32 ± 0.04	0.33 ± 0.05	−0.00	−3.07	0.0021

*Note: Computed across all 416 Indonesian rural regencies (*Kabupaten*; excluding 98 urban municipalities [*Kota*] to prevent metropolitan service-economy confounding) from World Bank INDO-DAPOER / Statistics Indonesia (BPS) official subnational series (2011–2020; file integrity checked with SHA-256). Extractive/geothermal corridors denote top-quartile mining GDP share or above-median active geothermal DBH revenue-sharing regencies.*

3.3. Tier 3: subnational TWFE, doubly robust AIPW, and RIF quantile decoupling

Table 4 and Figure 4 test these subnational patterns for associations and distributional differences. Two-Way Fixed-Effects (TWFE) panel models cover 508 districts (2011–2020; Table 4, Panel A). In them, a 1-SD increase in district extractive/geothermal endowment after 2014 is associated with modest fiscal-led improvements in purchased/piped water access (unsafe water β = −1.2143 pp, p = 0.0010) and in bottom-quintile expenditure share (β = +0.6954 pp, p = 0.0002). Aggregate poverty headcount stays unchanged (β = +0.0616 pp, p = 0.484), and agrarian employment shows a statistically insignificant downward trend (β = −0.3929 pp, p = 0.196). A second analysis matches post-2014 rural corridor regencies (n = 211) directly against structurally comparable non-corridor rural regencies (n = 204). Matching uses adult literacy, household electrification, urbanization, and log per-capita public spending, with Doubly Robust AIPW (Table 4, Panel B; IPTW reducing mean |SMD| from 0.398 to 0.086 and max |SMD| from 0.578 to 0.133). Three results emerge. First, corridor regencies show an agrarian, forestry, and fishery employment share 2.04 pp lower than matched controls, an imprecise estimate (95% CI: −4.25 to +0.17, z = −1.81, p = 0.0707; VanderWeele E-value = 1.47; Cinelli–Hazlett RV_q = 8.54%). The apparent raw water advantage disappears after adjustment, since AIPW safe-water deprivation is +0.48 pp higher in extractive/geothermal corridors than in fiscal-matched controls (39.61% vs. 39.13%, z = 0.34, p = 0.737; 95% CI −2.34 to +3.31). The poorest-20% relative expenditure ratio shows no detectable difference (ATE = +0.002 pp, 95% CI −1.32 to +1.32, 43.17% vs. 43.17%, p = 0.998). The AIPW contrast is a cross-section of post-2014 regencies in which every district experienced the 2014 policy, so these estimates describe differences between corridor and non-corridor regencies, not the effect of the downstreaming mandate.

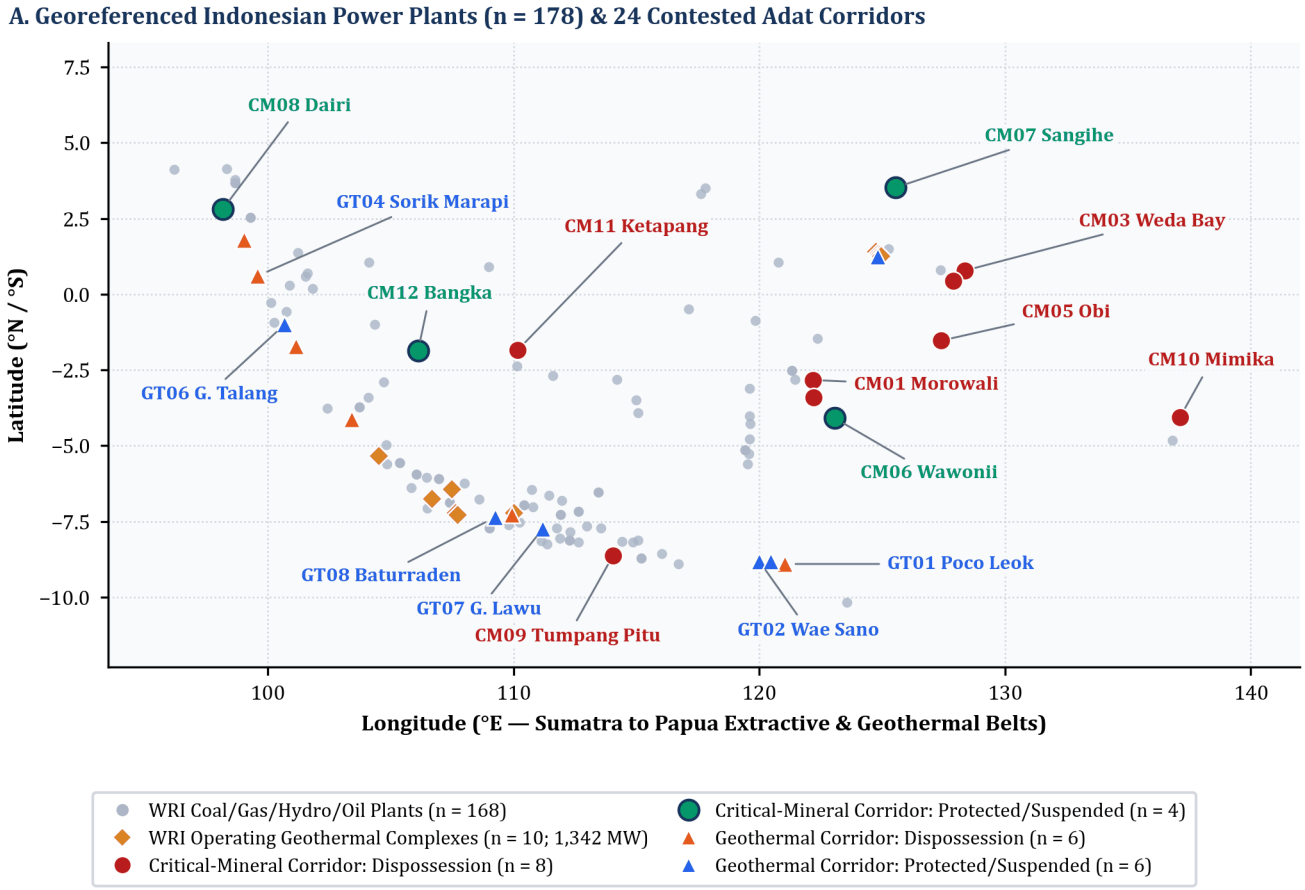
Firpo–Fortin–Lemieux RIF unconditional quantile regressions across post-2014 rural *Kabupaten* (Table 4, Panel C; Figure 4B) describe the pattern of 'Fiscal Rent–Ecological Welfare Decoupling.' Higher extractive/geothermal fiscal endowment compresses the monetary poverty gap index at all five quantiles (Q10 to Q90). The coefficient β_Ext ranges from −0.085 at Q10 (p =

0.0013) to −0.718 at Q90 ($p = 4.23 \times 10^{-12}$), reflecting central-to-district DBH revenue-sharing transfers into local budgets. The picture differs for household safe-water deprivation. At Q10 (unsafe water = 18.0%), Q25 (25.5%), Q50 (35.7%), and Q75 (48.5%), extractive/geothermal intensity yields no statistically detectable reduction (β_Ext = −0.523 to +0.186 pp, p = 0.325–0.608). Rural regencies with higher unprotected agrarian/customary livelihood shares face significantly deeper poverty gaps at Q10 (+0.098 per +10 pp, $p = 1.23 \times 10^{-09}$), Q25 (+0.116, $p = 1.76 \times 10^{-10}$), and Q50 (+0.100, $p = 2.42 \times 10^{-06}$). Fiscal resource rents thus alleviate headline monetary metrics on paper. They do not compensate agrarian households or protect local water commons. At Q90, the water coefficient is −1.572 pp (p = 0.044) and the agrarian-share coefficient is −0.267 per +10 pp ($p = 4.73 \times 10^{-04}$), the reverse of the pattern at lower quantiles. These Q90 estimates are treated as exploratory: they indicate that the upper tail of the distribution (65.8% unsafe water) behaves differently from the rest and are not interpreted further.

Table 4. Subnational Panel Econometrics (TWFE Post-2014 Downstreaming Interaction, N = 508 Districts), Doubly Robust AIPW Matching (N = 415 *Kabupaten*), and RIF Unconditional Quantile Regressions (Tier 3).

