

The Impact of Economic Activity on Deforestation in Indonesia

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ABSTRACT

This study empirically analyses the impact of regional economic activity on deforestation across 16 major provinces in the Sumatra, Kalimantan, and Papua regions during the 2023–2025 period. It employed a short-panel data econometric approach ($N = 16$, $T = 3$, Total $N \times T = 48$ observations) and evaluated spatial and temporal dynamics through Pooled OLS, Fixed Effects (FE), and Random Effects (RE) estimations. Formal specification tests specifically the Chow Test ($F = 18.7819$, $p < 0.0001$) and the Hausman Test ($\text{Chi-Sq} = 135.5477$, $p < 0.0001$) confirmed that the Fixed Effects model was the most consistent and valid estimator, as it accounted for unobserved regional heterogeneity. Pooled OLS estimation results revealed a positive and significant elasticity of Gross Regional Domestic Product (GRDP) with respect to deforestation ($\beta = 1.1790$, $p = 0.0408$), demonstrating that a 1% increase in regional economic activity drove a 1.18% rise in the rate of forest cover loss. In the Fixed Effects model, internal variance was absorbed by spatial fixed effects due to the low variation in short-term temporal data relative to inter-regional disparities. These empirical findings confirmed the initial phase of the Environmental Kuznets Curve (EKC), demonstrating that economic growth in natural resource-rich regions remained extractive in nature. Policy recommendations emphasised strengthening the enforcement of Regional Spatial Plans (RTRW), rigorously evaluating National Strategic Projects (PSN), and accelerating the clean energy transition at the regional level.

INTRODUCTION

Indonesia possesses the third-largest tropical rainforest expanse globally, maintaining 95.6 million hectares of primary and secondary forest cover across its archipelagic landmass (KLHK, 2024; CNBC Indonesia, 2025). These forest ecosystems render crucial global ecological services, functioning as primary terrestrial carbon sinks and vital biodiversity sanctuaries. Archipelagic economic expansion creates an escalating structural tension between resource-driven growth and forest conservation. Recent ecological monitoring documents an alarming 66% surge in national deforestation, rising from 261,575 hectares in 2024 to 433,751 hectares in 2025 (Auriga Nusantara, 2026; Kompas.com, 2026). This unprecedented expansion of forest loss concentrates heavily across resource-rich island frontiers, specifically Sumatera, Kalimantan, and Papua (Mongabay Indonesia, 2026).

Ecological degradation within these three strategic regions presents distinct sectoral drivers. Kalimantan experienced the highest absolute deforestation volume in 2025, losing 158,283 hectares of forest cover due to intensive coal mining concessions, timber plantations, and agricultural land clearing (Auriga Nusantara, 2026; Trase Earth, 2025). Sumatera recorded catastrophic deforestation spikes in northern provinces including West Sumatera (1,034% increase to 26,940 ha), Aceh (426% increase to 38,157 ha), and North Sumatera (281% increase to 20,512 ha) triggering severe flash floods and landslides (Kompas.com, 2026). Concurrently, Papua witnessed a 348% explosion in deforestation, driven by state-mandated Megaprojects, regional administrative expansion, and infrastructure construction for Strategic National Projects (PSN) such as the Siboru Fak Fak Airport and food estate initiatives (Mongabay Indonesia, 2026; Simontini, 2025).

Theoretical literature establishes three fundamental frameworks to unpack the macroeconomic drivers of environmental degradation. The Environmental Kuznets Curve (EKC) hypothesis posits an inverted U-shaped relationship between economic development and environmental pressure (Grossman & Krueger, 1995; Stern, 2004). During initial development phases, economies prioritize industrial production and resource extraction, yielding a scale effect that accelerates environmental damage. Environmental Economics theory formalizes deforestation as a classic negative externality resulting from market failures, where private returns from land clearing outweigh public conservation values (Mather, 1992; Rudel et al., 2005). Furthermore, Sustainable Development theory mandates an equilibrium among economic efficiency, social equity, and ecological integrity (United Nations, 2015; World Bank, 2023).

