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Economic Growth, Welfare, Sectoral Contributions, and Deforestation in West Kalimantan, Indonesia

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ABSTRACT

Regional economic dynamics are important for understanding deforestation because their linkage with forest loss reveals whether local development trajectories intensify land-conversion pressure or move toward a more forest-compatible pathway. This study examines the effects of economic growth, per capita GRDP, poverty, and agricultural and mining sector contributions on deforestation across regencies/cities in West Kalimantan, Indonesia, during 2015–2024. Beyond testing relationships between economic factors and forest loss, it provides an empirical foundation for regional development governance strategies aligned with forest protection. Using balanced panel data for 13 regencies/cities and 130 observations, the analysis applies panel data regression to capture interregional and intertemporal variation. Model selection identifies the two-way fixed effects model as the most appropriate specification because it controls for spatial heterogeneity across regencies/cities and temporal heterogeneity across years. The results show that economic growth and agricultural sector contribution are positively and significantly associated with deforestation, indicating that regional expansion remains associated with land-extensive development. By contrast, per capita GRDP and poverty do not show significant effects after controlling for regency/city and year effects. The mining sector contribution has a negative coefficient and is only weakly significant; it should be interpreted cautiously because sectoral output shares do not necessarily represent the physical footprint of extraction. Overall, findings suggest deforestation in West Kalimantan is driven more by growth structure and composition than by welfare indicators alone. Forest-compatible regional development should prioritize agricultural intensification, stronger land-use governance, and stricter control of frontier expansion.

KEYWORDS*: *forest loss, land-based development, land-use governance, natural capital depreciation, carbon emissions

INTISARI

Penelitian ini menganalisis pengaruh dinamika ekonomi regional terhadap deforestasi pada 13 kabupaten/kota di Provinsi Kalimantan Barat selama periode 2015–2024. Fokus kajian diarahkan pada hubungan antara pertumbuhan ekonomi, PDRB per kapita, tingkat kemiskinan, kontribusi sektor pertanian, dan kontribusi sektor pertambangan terhadap kehilangan hutan. Penelitian ini penting karena pola pembangunan daerah dapat memperkuat tekanan konversi

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lahan atau, sebaliknya, diarahkan menuju jalur pembangunan yang lebih kompatibel dengan perlindungan hutan. Metode yang digunakan adalah regresi data panel dengan data panel seimbang sebanyak 130 observasi. Hasil pemilihan model menunjukkan bahwa model fixed effects dua arah merupakan spesifikasi paling tepat karena mampu mengendalikan heterogenitas spasial antar kabupaten/kota serta heterogenitas temporal antar tahun. Hasil analisis menunjukkan bahwa pertumbuhan ekonomi dan kontribusi sektor pertanian berpengaruh positif dan signifikan terhadap deforestasi. Temuan ini mengindikasikan bahwa ekspansi ekonomi daerah di Kalimantan Barat masih terkait dengan pola pembangunan berbasis perluasan lahan. Sebaliknya, PDRB per kapita dan tingkat kemiskinan tidak menunjukkan pengaruh signifikan setelah efek wilayah dan waktu dikendalikan. Kontribusi sektor pertambangan memiliki koefisien negatif dengan tingkat signifikansi lemah sehingga perlu ditafsirkan secara hati-hati karena proporsi output sektoral tidak selalu mencerminkan jejak fisik ekstraksi di lapangan. Secara keseluruhan, deforestasi di Kalimantan Barat lebih dipengaruhi oleh struktur dan komposisi pertumbuhan ekonomi dibandingkan indikator kesejahteraan semata. Oleh karena itu, pembangunan daerah yang kompatibel dengan keberlanjutan hutan perlu menekankan intensifikasi pertanian, penguatan tata kelola penggunaan lahan, dan pengendalian ekspansi wilayah frontier.

KATA KUNCI : Kehilangan hutan; Pembangunan berbasis lahan; Tata kelola penggunaan lahan: Depresiasi modal alam: Emisi karbon

INTRODUCTION

Deforestation remains a strategic issue in sustainable development because its consequences extend beyond the numerical reduction of forest cover. Forest loss weakens carbon storage, disrupts hydrological functions, reduces biodiversity, and undermines the ecological foundation of long-term economic activity (Lambin *et al*. 2003). From the perspective of environmental economics, deforestation reflects land-allocation decisions shaped by market incentives, land-use change, infrastructure access, and institutional quality (Geist & Lambin 2002). Therefore, analyzing deforestation requires not only ecological interpretation but also an assessment of the economic mechanisms that determine how land and natural resources are allocated, valued, and converted within regional development processes.