Econometric Specification & Target Outcome	Sample Domain (Units / Obs)	Point Estimate (β or ATE)	Robust / Bootstrap SE	95% Confidence Interval	p-Value & Sensitivity / Balance
Panel A: Two-Way Fixed-Effects (TWFE) Post-2014 × Extractive/Geothermal Z-Index (District & Year FE)					
Agrarian, Forestry & Fishery Livelihood Share (%)	508 dist (4,478)	−0.3929	0.3033	[−0.9888, +0.2029]	p = 0.1957 (t = −1.30)
Household Safe-Water Deprivation (%)	508 dist (4,983)	−1.2143	0.3666	[−1.9345, −0.4941]	p = 0.0010 (t = −3.31)
Poorest-20% Relative Expenditure Ratio (%)	508 dist (4,998)	+0.6954	0.1872	[+0.3276, +1.0632]	p = 0.0002 (t = 3.71)
Within-District Gini Inequality Index	508 dist (4,998)	−0.0034	0.0015	[−0.0063, −0.0006]	p = 0.0193 (t = −2.35)
District Poverty Headcount Rate (%)	508 dist (4,998)	+0.0616	0.0879	[−0.1111, +0.2343]	p = 0.4838 (t = 0.70)
Panel B: Doubly Robust AIPW Treatment Effects Across Rural Regencies (Post-2014 Corridor vs. Matched Non-Corridor)					
Agrarian, Forestry & Fishery Livelihood Share (%)	415 Kab (211 T / 204 C)	−2.038 pp	1.128	[−4.248, +0.172]	p = 0.0707; E-val = 1.47; |SMD| = 0.086
Household Safe-Water Deprivation (%; E[Y1]=39.61% vs. E[Y0]=39.13%)	415 Kab (211 T / 204 C)	+0.484 pp	1.443	[−2.344, +3.312]	p = 0.7370 (Null Dividend); max |SMD| = 0.133
Poorest-20% Relative Expenditure Ratio (%; E[Y1]=43.17% vs. E[Y0]=43.17%)	415 Kab (211 T / 204 C)	+0.002 pp	0.672	[−1.315, +1.318]	p = 0.9979 (Null Bottom-Quintile Gain)
Panel C: Firpo–Fortin–Lemieux RIF Unconditional Quantile Effects Across Post-2014 Rural *Kabupaten*					
Quantile (unsafe water; poverty gap P1)	**Sample**	**Water: β_Ext (pp)**	**Poverty gap: β_Ext**	**Poverty gap: β_Agr (+10 pp)**	**p values**
Q10 Quantile (Unsafe Water = 18.0%; PovGap = 0.70)	Post-2014 Rural Kab	Water β_Ext = −0.523 pp	PovGap β_Ext = −0.085	PovGap β_Agr(+10pp) = +0.098	p_Wat=0.325; p_Agr=1.23×10^{-09}
Q25 Quantile (Unsafe Water = 25.5%; PovGap = 1.08)	Post-2014 Rural Kab	Water β_Ext = −0.241 pp	PovGap β_Ext = −0.149	PovGap β_Agr(+10pp) = +0.116	p_Wat=0.534; p_Agr=1.76×10^{-10}
Q50 Quantile (Unsafe Water = 35.7%; PovGap = 1.75)	Post-2014 Rural Kab	Water β_Ext = +0.186 pp	PovGap β_Ext = −0.175	PovGap β_Agr(+10pp) = +0.100	p_Wat=0.608; p_Agr=2.42×10^{-06}
Q75 Quantile (Unsafe Water = 48.5%; PovGap = 2.83)	Post-2014 Rural Kab	Water β_Ext = −0.479 pp	PovGap β_Ext = −0.318	PovGap β_Agr(+10pp) = +0.047	p_Wat=0.343; p_Agr=1.19×10^{-01}
Q90 Quantile (Unsafe Water = 65.8%; PovGap = 4.67)	Post-2014 Rural Kab	Water β_Ext = −1.572 pp	PovGap β_Ext = −0.718	PovGap β_Agr(+10pp) = −0.267	p_Wat=0.044; p_Agr=4.73×10^{-04}

Note: TWFE models include district and year fixed effects plus time-varying controls (log per-capita public expenditure, household electrification, and adult literacy), with standard errors clustered by district. Doubly Robust AIPW combines Newton–Raphson propensity-score weighting with linear outcome regressions across literacy, electrification, urbanization, and log fiscal spending (reducing unweighted mean |SMD| from 0.398 to 0.086 and max |SMD| from 0.578 to 0.133). Panel A and Panel B estimates use different sample sizes; the Panel B contrast is a cross-section of post-2014 regencies.



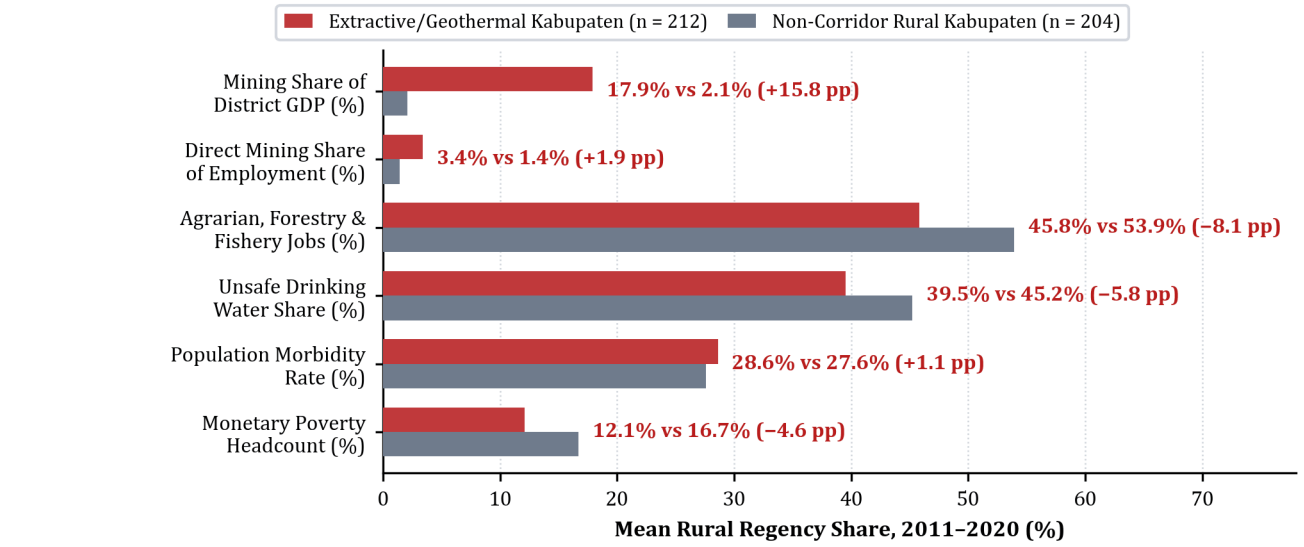


Figure 3. Georeferenced spatial distribution of Indonesian power infrastructure and contested customary corridors paired with the subnational Rural Enclave Dispossession Paradox. (A) Archipelagic map overlaying 178 Indonesian WRI power plants (including 10 utility geothermal complexes totaling 1,342.0 MW) with all 24 contested critical-mineral (CM01–CM12) and geothermal (GT01–GT12) corridors stratified by territorial outcome. (B) Structural comparison across all 416 rural regencies (*Kabupaten*), contrasting a +15.8 pp mining GDP share premium (17.9% vs. 2.1%) against minimal direct mining employment (3.4%), an 8.1 pp lower agrarian/forestry/fishery employment share, and +1.1 pp elevated morbidity.