Despite extensive global scholarship on the EKC and land-use change, existing empirical literature presents a critical methodological and empirical gap. Most Indonesian deforestation studies rely either on spatial land-cover mapping without macro-econometric integration (Irvin et al., 2020; Kuapanich et al., 2026) or aggregate national time-series analysis that obscures severe inter-provincial heterogeneity (Basconcillo & Rimkute, 2023; Khoiriyah et al., 2025). Furthermore, literature frequently evaluates land-use drivers in isolation from regional energy grid structures and fossil fuel dependence (Fünfgeld, 2026; Pattinussa & Aaron,

2025). The simultaneous interactions among Gross Regional Domestic Product (GRDP), industrial electricity consumption, fossil fuel reliance, and forest loss across Indonesia's primary forest frontiers remain unexamined within a rigorous panel data framework.

This research resolves this literature gap by delivering three novel scientific contributions. First, it establishes a newly harmonized, verified short-panel dataset across 16 primary forest-frontier provinces in Sumatera, Kalimantan, and Papua for the 2023–2025 period ($N = 16$, $T = 3$, $N \times T = 48$ observations). Second, it implements rigorous econometric specification diagnostics utilizing Chow and Hausman tests to isolate structural spatial fixed effects from Pooled OLS parameters. Third, it quantifies explicit elasticity coefficients connecting regional macro-economic scale and energy grid structures to deforestation, providing an empirical foundation for decarbonized regional planning and national forest governance.

LITERATURE REVIEW

Sustainable Development Theory establishes that long-term economic prosperity requires non-declining natural capital stocks (United Nations, 2015; Pearce & Turner, 1990). In developing market economies reliant on primary commodities, capital accumulation frequently operates through land conversion and natural resource depletion. When regional economic growth relies on land-extensive sectors such as palm oil monoculture, open-pit mining, and industrial logging economic expansion generates direct trade-offs with forest preservation (Pattinussa & Aaron, 2025; Moretti et al., 2025).

Environmental Economics formalizes deforestation as an unpriced environmental spillover (Mather, 1992; Baumol & Oates, 1988). Market mechanisms fail to capture the societal values of carbon sequestration, hydrological regulation, and biodiversity preservation. Consequently, private economic agents convert natural forests into commercial agricultural or mining assets whenever private marginal benefits exceed private land-clearing costs (Rudel et al., 2005; Hamilton & Friess, 2016). In Indonesia, institutional frameworks and concession allocations frequently lower private land-clearing costs, amplifying deforestation pressures during economic upturns (Fünfgeld, 2026; Jong, 2025).

The Environmental Kuznets Curve (EKC) framework provides a structural explanation for the dynamic path of pollution and resource depletion (Grossman & Krueger, 1995; Dinda, 2004). The EKC architecture identifies three structural mechanisms: scale, composition, and technique effects. In early-stage developing regions, the scale effect dominates: expanding economic output increases resource consumption and land conversion. Only when regions reach higher income thresholds do technique improvements and environmental demand shift the trajectory downward (Stern, 2004; Chin-Hong & Meng-Chang, 2026). In resource-rich Indonesian provinces, economic activities remain entrenched within the initial scale-effect regime.

Empirical literature underscores the interplay between energy demand and resource extraction. Regional electricity consumption reflects industrial

expansion, urban growth, and infrastructure utilization (ESDM, 2025; Kemenko Perekonomian, 2026). In mineral-rich provinces, heavy electricity consumption directly correlates with ore processing, smelter operation, and coal mining logistics, which spatially overlap with forest ecosystems (Kurniawan et al., 2025; Kartiasih et al., 2025). Moreover, high reliance on fossil fuels within regional energy grids reinforces extractive economic structures, accelerating land clearing for energy feedstock and infrastructure rights-of-way (Khoiriyah et al., 2025; Basconcillo & Rimkute, 2023).

Based on these theoretical foundations and empirical findings, this study formulates four testable hypotheses:

- H1: Regional Gross Domestic Product (GRDP) exerts a statistically significant positive effect on deforestation across Sumatera, Kalimantan, and Papua provinces.
- H2: Regional electricity consumption exerts a statistically significant positive effect on deforestation across Sumatera, Kalimantan, and Papua provinces.
- H3: Fossil energy structure (percentage of fossil fuel reliance) exerts a statistically significant positive effect on deforestation across Sumatera, Kalimantan, and Papua provinces.
- H4: Regional Gross Domestic Product, electricity consumption, and fossil energy structure exert a statistically significant joint (simultaneous) effect on deforestation across Sumatera, Kalimantan, and Papua provinces.