The urgency of this issue is evident in Indonesia, where forest loss remains a major development and environmental governance concern (Sloan & Sayer 2015). Official statistics indicate that Indonesia's net deforestation during 2013–2022 still reflects persistent pressure on forest resources (Badan Pusat Statistik 2026), a pattern consistent with satellite-based evidence showing that Indonesia remained one of the major global centers of forest loss in the early twenty-first century

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(Hansen *et al*. 2013). Temporary declines in deforestation should not be interpreted automatically as a stable recovery trend because they may be affected by commodity-price fluctuations, plantation expansion, regulatory interventions, and differences in regional economic structure. These conditions make subnational analysis essential (Austin *et al*. 2019), since regions operating under the same national policy framework may experience different combinations of economic incentives, institutional capacity, and land-use pressures.

West Kalimantan provides a highly relevant case for examining this relationship because its economy remains closely connected to land-based activities, while its forests perform critical ecological functions in the wider Borneo landscape (Gaveau *et al*. 2014). In 2024, official provincial statistics recorded that the economy of West Kalimantan reached Rp300,166.89 billion, per capita GRDP reached Rp 52.70 million, and year-on-year economic growth in the fourth quarter was 4.98% (Badan Pusat Statistik Provinsi Kalimantan Barat 2025). These indicators demonstrate continued regional expansion, but they also raise an important analytical question: whether economic growth in the province is increasingly compatible with forest protection or continues to generate pressure for land conversion. This question is particularly important because agriculture, plantations, and extractive activities remain central to development trajectories in West Kalimantan, making the province a suitable setting for evaluating the environmental consequences of regional economic transformation.

Previous studies suggest that economic growth may increase pressure on forests through agricultural expansion, plantations, infrastructure development, and extractive activities, especially where deforestation is driven by enterprise-based frontier expansion rather than by isolated subsistence clearing (Rudel 2007). However, the relationship between development and forest loss is not always linear. The Environmental Kuznets Curve perspective suggests that environmental pressure may decline at higher income levels when structural transformation, productivity improvement, and stronger institutions emerge. Similar ambiguity applies to per capita income and poverty. Higher income may reduce dependence on forest clearing, yet it can also stimulate land-based investment if growth remains tied to resource extraction and plantation expansion. Poverty may encourage land conversion in some settings, but large-scale forest loss is often associated with actors that possess greater capital, access to permits, and connections to resource rents. Sectoral structure is therefore crucial, because agriculture is a major driver of tropical deforestation, while mining may affect forests directly or indirectly depending on how production, infrastructure, and land expansion are spatially linked (Busch & Ferretti-Gallon 2017).

Against this background, this study addresses the limited empirical understanding of how regional economic development shapes deforestation at the regency/city level in West Kalimantan. The novelty of the study lies in its use of balanced regency/city-level panel data for 2015–2024 to explain deforestation through a combined analysis of growth indicators, welfare variables, and sectoral structure. Specifically, the study examines whether economic growth, per capita GRDP,

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poverty, the contribution of the agricultural sector, and the contribution of the mining sector significantly explain variations in deforestation across regencies/cities after accounting for territorial and temporal heterogeneity. Accordingly, the study aims to analyze the effects of these variables on deforestation and to identify the most appropriate panel data model for explaining interregional and intertemporal variation. By integrating development indicators with land-use outcomes, the findings are expected to strengthen the empirical basis for regional development governance strategies that are more consistent with forest protection and environmental sustainability.

RESEARCH METHODS

Research Location and Time

This study was conducted in West Kalimantan Province, Indonesia, with regencies/cities as the unit of analysis. The observation period covers 2015–2024 and the final dataset consists of 13 regencies/cities observed for ten years, producing a balanced panel of 130 observations. The district/city scale was selected because deforestation dynamics, economic growth, income conditions, poverty, and sectoral economic structure vary substantially within the province. This level of observation is therefore appropriate for capturing both spatial and temporal variation relevant to regional policy analysis (Gujarati & Porter 2009).

Data Types, Sources, and Variable Operationalization

The study used secondary quantitative data compiled in panel form. Deforestation was treated as the dependent variable, while economic growth, per capita income, poverty rate, the contribution of the agricultural sector, and the contribution of the mining sector were used as explanatory variables. The data were compiled from processed research datasets and official statistical publications, particularly those issued by Statistics Indonesia, Statistics Indonesia of West Kalimantan, and relevant forestry or environmental statistics. The use of documented secondary data is appropriate for regional comparative analysis because it supports consistency, replicability, and temporal coverage across districts/cities (Johnston 2014). To avoid ambiguity in the empirical specification, each variable was defined operationally before estimation, as presented in **Table 1.**

Table 1. Operational Definitions of Variables

Variable	Operational definition and measurement	Role in model
Deforestation	Annual deforestation or forest-cover loss in each regency/city, measured as area of forest loss per year and expressed in hectares per year (ha/year).	Dependent variable
Economic growth	Annual rate of change in Gross Regional Domestic Product (GRDP) at constant prices, expressed in percent (%).	Explanatory variable
Per capita income	GRDP per capita, reflecting average regional output per resident, expressed in rupiah or million rupiah per person	Explanatory variable