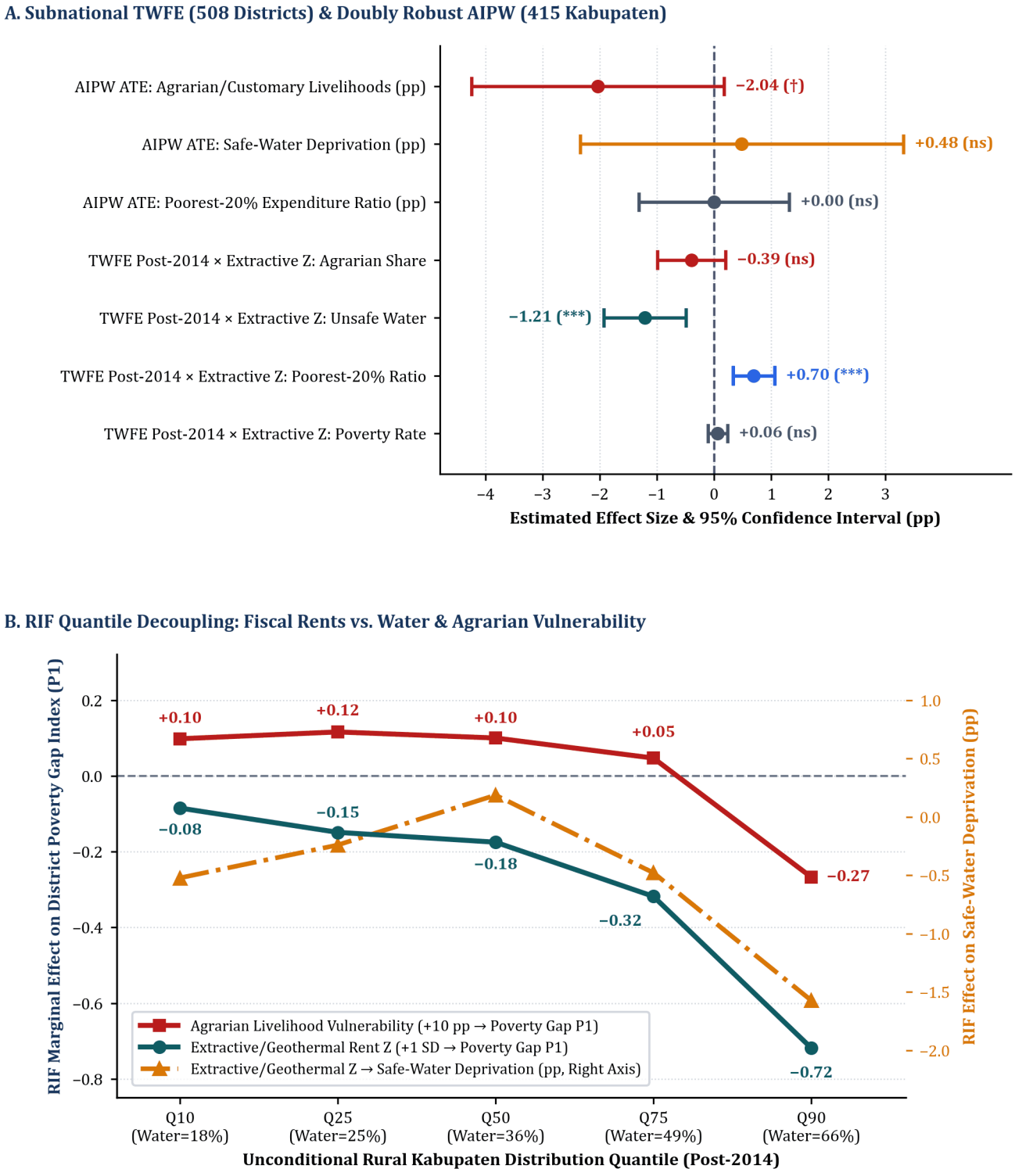


Figure 4. Subnational associations and distributional quantile decoupling across Indonesian districts. (A) Forest plot of Two-Way Fixed-Effects (TWFE; 508 districts, N = 4,998) and Doubly Robust AIPW treatment effects (415 rural *Kabupaten*; max weighted |SMD| = 0.133), showing an imprecise lower agrarian share (AIPW ATE = −2.04 pp; 95% CI includes zero) alongside no detectable safe-water (+0.48 pp) or bottom-quintile expenditure (+0.002 pp) differences. (B) Firpo–Fortin–Lemieux Recentered Influence Function (RIF) unconditional quantile curves (Q10–Q90) illustrating Fiscal Rent–Ecological Welfare Decoupling between monetary poverty-gap compression, stagnant safe-water deprivation, and unprotected agrarian livelihood vulnerability.

3.4. Tier 4: fsQCA necessity, sufficiency, and asymmetry across 24 corridors

Why do some Indigenous and local communities halt green-extractive encroachment, while others lose their land for good? We looked across 24 contested corridors (Table 5, Panel A; Figure 5B). Protective territorial outcomes (>0.50 membership) were achieved in 4 of 12 critical-mineral corridors (33.3%; mean fuzzy outcome = 0.36) and in 6 of 12 geothermal corridors (50.0%; mean fuzzy outcome = 0.47). Necessity screening is exact and single-condition, set against Ragin's strict 0.90 consistency benchmark. It reveals a set-theoretic asymmetry (Table 5, Panel B; Figure 5A). Three mobilization conditions each exceed 0.90 necessity consistency for a Protective Territorial Outcome (OUTCOME_PROTECT), and each shows non-trivial

Relevance of Necessity (RoN): Translocal Environmental–Indigenous Coalitions (COALITION: consistency = 1.0000, coverage = 0.6246, RoN = 0.5707), Indigenous Participatory Counter-Mapping (CMAP: consistency = 0.9340, coverage = 0.6371, RoN = 0.6371), and Legal-Constitutional & Safeguard Mobilization (LEGAL: consistency = 0.9010, coverage = 0.6941, RoN = 0.7352). No corridor secured territorial protection without translocal coalition backing. Because the corridors were selected for contestation, a coalition is present (membership ≥ 0.33) in 23 of 24 cases, all but GT10. Nearly all also needed georeferenced counter-mapping and formal legal or lender-safeguard action. According to the membership matrix in Figure 5B, the ten protected corridors are CM06, CM07, CM08, and CM12 among the critical-mineral cases and GT01, GT02, GT06, GT07, GT08, and GT12 among the geothermal cases.

We built the exact 2^5 = 32 truth table. Only 8 configurations are populated, a strong empirical clustering (Table 6, Panel A). Such limited diversity is typical of structured regimes. Conservative Quine–McCluskey Boolean minimization, applied to configurations passing raw consistency ≥ 0.80 and PRI ≥ 0.65, gives one conjunctural sufficiency pathway for territorial protection (Table 6, Panel B; Figure 6A): CMAP * LEGAL * COALITION * ~PSN_LOCK * ECOL_VIS → OUTCOME_PROTECT, with Solution Consistency = 0.9057, PRI = 0.8838, and Raw/Unique Coverage = 0.6340. Seven major protective victories across both sectors sit under this five-factor conjunction. They are Wawonii Island nickel (CM06), Sangihe Island gold-copper (CM07), Dairi zinc-lead (CM08), Bangka coastal/offshore tin zonation (CM12), Wae Sano geothermal (GT02), Gunung Talang geothermal (GT06), and Baturraden Mount Slamet geothermal (GT08). The protective pathway covers seven of the ten protected corridors. GT07 (outcome fully in, ECOL_VIS = 0.33) falls below the 0.80 consistency cutoff in row 11100, and GT01 and GT12 (outcome 0.67, PSN_LOCK = 0.67) are not covered by the solution. GT12 (Lahendong–Tompaso) shares the configuration of GT01, with all five conditions and the outcome at 0.67.

We also modeled the negated outcome (~OUTCOME_PROTECT: Unchecked Customary Dispossession). It points to an asymmetry, not a mirror-image inversion (Table 5, Panel B; Table 6, Panel C). National Strategic Project security lock-in (PSN_LOCK) emerges as a near-necessary condition for unchecked dispossession (consistency = 0.9529, coverage = 0.8337, RoN = 0.7505). Quine–McCluskey minimization identifies two sufficient dispossession pathways, with Overall Solution Consistency = 0.9402, PRI = 0.9271, and Solution Coverage = 0.7407. (1) Pathway P1_Disp (~LEGAL * PSN_LOCK * ECOL_VIS; consistency = 0.9341, raw coverage = 0.6679, unique coverage = 0.4793). It covers 11 major extractive and geothermal enclaves: Morowali IMIP (CM01), North Konawe (CM02), Weda Bay IWIP (CM03), East Halmahera (CM04), Obi Island Kawasi (CM05), Tumpang Pitu (CM09), Mimika (CM10), Ketapang bauxite (CM11), Mataloko (GT03), Sorik Marapi (GT04), and Dieng (GT09). Even where acute ecological damage is highly visible and partial counter-mapping or NGO advocacy exists (e.g., CM03 Weda Bay, CM10 Mimika, GT09 Dieng), PSN security lock-in combined with blocked judicial review appears to lock in dispossession in these cases. (2) Pathway P2_Disp (~CMAP * ~COALITION * PSN_LOCK * ~ECOL_VIS; consistency = 1.0000, raw coverage = 0.2614, unique coverage = 0.0729). It covers Sarulla (GT05), Rantau Dedap (GT10), and Muara Laboh (GT11). There, individual plot-by-plot compensation quietly fragments customary *ulayat* claims, because neither counter-mapping nor translocal alliances are present.

Table 5. Calibrated 24-Corridor Fuzzy-Set Membership Profile and Exact Ragin fsQCA Single-Condition Necessity Analysis for Protective Territorial Outcomes vs. Unchecked Dispossession (Tier 4: N = 24 Contested Corridors).