METHODOLOGY

This study adopts an explanatory quantitative research design utilizing a short panel econometric framework. The research locus encompasses 16 key forest-frontier provinces across three major Indonesian island regions: Sumatera (10 provinces: Aceh, North Sumatera, West Sumatera, Riau, Jambi, South Sumatera, Bengkulu, Lampung, Bangka Belitung, Kepulauan Riau), Kalimantan (5 provinces: West Kalimantan, Central Kalimantan, South Kalimantan, East Kalimantan, North Kalimantan), and Papua (1 consolidated regional block). The temporal scope covers three consecutive annual observation periods (2023–2025), yielding a balanced panel dataset of 48 total observations ($N = 16$, $T = 3$, $N \times T = 48$).

Data collection relies exclusively on audited secondary records published by official government ministries, national statistical agencies, and verified international remote-sensing research institutes. Deforestation data (Y) measures total annual forest cover loss in hectares, compiled from status reports published by Yayasan Auriga Nusantara (STADI 2024, 2025), MapBiomas Indonesia, Global Forest Watch (GFW), and the Ministry of Forestry (Kemenhut, 2025). Economic activity (X1) is operationalized as Real Gross Regional Domestic Product (GRDP) at 2010 Constant Market Prices in Trillion Indonesian Rupiah (IDR Trillion), sourced from the Central Bureau of Statistics (BPS, 2024, 2025). Regional electricity consumption (X2) is measured in Gigawatt-Hours (GWh), extracted from the Ministry of Energy and Mineral Resources (KESDM, 2025) and BPS Regional Electricity Statistics. Fossil energy structure (X3) represents the percentage share of fossil fuels (coal, oil, gas) within total regional power

generation grids, obtained from the Handbook of Energy and Economic Statistics of Indonesia (HEESI, KESDM, 2024, 2025).

To satisfy rigorous econometric standards, all continuous variables are transformed into natural logarithmic specifications (Log-Log / Double Log formulation). This mathematical transformation converts raw regression parameters directly into elasticity coefficients, measuring percentage responses in deforestation resulting from a 1% change in macroeconomic predictors, while simultaneously stabilizing error variances and mitigating potential heteroskedasticity (Ghozali, 2018; Wooldridge, 2010). The empirical model is specified as follows:

$$\ln(\text{Deforestation}_{it}) = \beta_0 + \beta_1 * \ln(\text{GRDP}_{it}) + \beta_2 * \ln(\text{Electricity}_{it}) + \beta_3 * \ln(\text{Fossil}_{it}) + u_i + e_{it}$$

where i denotes the cross-sectional provincial unit ($i = 1, \dots, 16$), t represents the annual time period ($t = 2023, 2024, 2025$), β_0 is the intercept, $\beta_1, \beta_2, \beta_3$ represent elasticity parameters, u_i captures unobserved, time-invariant province-specific individual effects, and e_{it} is the idiosyncratic error term.

Econometric estimation evaluates three alternative panel structures: Pooled Ordinary Least Squares (OLS), the Fixed Effects Model (FE / Within Estimator), and the Random Effects Model (RE / GLS Estimator). Model selection adheres to formal diagnostic testing. The Chow Test (F-test) evaluates whether Pooled OLS or Fixed Effects is superior by testing the null hypothesis that all individual effects u_i are zero:

$$F_{\text{Chow}} = [(R^2_{\text{FE}} - R^2_{\text{Pooled}}) / (N - 1)] / [(1 - R^2_{\text{FE}}) / (N * T - N - K)]$$

If the Chow p -value is less than 0.05, Pooled OLS is rejected in favor of Fixed Effects. Subsequently, the Hausman Test determines whether Fixed Effects or Random Effects is the appropriate model by evaluating correlation between individual effects u_i and regressors X_{it} :

$$\text{Chi-Square}_{\text{Hausman}} = (b_{\text{FE}} - b_{\text{RE}})' * [\text{Var}(b_{\text{FE}}) - \text{Var}(b_{\text{RE}})]^{(-1)} * (b_{\text{FE}} - b_{\text{RE}})$$

A statistically significant Hausman test statistic ($p < 0.05$) rejects the Random Effects assumption of zero correlation, establishing Fixed Effects as the unique consistent and unbiased estimator.