Sector (means of fuzzy-set memberships)	PSN_LOCK / CMAP / LEGAL	COALITION / ECOL_VIS	Mean OUTCOME_PROTECT	Protected corridors (>0.50)	Dispossessed corridors
Panel A: Sectoral Fuzzy-Set Means Across N = 24 Contested Corridors (12 Critical Mineral vs. 12 Geothermal)					
Critical-mineral corridors (CM01–CM12)	0.67 / 0.58 / 0.53	0.67 / 0.86	0.36	4 / 12 (33.3%)	8
Geothermal corridors (GT01–GT12)	0.67 / 0.64 / 0.56	0.67 / 0.67	0.47	6 / 12 (50.0%)	6
Panel B: Exact Single-Condition Necessity Screening (X and ~X Tested Against Both Outcomes)					
Set-Theoretic Condition / Contested Corridor Sub-Sector	**Protective Outcome Necessity Consistency**	**Protective Coverage (RoN)**	**Dispossession (~OUTCOME) Necessity Consistency**	**Dispossession Coverage (RoN)**	**Set-Theoretic Necessity Benchmark (≥0.90)**
Translocal Environmental-Indigenous Coalition (COALITION)	1.0000	0.6246 (0.571)	0.5471	0.4785 (0.489)	Strictly Necessary for Protection (1.000 ≥ 0.90)
Indigenous Participatory Counter-Mapping (CMAP)	0.9340	0.6371 (0.637)	0.4979	0.4754 (0.548)	Necessary for Protection (0.934 ≥ 0.90)
Legal-Constitutional & Lender Mobilization (LEGAL)	0.9010	0.6941 (0.735)	0.4250	0.4584 (0.611)	Necessary for Protection (0.901 ≥ 0.90)
Acute Visible Ecological-Hydrological Disruption (ECOL_VIS)	0.8340	0.4545 (0.361)	0.7857	0.5995 (0.435)	High Salience Across Both Outcomes (0.835 / 0.786)
National Strategic Project Security Lock-In (PSN_LOCK)	0.3980	0.2488 (0.400)	0.9529	0.8337 (0.750)	Near-Necessary for Dispossession (0.953 ≥ 0.90)
Absence of PSN Security Lock-In (~PSN_LOCK)	0.7340	0.9175 (0.960)	0.1414	0.2475 (0.727)	Enabling Institutional Opening (0.736)
Absence of Legal-Constitutional Mobilization (~LEGAL)	0.2970	0.2695 (0.617)	0.7164	0.9102 (0.929)	Core Component of Dispossession Pathway P1
Absence of Indigenous Counter-Mapping (~CMAP)	0.2310	0.2473 (0.676)	0.6200	0.9293 (0.957)	Core Component of Quiet Enclosure Pathway P2

Note: Four-value fuzzy sets calibrated at 0.00 (fully out), 0.33 (more out than in), 0.67 (more in than out), and 1.00 (fully in) (the membership matrix is shown in Figure 5B). RoN denotes Schneider & Wagemann Relevance of Necessity. Sector means are of the calibrated memberships in Figure 5B. Values in Panel B reproduce from the matrix in Figure 5B.

Table 6. Exact Ragin Truth-Table Configurations and Conservative Quine–McCluskey Boolean Sufficiency Solutions Showing Asymmetry Between Territorial Protection and Unchecked Dispossession (N = 24 Corridors).

Outcome / Boolean Configuration Pathway	Raw Consistency	PRI Consistency	Raw Coverage	Unique Coverage	Empirically Covered Contested Corridors (Membership > 0.50)
Panel A: Observed Truth-Table Rows (2^5 = 32 Logical Corners; 8 Populated Empirical Configurations, N = 24)					
Row [11101] (CMAP=1, LEGAL=1, COALITION=1, PSN_LOCK=0, ECOL_VIS=1)	0.9057	0.8838	n = 7 cases	Coded = 1	CM06, CM07, CM08, CM12, GT02, GT06, GT08
Row [11100] (CMAP=1, LEGAL=1, COALITION=1, PSN_LOCK=0, ECOL_VIS=0)	0.7785	0.7155	n = 1 cases	Coded = 0	GT07
Row [11111] (CMAP=1, LEGAL=1, COALITION=1, PSN_LOCK=1, ECOL_VIS=1)	0.5467	0.3774	n = 2 cases	Coded = 0	GT01, GT12
Row [10111] (CMAP=1, LEGAL=0, COALITION=1, PSN_LOCK=1, ECOL_VIS=1)	0.3793	0.1325	n = 3 cases	Coded = 0	CM03, CM10, GT03
Row [00111] (CMAP=0, LEGAL=0, COALITION=1, PSN_LOCK=1, ECOL_VIS=1)	0.2982	0.0661	n = 4 cases	Coded = 0	CM01, CM05, CM09, GT04
Row [10011] (CMAP=1, LEGAL=0, COALITION=0, PSN_LOCK=1, ECOL_VIS=1)	0.2936	0.0000	n = 1 cases	Coded = 0	CM11
Row [00011] (CMAP=0, LEGAL=0, COALITION=0, PSN_LOCK=1, ECOL_VIS=1)	0.2619	0.0000	n = 3 cases	Coded = 0	CM02, CM04, GT09
Row [01010] (CMAP=0, LEGAL=1, COALITION=0, PSN_LOCK=1, ECOL_VIS=0)	0.2215	0.0000	n = 1 cases	Coded = 0	GT05
Row [00010] (CMAP=0, LEGAL=0, COALITION=0, PSN_LOCK=1, ECOL_VIS=0)	0.1988	0.0000	n = 2 cases	Coded = 0	GT10, GT11
Panel B: Conservative Quine–McCluskey Sufficiency Solution for Protective Territorial Outcome (OUTCOME_PROTECT)					
Pathway P1_Prot: CMAP * LEGAL * COALITION * ~PSN_LOCK * ECOL_VIS	0.9057	0.8838	0.6340	0.6340	CM06 Wawonii, CM07 Sangihe, CM08 Dairi, CM12 Bangka, GT02 Wae Sano, GT06 G. Talang, GT08 Baturraden
Overall Protective Solution Metrics	Cons = 0.9057	PRI = 0.8838	Cov = 0.6340	(+Preemptive GT07)	Exceeds Strict Ragin (0.80) & PRI (0.65) Sufficiency Benchmarks
Panel C: Asymmetric Quine–McCluskey Sufficiency Solution for Unchecked Dispossession (~OUTCOME_PROTECT)					
Pathway P1_Disp: ~LEGAL * PSN_LOCK * ECOL_VIS	0.9341	—	0.6679	0.4793	CM01 (Morowali), CM02 (North), CM03 (Weda), CM04 (East), CM05 (Obi), CM09 (Tumpang), CM10 (Mimika), CM11 (Ketapang–Sanggau), GT03 (Mataloko), GT04 (Sorik), GT09 (Dieng)
Pathway P2_Disp: ~CMAP * ~COALITION * PSN_LOCK * ~ECOL_VIS	1.0000	—	0.2614	0.0729	GT05 (Sarulla), GT10 (Rantau), GT11 (Muara)
Overall Dispossession Solution Metrics	Cons = 0.9402	PRI = 0.9271	Cov = 0.7407	2 Disjunct Paths	Confirms Asymmetric PSN Security Override vs. Quiet Fragmentation

Note: Exact Quine–McCluskey minimization performed over empirically observed configurations meeting raw consistency ≥ 0.80 and Proportional Reduction in Inconsistency (PRI) ≥ 0.65 without speculative simplifying assumptions on logical remainders.[41,42] GT07 (outcome 1.00) is not covered by the protective solution because row 11100 has raw consistency 0.7785, below 0.80; GT01 and GT12 (outcome 0.67) are not covered either.

3.5. Integrative process-tracing synthesis and mixed-methods joint display

Table 7 synthesizes our geospatial, econometric, and configurational findings through within-case counterfactual process tracing.[43–45,67] One comparison sets small-island mineral victories in Wawonii (CM06) and Sangihe (CM07) against PSN smelter hubs in Morowali (CM01), Weda Bay (CM03), and Obi Island (CM05), and it is consistent with a leading role for statutory power (~PSN_LOCK * LEGAL). Wawonii is a small island that makes up almost all of Konawe Kepulauan Regency (867.58 km^2 of land area). Sangihe is a volcanic island in North Sulawesi (Sangihe Islands Regency, 736.98 km^2 of land area). On both islands participatory counter-maps overlayed smallholder clove, nutmeg, sago, and coastal fishery zones directly onto mining concessions. That let translocal legal coalitions win court rulings. On Wawonii, PTUN Jakarta and the Supreme Court (MA) annulled the forest-use permit of PT Gema Kreasi Perdana,[68] and the Constitutional Court rejected the company's challenge to the small-island mining ban of Coastal and Small Islands Law No. 1/2014.[60] On Sangihe, the MA upheld the annulment of the ministerial approval for the production stage of the PT Tambang Mas Sangihe contract of work.[69] Weda Bay (CM03) and Obi Island (CM05) differed sharply. Documentation there was extensive. It covered

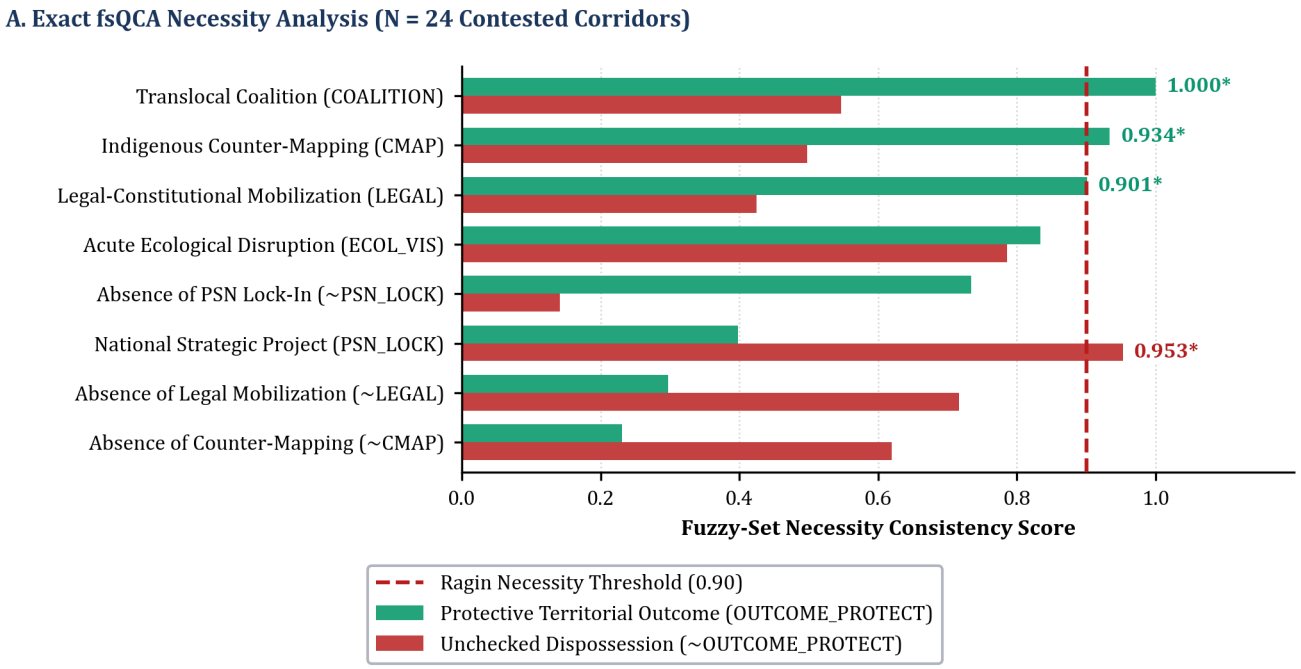
turbid karst rivers in Sagea, threats to uncontacted/nomadic O Hongana Manyawa forest territories, and spring-water contamination concerns in Kawasi. Executive PSN and Vital National Object designations still insulated the battery-nickel smelters from domestic permit cancellation. Outcomes stopped at non-statutory corporate buffer pledges (CM03 = 0.33) or state-directed village relocation (CM05 = 0.00).

Cross-sectoral process tracing also explains why multilateral lender safeguards and preemptive sacred cartography open protective routes in highland base-metal and geothermal corridors. In Dairi (CM08, North Sumatra) and Wae Sano (GT02, Flores), Batak Pakpak farmers and Manggarai customary communities (*compang*/*gendang*) mapped seismic fault zones, sacred crater lakes, and village water springs. At the same time, they pursued domestic administrative litigation and filed a complaint with the IFC Compliance Advisor Ombudsman (CM08; it concerned IFC's indirect exposure through an investment in the Postal Savings Bank of China) and World Bank safeguard teams (GT02). The results were Supreme Court environmental-permit revocation in Dairi[70] and World Bank funding withdrawal in Wae Sano. Gunung Lawu (GT07; Figure 6A upper-left quadrant) is an even sharper case of a 'Preemptive Sacred-Cultural Veto Pathway'. Exploratory drilling there had not yet caused physical ecological damage (ECOL_VIS = 0.33, placing Truth-Table Row 11100 at 0.779 raw consistency, just below the 0.80 automated cutoff). Cross-regency Javanese cultural custodians, *pesantren*, and academic heritage mappers nonetheless documented hundreds of sacred temple/spring sites across Mount Lawu. That documentation compelled the Ministry of Energy and Mineral Resources to remove the WKP from its plans in 2023 (OUTCOME_PROTECT = 1.00). Poco Leok (GT01; Truth-Table Row 11111) ran the other way. Strong Manggarai *gendang* counter-mapping and Church-NGO coalitions met national geothermal priority status head-on (PSN_LOCK = 0.67). The result was a protracted standoff and partial moratorium demands (0.67), not outright cancellation.

Table 7. Integrative Mixed-Methods Joint Display Linking Satellite Deforestation, Subnational Enclave/AIPW/RIF Econometrics, Set-Theoretic fsQCA Pathways, and Comparative Process-Tracing Evidence.

Analytical Mechanism	Geospatial & Subnational Econometric Evidence (Tiers 1–3)	Set-Theoretic fsQCA & Within-Case Process Tracing (Tier 4: N = 24 Corridors)	Mixed-Methods Integration Type & Theoretical Meta-Inference
1. Post-2014 Smelter Downstreaming & PSN Security Lock-In	Tier 1: IDN #1 in the data analyzed (3,603.3 km^2; 23.8% share); Critical-mineral clearing was 23.5% higher (mean annual) after 2014 (88.6%–88.9% of Sulawesi rain-forest mining loss; 96.6% SW Borneo swamp loss).	fsQCA Dispossession P1 (~LEGAL * PSN_LOCK * ECOL_VIS; Cons = 0.934): Morowali IMIP (CM01), North Konawe (CM02), Weda Bay IWIP (CM03), Obi HPAL (CM05), & Mimika (CM10) expand unabated under PSN/Vital Object security despite severe karst/coastal siltation.	CONFIRMATION & SPATIAL MECHANISM: Macro satellite deforestation increases appear to materialize locally through executive PSN fast-tracking that insulates smelter parks from local veto.
2. Fiscal Rent–Ecological Welfare Decoupling & Water Vulnerability	Tier 3: Corridor *Kabupaten* generate 17.92% mining GDP & DBH rents (compressing monetary poverty gap), yet employ only 3.39% in mining, have an agrarian employment share 8.12 pp lower (AIPW –2.04 pp), have 1.10 pp higher unadjusted morbidity ($p = 3.99 \times 10^{-5}$), and show no detectable AIPW safe-water difference (+0.48 pp, p = 0.737).	Process Tracing in Obi Kawasi (CM05 — Toduku spring chromium concerns), Weda Bay Sagea (CM03 — karst river turbidity), Sorik Marapi (GT04 — H2S leaks & water-rights strife), & Dieng (GT09 — well/pipe proximity hazards).	PRODUCTIVE DISCORDANCE: Suggests why aggregate monetary poverty is lower in corridor regencies even as water security, agrarian employment, and health indicators show no advantage.
3. Judicialized Counter-Mapping & Lender Safeguard Leverage	Tier 1: Critical minerals show the highest 50-km protected/community reserve encroachment (0.84 km^2). Tier 2: IDN #3 in WRI geothermal capacity (1,342 MW) across upland watersheds.	fsQCA Protective Solution (CMAP * LEGAL * COALITION * ~PSN_LOCK * ECOL_VIS; Cons = 0.906, PRI = 0.884): Court annulments of permits in Wawonii (CM06) & Sangihe (CM07), and a Constitutional Court ruling upholding the Small Islands Law 1/2014 mining ban; PTUN/IFC-CAO halt in Dairi (CM08) & World Bank exit in Wae Sano (GT02).	EXPLANATION: Participatory BRWA/customary maps halt extraction only when translated into binding judicial reviews or multilateral lender safeguard compliance.
4. Quiet Bureaucratic Enclosure vs. Preemptive Sacred Veto	Tier 3 RIF Quantiles: Unprotected agrarian livelihood dependence increases rural poverty gap across Q10–Q50 (+0.098 to +0.116 per +10 pp, $p < 2.5 \times 10^{-6}$).	fsQCA Dispossession P2 (~CMAP * ~COALITION * PSN_LOCK * ~ECOL_VIS; Cons = 1.000: Sarulla GT05, Rantau Dedap GT10, Muara Laboh GT11) vs. Deviant Protective Case Gunung Lawu (GT07: sacred-mountain counter-mapping halted auction pre-drilling).	THEORETICAL REFINEMENT: Absent counter-mapping, piecemeal compensation quietly fragments *ulayat* commons; conversely, sacred-cultural mobilization can veto tenders preemptively.