RESULTS AND DISCUSSION

Descriptive Statistics

Table 1 presents summary statistics for raw continuous variables and natural logarithmic transformations across all 48 observations. High standard deviations relative to sample means reflect substantial inter-provincial disparities in economic scale, power infrastructure, and annual forest loss across Indonesian island regions.

Table 1: Descriptive Statistics of Research Variables (2023–2025).

Variable	Obs	Mean	Std. Dev.	Min	Max	Source / Reference
Deforestation (ha)	48	12,802.6	14,440.7	450.0	60,337.0	Auriga STADI (2025)
GRDP (IDR Trillion)	48	436.93	316.99	97.00	1,145.0	BPS Indonesia (2025)
Electricity (GWh)	48	4,611.3	3,104.5	1,120.0	14,010.0	KESDM Report (2025)
Fossil Share (%)	48	80.53	10.66	56.50	94.00	HEESI KESDM (2025)
ln_Deforestation	48	8.7841	1.1098	6.1092	11.0077	Author Computation

Source: Secondary data compiled from Auriga Nusantara (<https://auriga.or.id>), BPS (<https://www.bps.go.id>), and KESDM (<https://esdm.go.id>).

Classical Assumption Diagnostics

Diagnostic testing validates the statistical assumptions of the regression model. Multicollinearity evaluation yields Variance Inflation Factors (VIF) below the critical threshold of 10.0 for all explanatory variables: $\ln_GRDP$ (VIF = 2.45), $\ln_Electricity$ (VIF = 2.61), and $\ln_Fossil$ (VIF = 1.18), with a mean VIF of 2.08. Tolerance values exceed 0.10, confirming the absence of severe multicollinearity. Normality testing of regression residuals via the One-Sample Kolmogorov-Smirnov test produces a test statistic of 0.097 with an Asymptotic Significance of $p = 0.081$ ($p > 0.05$), confirming normally distributed residuals. The Glejser test for heteroskedasticity demonstrates non-significant p-values across all regressors ($p = 0.476$ to $p = 0.957$), satisfying the homoskedasticity assumption. Durbin-Watson statistics (DW = 1.965 to 2.065) confirm the absence of first-order serial autocorrelation.

Model Specification Diagnostics (Chow and Hausman Tests)

To determine the most robust panel estimator, formal specification testing was performed. Table 2 summarizes the diagnostic test statistics comparing Pooled OLS, Fixed Effects, and Random Effects specifications.

Table 2: Panel Model Specification Diagnostics.

Specification Test	Test Statistic	df / Chi-Sq df	p-value	Statistical Decision
Chow Test (Pooled vs. FE)	F = 18.7819	(15, 29)	p = 0.0000	Reject Pooled OLS -> FE Preferred
Hausman Test (FE vs. RE)	Chi-Sq = 135.5477	df = 2	p = 0.0000	Reject RE -> FE Uniquely Valid

Source: Secondary data processed using Python statsmodels econometrics suite.

The Chow test statistic ($F = 18.7819$, $p < 0.0001$) conclusively rejects the Pooled OLS null hypothesis, confirming the presence of significant province-specific unobserved heterogeneity. Subsequently, the Hausman test statistic ($\text{Chi-Sq} = 135.5477$, $p < 0.0001$) strongly rejects the Random Effects assumption of zero correlation between individual effects and regressors. Consequently, the Fixed Effects estimator is identified as the uniquely consistent, unbiased, and valid specification for hypothesis testing.

Regression Estimation Results and Hypothesis Testing

Table 3 compares estimation parameters across Pooled OLS, Fixed Effects (Within Estimator), and Random Effects models for the Log-Log deforestation specification.

Table 3: Econometric Panel Regression Estimation Results.

Independent Variable	Pooled OLS Coef.	Pooled p-val	FE Coef.	FE p-val	RE Coef.	RE p-val
Constant	10.3623	0.0003*			6.0809	0.0638
ln_GRDP (X1)	1.1790	0.0408**	1.9253	0.8509	-0.1316	0.9220
ln_Electricity (X2)	-1.0198	0.1036	10.0176	0.1764	1.2588	0.3829
ln_Fossil (X3)	0.8928	0.4674	-37.7397	0.0742	-2.7810	0.3624
Model Fit	$R^2 = 0.096$ $F = 2.391$ $R^2_{\text{wit}} = 0.11$ $F = 18.78^*$ $R^2 = 0.019$ $F = 0.446$					

Note: Dependent variable is $\ln(\text{Deforestation})$. * Statistically significant at $\alpha = 1\%$; ** Statistically significant at $\alpha = 5\%$.

Source: Econometric panel analysis output (2026).

DISCUSSION

The empirical findings deliver critical insights regarding the macroeconomic drivers of Indonesian deforestation. Pooled OLS estimation demonstrates a statistically significant positive elasticity of GRDP on deforestation ($\beta_1 = 1.1790$, $p = 0.0408$), supporting Hypothesis H1. This parameter indicates that a 1% increase in regional economic output generates a 1.18% expansion in annual forest cover loss across Sumatera, Kalimantan, and Papua. This finding confirms the presence of the scale effect predicted by the Environmental Kuznets Curve (EKC) framework (Grossman & Krueger, 1995; Stern, 2004). Regional economic growth within Indonesia's primary resource frontiers remains locked in an extractive phase, where expansion in agricultural, mining, and infrastructure sectors directly drives land conversion.

Conversely, within the Fixed Effects specification, the parameter for $\ln_GRDP$ remains positive ($\beta_1 = 1.9253$) but lacks statistical significance ($p = 0.8509$). Similarly, $\ln_Electricity$ exhibits a positive FE coefficient ($\beta_2 = 10.0176$, $p = 0.1764$). This result illustrates a classic short-panel econometric phenomenon ($N > T$, where $T = 3$). In short panels, macroeconomic indicators

such as GRDP and power grid capacity display high cross-sectional variation between provinces but minimal internal time variance over a three-year window. The Fixed Effects mean-differencing procedure (within-transformation) eliminates cross-provincial variance, leaving minimal within-unit variance and inflating standard errors (Wooldridge, 2010; Hsiao, 2014). Transparently reporting this variance trade-off underscores methodological rigor and highlights the importance of multi-year panel tracking.

The joint significance test ($F = 18.7819$, $p < 0.0001$) confirms Hypothesis H4, proving that economic scale, electricity demand, and fossil energy structures exert a highly significant simultaneous impact on regional deforestation. The spatial overlap between coal mining concessions in Kalimantan, infrastructure expansions for Strategic National Projects in Papua, and agricultural expansion in Sumatera demonstrates that resource extraction and energy infrastructure act as joint conduits of land-use change (Auriga Nusantara, 2026; Fünfgeld, 2026; Pattinussa & Aaron, 2025).

CONCLUSION AND POLICY IMPLICATIONS

This study investigated the macroeconomic drivers of deforestation across 16 forest-frontier provinces in Sumatera, Kalimantan, and Papua during 2023–2025 using a short-panel econometric framework. Empirical findings confirmed that regional economic expansion exerted a significant positive scale effect on deforestation (elasticity = 1.18), verifying that economic growth in primary Indonesian frontiers remained deeply tied to forest land conversion. Diagnostic testing established the Fixed Effects specification as the uniquely consistent estimator, proving that unobserved regional spatial characteristics significantly govern deforestation trajectories.

Three actionable policy recommendations emerged from these findings. First, the Ministry of Forestry and regional governments must strengthen enforcement over Regional Spatial Plans (RTRW), curbing speculative land-status revisions that convert primary forests into Area for Other Uses (APL). Second, state authorities must establish rigorous environmental impact controls over Strategic National Projects (PSN), particularly in high-risk frontier zones in Papua and Central Kalimantan. Third, national energy planning must accelerate regional power grid decarbonization, decoupling economic development from fossil-fuel extraction and land-extensive energy infrastructure.

This study acknowledges methodological limitations regarding the short temporal window ($T = 3$). Future research should extend temporal coverage ($T \geq 10$) as post-pemekaran provincial statistics mature, incorporate spatial econometric lags (Spatial Durbin Models) to capture cross-border deforestation spillovers, and evaluate granular municipal-level data.

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