Note: Structured following Behrens & Rohlfing (2026),[44] Runhardt (2024),[45] and Younas & Fàbregues (2026)[46] mixed-methods integration standards. All corridor codes correspond 1:1 to the membership matrix in Figure 5B.



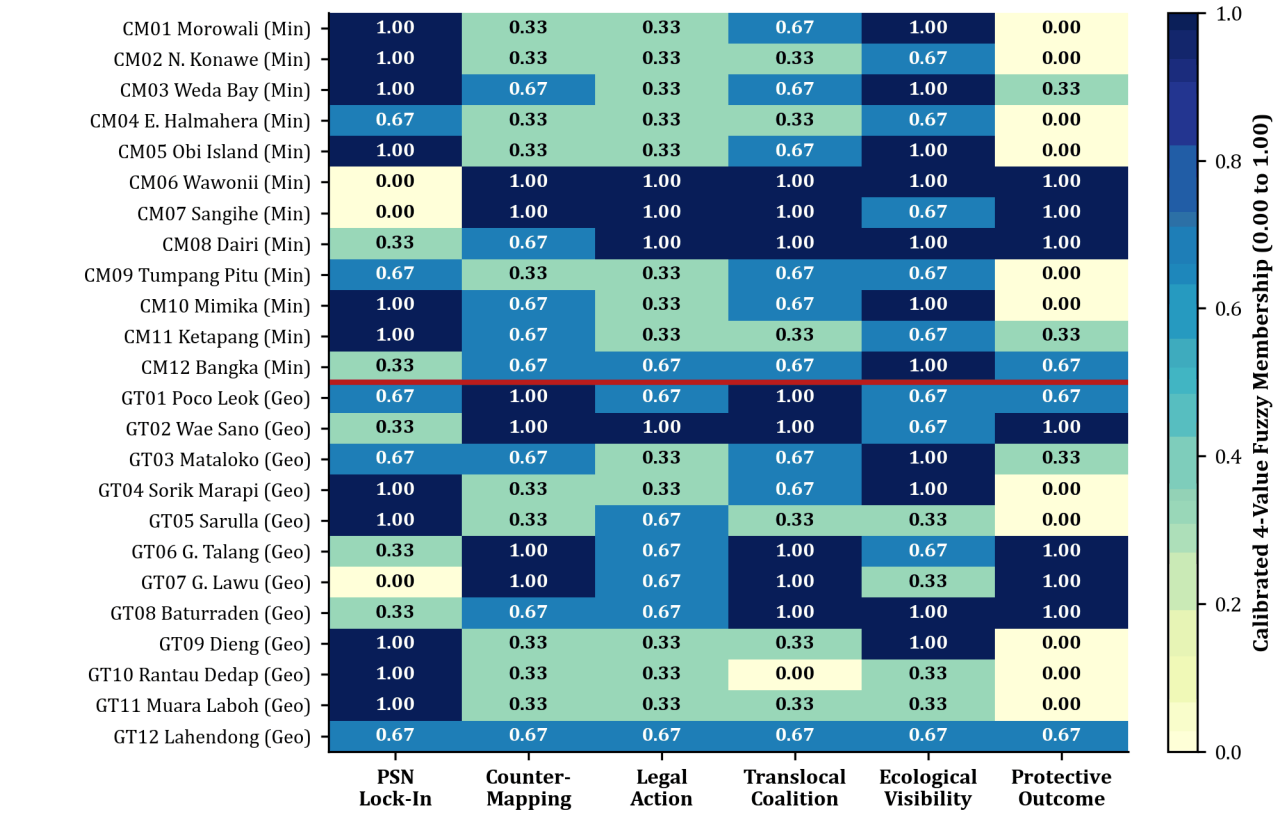


Figure 5. Set-theoretic necessity screening and calibrated 24-corridor fuzzy-set membership matrix. (A) Exact Ragin fsQCA necessity consistency scores against the 0.90 benchmark, indicating that Translocal Coalitions (1.000), Indigenous Counter-Mapping (0.934), and Legal Mobilization (0.901) are necessary for protective territorial outcomes, whereas National Strategic Project status (PSN_LOCK = 0.953) is near-necessary for unchecked dispossession. (B) Complete 24 × 6 calibrated four-value fuzzy-set heatmap contrasting 12 critical-mineral corridors (CM01–CM12) and 12 geothermal corridors (GT01–GT12).

4. Discussion

4.1. Theorizing 'Dual Green Extractivism' and executive PSN exceptionalism

Our multi-scale findings advance agrarian and energy-transition theory by proposing that critical-mineral downstreaming and volcanic geothermal power make up 'Dual Green Extractivism'. These are two materially distinct yet institutionally homologous frontiers of decarbonization-driven territorial enclosure.[1,2,7] One covers ultramafic coastal-lowland forests in Sulawesi, Halmahera, and Kalimantan (23.5% higher mean annual satellite-measured clearing after 2014; 88.6%–96.6% share in Sulawesi rain forests and Southwest Borneo swamp forests), while the other covers volcanic montane watersheds in Sumatra, Java,

and Flores (1,342.0 MW operating geothermal plus contested expansion WKPs). In both sectors, state licensing rests on one colonial-era premise: state forest domination (*Kawasan Hutan*). It also rests on 'dispossession by archive'.[4] Customary boundaries stay unratified. So ministries can classify ancestral agroforests, sago commons, and sacred volcanic slopes as state production or protection forests. Such forests are then eligible for industrial lease or geothermal environmental-services permits.

Our fsQCA results suggest that state power is not monolithic. Executive National Strategic Project (PSN) designation appears to act as an institutional switch. It governs whether green extractivism becomes legally contestable (PSN_LOCK necessity for dispossession = 0.9529; Solution Consistency = 0.9402). Some transition projects are wrapped in PSN and Vital National Object security decrees, such as Indonesia's flagship bilateral battery-nickel and alumina industrial parks (CM01, CM02, CM03, CM05, CM11) and priority grid geothermal fields (GT04, GT05, GT09, GT10, GT11). For these, accelerated land-procurement statutes, centralized permitting, and security-force deployment appear to neutralize community opposition, even amid acute ecological disruption.[24,71] The picture changes without PSN insulation (~PSN_LOCK). It also changes where projects depend on multilateral development finance subject to international Indigenous Peoples and environmental safeguards (GT02, CM08). Domestic courts and lender accountability mechanisms then remain viable arenas for halting dispossession.

4.2. Explaining fiscal rent–ecological welfare decoupling in extractive regencies

Our Tier 3 INDO-DAPOER econometrics contribute to a long-running debate in the resource-curse and mining-poverty literature.[21,72,73] Advocates of mineral downstreaming and geothermal expansion often point to falling district monetary poverty and rising regional GDP in Morowali, Halmahera, and other extractive regencies as evidence of inclusive prosperity. Our data agree on the headline numbers. Extractive and geothermal corridor *Kabupaten* show a +15.83 pp higher mining GDP share (17.92% vs. 2.09%), and they receive large DBH revenue-sharing transfers that narrow monetary poverty gaps across RIF quantiles (Table 3; Table 4, Panel C). Yet a reading that stops at monetary poverty hides a deeper problem, the 'Fiscal Rent–Ecological Welfare Decoupling.'

Two patterns stand out. First, modern pyrometallurgical and hydrometallurgical smelters, along with binary and flash geothermal plants, are capital-intensive enclaves, and their skilled technical labor is reported to be largely recruited from outside customary villages.[48] Jobs are scarce. Across all 212 corridor *Kabupaten*, direct mining and quarrying absorbs just 3.39% of total employment, while the agrarian, forestry, and fishery employment share is 8.12 pp lower than in non-corridor regencies (Doubly Robust AIPW ATE = −2.04 pp, 95% CI −4.25 to +0.17). Second, propensity-score matching against non-corridor regencies with equivalent fiscal spending, literacy, electrification, and urbanization leaves no detectable gain in the extractive and geothermal regencies. Safe drinking water access shows no detectable net improvement (AIPW ATE = +0.48 pp, p = 0.737; 39.61% lacking safe water). The poorest-20% relative expenditure share shows no detectable change (ATE = +0.002 pp, p = 0.998). Unadjusted morbidity is statistically significantly higher by +1.10 pp ($p = 3.99 \times 10^{-05}$; Table 3, not an AIPW estimate). Recent eco-hydrological evidence links tropical forest clearing to degraded watershed filtration.[12] Fiscal cash cannot replace intact spring watersheds, clean coastal fisheries, and secure customary agroforests.

4.3. Judicialized counter-mapping and preemptive sacred mobilization

Our Tier 4 configurational and process-tracing findings also refine critical cartography scholarship on Indigenous counter-mapping.[36,37,74] Counter-mapping is necessary for territorial protection in contested Indonesian corridors (consistency = 0.9340). On its own, however, it is not sufficient. In Weda Bay (CM03), Mimika (CM10), Ketapang (CM11), and Mataloko (GT03), participatory maps documented customary boundaries. Without successful judicial review or PSN removal, extraction still expanded across the mapped *ulayat* lands. In these corridors, binding territorial protection came from participatory cartography only through 'Judicialized Counter-Mapping.' This is the conjunctural fusion of three elements: community spatial boundary-making (CMAP), translocal legal-environmental coalitions (COALITION = 1.0000 necessity), and statutory or safeguard litigation (LEGAL = 0.9010 necessity; joint sufficiency = 0.9057, PRI = 0.8838).

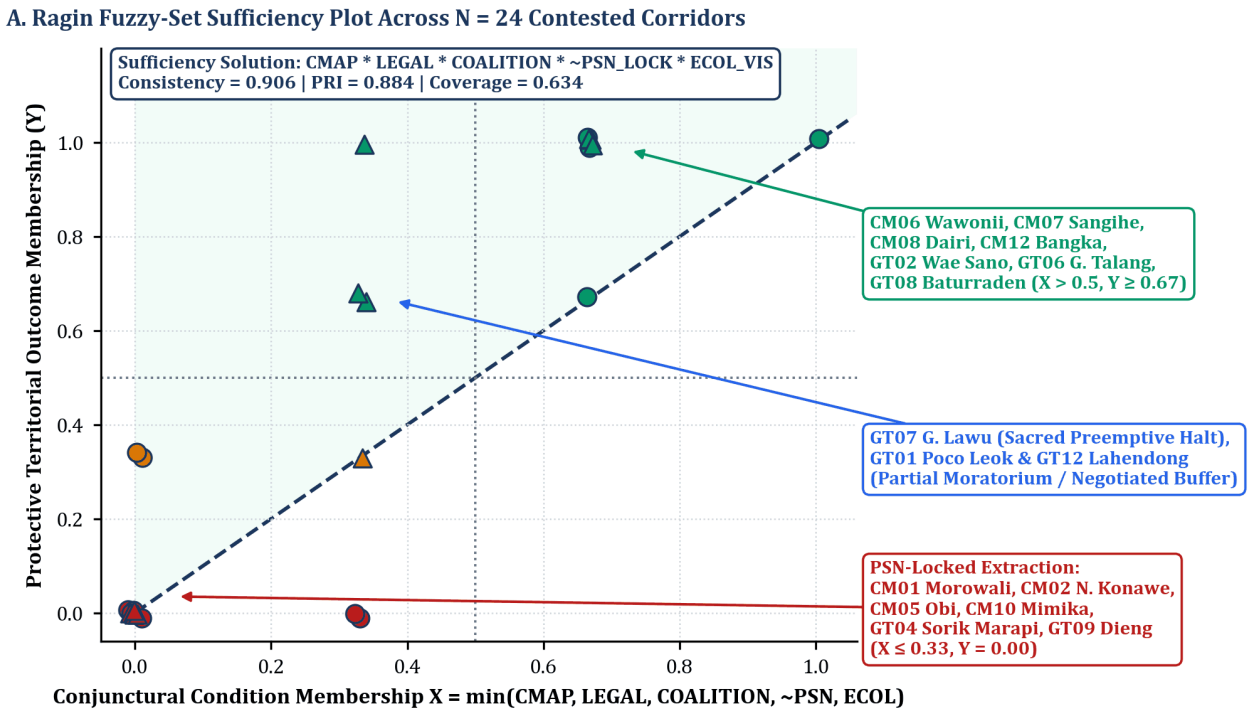
Community-drawn GIS overlays turn vernacular agro-ecological realities into legally legible evidentiary exhibits. The realities include small-island watershed limits in Wawonii (CM06) and Sangihe (CM07), seismic tailings trajectories above Batak Pakpak villages in Dairi (CM08), crater-lake spring networks in Wae Sano (GT02), and sacred cultural landscapes on Gunung Lawu (GT07). Once translated, such exhibits can trigger statutory prohibitions under Law No. 1/2014 on Small Islands, administrative environmental-permit annulment in PTUN/Supreme Court, or multilateral lender withdrawal.[75] Gunung Lawu (GT07) adds a lesson about timing. Preemptive use may matter. When sacred-landscape counter-mapping is mobilized during pre-tender zoning, rather than after physical land clearing, communities may avert irreversible ecological damage.

4.4. Five-pillar policy and statutory safeguard reform protocol

Turning these empirical findings into governance reform means dismantling the legal asymmetries that set national decarbonization targets against Indigenous territorial rights (Figure 6B). Five steps follow. First, Indonesia should enact mandatory Pre-Concession Customary Cadastral Screening. BRWA participatory polygons (Indigenous Territory Registration Agency) would be integrated directly into the statutory 'One Map Policy' (*Kebijakan Satu Peta*) licensing portal. The Ministry of Energy and Mineral Resources would then be barred from issuing Mining Permit Areas (WIUP/IUP) or Geothermal Working Areas (WKP) over mapped *wilayah adat* before boundaries are resolved.[76,77] Second, Parliament should pass the long-pending Indigenous Peoples Bill (RUU *Masyarakat Adat*). It would operationalize Constitutional Court Ruling MK No. 35/PUU-X/2012 without waiting for district *Perda* bottlenecks. It should also codify enforceable Free, Prior and Informed Consent (FPIC). Communities would hold binding veto authority before environmental impact approval (AMDAL).[38,77]

Third, executive National Strategic Project (PSN) regulations must be reformed. Fast-track exemptions from spatial-plan compliance and administrative court injunctions should end. Strict enforcement of anti-SLAPP protections under Article 66 of Environmental Law No.

32/2009[78] should accompany this, so that community mapmakers and environmental defenders are no longer criminalized.[79] Fourth, central and regional governments must strictly enforce categorical ecological no-go zones across small islands (≤2,000 km^2 under Law No. 1/2014 and MK No. 35/PUU-XXI/2023), karst subterranean river systems (such as Sagea), and territories of uncontacted/nomadic Indigenous peoples (such as O Hongana Manyawa in Halmahera).[31,77,80] Fifth, Fiscal Rent–Ecological Welfare Decoupling needs a fiscal remedy. Central-to-district Mineral and Geothermal Revenue Sharing (DBH *Pertambangan* and DBH *Panas Bumi*) should be legally ring-fenced, with, for illustration, at least 30% earmarked. Three uses are named: rural safe piped-water infrastructure, independent heavy-metal/H2S watershed monitoring, and customary agroforestry restoration in affected villages.



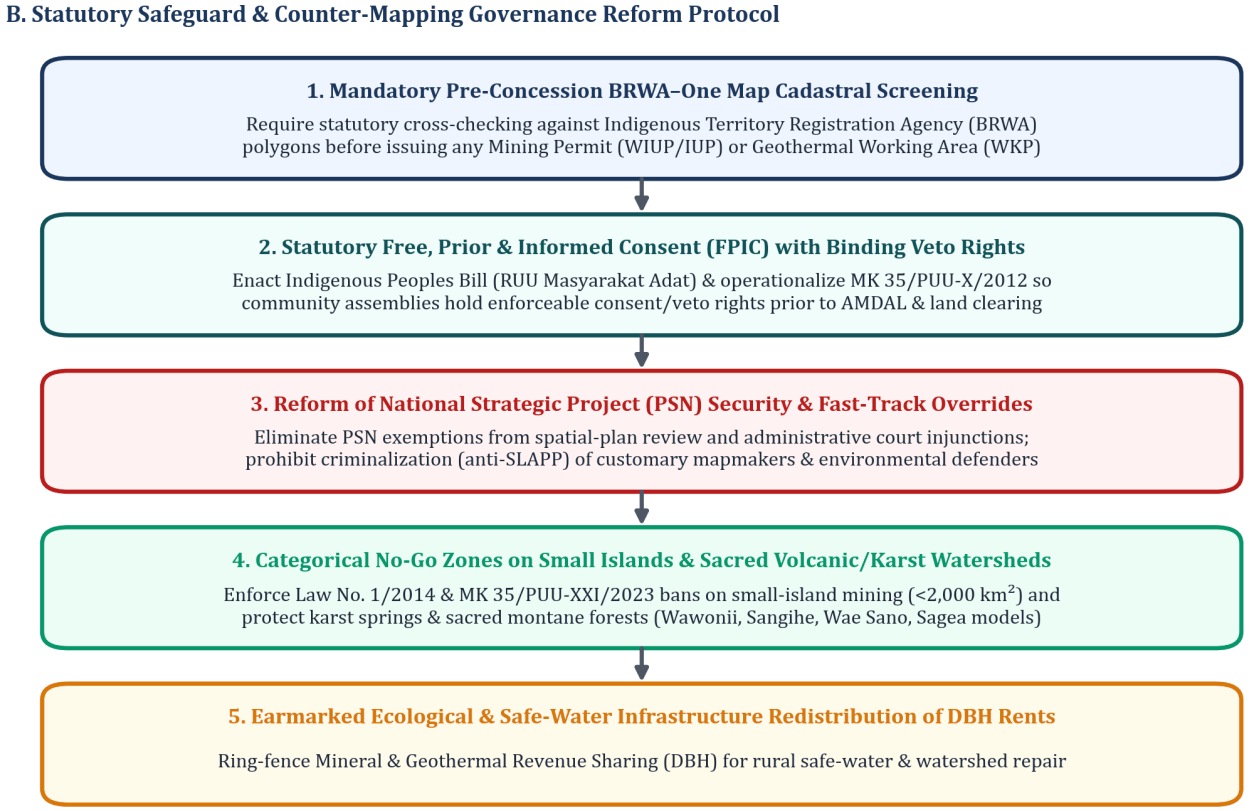


Figure 6. Ragin fuzzy-set X–Y sufficiency plot and statutory safeguard governance reform protocol. (A) Sufficiency plot of the conjunctural protective pathway CMAP * LEGAL * COALITION * ~PSN_LOCK * ECOL_VIS → OUTCOME_PROTECT (Consistency = 0.906, PRI = 0.884, Coverage = 0.634), distinguishing judicialized small-island/watershed victories (CM06, CM07, CM08, CM12, GT02, GT06, GT08) and preemptive sacred mobilization (GT07) from PSN-locked enclaves. (B) Five-pillar legal and institutional reform protocol integrating pre-concession BRWA cadastral screening, binding FPIC, PSN judicial accountability, small-island no-go zones, and earmarked DBH water-infrastructure repair.

4.5. Methodological limitations and future research directions

Four methodological boundaries deserve transparent discussion. First, in Tier 1, the Zenodo 7307210 global satellite mine-polygon series spans 2001–2019.[10] That window captures six full post-announcement/post-ban years of Indonesia's 2014 RKEF smelter wave (23.5% higher mean annual clearing), but the later 2020–2026 HPAL battery-nickel expansion in Halmahera and Sulawesi falls outside it, so our satellite deforestation figures are a conservative lower bound.[17] Extending the remote sensing is a high priority. Polygon-level coverage through 2026 with Sentinel-2 radar-optical fusion would do it. Second, Tier 3 INDO-DAPOER panel econometrics measure welfare at the district (*Kabupaten*/*Kota*) level. At that scale, Doubly Robust AIPW and RIF quantile regressions isolate structural decoupling. Village-level panel linkage below the district, for example PODES–SUSENAS georeferenced buffers within 5–10 km of smelter tailing outfalls and geothermal wellpads, would sharpen spatial exposure precision.

Third, in Tier 4, our N = 24 corridor archive purposefully samples documented critical-mineral and geothermal contestation corridors across Indonesia's principal islands. Silent concessions are not sampled. No public dispute occurred there. Our fsQCA necessity and sufficiency parameters therefore generalize to contested green-extractive frontiers, not to uncontested brownfield sites.[81] Fourth, future mixed-methods inquiry should pair hydrological isotope and heavy-metal field sampling, targeting hexavalent chromium in nickel laterite springs and boron/arsenic/H2S around geothermal reinjection wells, with longitudinal household health panels. The aim is simple. These designs would quantify the exact epidemiological pathways behind the +1.10 pp morbidity elevation identified in corridor regencies. Fifth, corridor status is defined from mining-share and revenue variables that also appear as outcomes, and the district contrasts are cross-sectional associations without pre-trend evidence; the Welch tests in Table 3 treat district-years as independent observations. Sixth, the corridors were coded by the authors without a second coder, and a four-value calibration makes the fsQCA results sensitive to the coding of individual corridors. Seventh, global rankings depend on database coverage: WRI v1.3.0 lists only ten Indonesian geothermal complexes.

5. Conclusion

This study triangulates 594,366 public records, with file integrity checked by SHA-256, from four sources: global 30-meter satellite mine-polygon deforestation panels, georeferenced power infrastructure registries, 10-year subnational panels across all 514 Indonesian districts, and comparative process tracing with exact Ragin fsQCA across 24 contested critical-mineral and geothermal corridors. The evidence suggests a pattern. In the contested corridors examined, decarbonization-driven resource extraction in Indonesia appears to operate as an asymmetric regime of 'Dual Green Extractivism.' Globally, Indonesia bears nearly one-quarter (23.77%; 3,603.26 km^2) of all direct industrial-mining deforestation. It ranks third worldwide in installed geothermal capacity (1,342.0 MW) in the WRI data used. Mean annual mineral-driven forest clearing was 23.5% higher in 2014–2019, after domestic smelter downstreaming began, than in 2001–2013. The affected bioregions are biodiverse: Sulawesi, Halmahera, Kalimantan, and Bangka–Belitung.

Subnationally, extractive and geothermal corridor regencies show Fiscal Rent–Ecological Welfare Decoupling. Large mining GDP shares (17.92%) and fiscal revenue-sharing transfers coincide with lower aggregate monetary poverty metrics. Yet capital-intensive enclaves employ just 3.39% of local workers. Their agrarian and customary livelihood share is lower (−8.12 pp raw; −2.04 pp Doubly Robust AIPW, an imprecise estimate). Unadjusted morbidity is higher (+1.10 pp). No net safe-water improvement is detectable (+0.48 pp AIPW). In set-theoretic terms, Indigenous counter-mapping (0.934), legal-constitutional mobilization (0.901), and translocal coalitions (1.000) are each necessary (consistency 0.90–1.00) and, in conjunction with the absence of PSN lock-in and visible ecological disruption, sufficient (Consistency = 0.9057, PRI = 0.8838) for territorial protection in the corridors examined. One condition applies. They must stay insulated from executive National Strategic Project security lock-in (PSN_LOCK = 0.9529 necessity for dispossession). An ecologically credible and socially just energy transition in Indonesia and across the Global South therefore appears to require subordinating mineral downstreaming and renewable siting to four things: binding customary cadastral recognition, statutory FPIC veto rights, small-island and sacred-watershed no-go zones, and democratic judicial accountability.

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6. Declarations

Statement on the Use of Artificial Intelligence

None. The authors declare that no generative artificial intelligence tools were used in the design, analysis, or writing of this manuscript.

Author Contribution Statement

Conceptualization: Y.M.P. Methodology: Y.M.P. Software: Y.M.P. Validation: S.D., S.I. Formal analysis: Y.M.P. Investigation: Y.M.P., S.D. Resources: Y.M.P. Data curation: Y.M.P. Writing – original draft: Y.M.P. Writing – review & editing: S.D., S.I. Visualization: Y.M.P. Supervision: S.D. Project administration: Y.M.P.

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Conflict of Interest / Competing Interests

The authors declare no competing interests.

Data Availability Statement

Dataset and analysis are available from corresponding author on reasonable academic request.

Ethics Approval and Consent to Participate

This study analyzed exclusively publicly archived satellite remote-sensing polygons, global power-infrastructure registries, aggregated sovereign and subnational official statistics, and public judicial, statutory, and accountability records. No human-subjects intervention

or collection of identifiable private personal data was conducted, and an institutional ethics exemption applies to public-data research.

Consent for Publication

Not applicable. No identifiable individual-level data, clinical records, or personal images are included.

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