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Variable	Operational definition and measurement	Role in model
	per year according to the reporting unit used in official statistics.	
Poverty rate	Percentage of the population living below the official poverty line in each regency/city, expressed in percent (%).	Explanatory variable
Agricultural sector contribution	Share of the agricultural sector in total GRDP, expressed as a percentage of GRDP (%). Under the official sectoral classification, this refers to the agriculture-related GRDP category used in regional statistics.	Explanatory variable
Mining sector contribution	Share of the mining and quarrying sector in total GRDP, expressed as a percentage of GRDP (%).	Explanatory variable

Data Collection

Data were collected through documentation and compilation of published secondary sources, followed by harmonization into a balanced district/city panel. The collection process involved identifying variables relevant to the theoretical framework, recording annual observations for each district/city, checking consistency across years and administrative units, and arranging all variables into a single dataset suitable for panel regression analysis. Documentation-based collection is widely used in secondary-data research because it enables systematic extraction, verification, and organization of records from published sources before they are transformed into an analyzable dataset (Bowen 2009). This procedure ensured comparability across regions and over time.

Data Analysis

The study employed explanatory quantitative analysis using panel data regression. The empirical model can be written as: $Deforestation_it = \alpha_i + \lambda_t + \beta 1\ Growth_{it} + \beta 2\ Income_{it} + \beta 3\ Poverty_{it} + \beta 4\ Agriculture_{it} + \beta 5\ Mining_{it} + \varepsilon_{it}$. In this specification, i denotes regency/city, t denotes year, α_i represents district/city-specific effects, λ_t represents year-specific effects, and ε_{it} is the error term. This formulation allows the model to control for unobserved territorial heterogeneity and common annual shocks while estimating the association between economic variables and deforestation over time.

Model selection compared pooled ordinary least squares (OLS), fixed effects, and random effects specifications through panel significance tests and the Hausman test. Diagnostic tests included variance inflation factors for multicollinearity, the Breusch-Pagan test for heteroskedasticity, the Jarque-Bera test for residual normality, and the Durbin-Watson statistic for autocorrelation. When heteroskedasticity or residual non-normality was detected, robust or clustered standard errors were applied to improve the reliability of statistical inference while preserving the estimated coefficient structure (Baltagi, 2021).

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RESULTS AND DISCUSSION

Model Specification and Overall Fit

The estimation results indicate that a two-way fixed effects model is the most appropriate specification for explaining district/city-level deforestation in West Kalimantan during 2015–2024. The model was preferred because district effects and year effects were both statistically significant, while the Hausman test favored fixed effects over random effects. Methodologically, this implies that unobserved territorial heterogeneity and common intertemporal shocks must be controlled before the effects of the explanatory variables are interpreted (Wooldridge 2010). Substantively, districts/cities in West Kalimantan differ in land endowment, economic structure, accessibility, and institutional setting, and these differences are likely to shape forest outcomes alongside annual policy and commodity-price changes. As shown in **Table 1**, the model selection tests consistently indicate that the two-way fixed effects model is the most appropriate specification, as both district and year effects are statistically significant and the Hausman test favors fixed effects over random effects.

Nevertheless, the preference for a two-way fixed effects model should not be interpreted as evidence of full causality. Fixed effects reduce bias from unobserved district characteristics that are constant over time and from shocks shared across years, but they do not eliminate all sources of endogeneity. In particular, the model does not fully address spatial dependence among neighboring districts, lagged land-use responses, possible reverse causality between deforestation and regional economic performance, or omitted time-varying variables such as road development, concession changes, enforcement intensity, fire events, and commodity-price movements that may affect both economic indicators and forest loss (Arellano 2003; Wooldridge 2010; Elhorst 2014). Therefore, the coefficients are interpreted as conditional within-panel associations rather than definitive causal effects.

Table 2. Model Selection Results

Test	Statistic	p-value	Decision
District effects vs. pooled model	F = 4.841	0.000002	District effects significant
District effects after controlling for year	F = 4.350	0.000014	Still significant
Year effects after controlling for district	F = 2.559	0.0107	Year effects significant
Hausman test (FE vs. RE)	Chi-square = 18.134	0.0028	Fixed effects preferred

Sources: Analysis Results, 2025

Beyond model selection, the diagnostic profile suggests that the estimated coefficients should be read as within-district temporal effects rather than as simple cross-sectional correlations. The relatively high R^2 indicates that the specification captures a substantial share of observed variation in deforestation, while the low VIF range suggests that the estimated coefficients are not driven by severe linear dependence among explanatory variables. At the same time, the significant Breusch-Pagan statistic and the highly non-normal residual distribution imply that deforestation shocks are unevenly distributed across districts and years, which is unsurprising in frontier regions where

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commodity booms, drought episodes, and land-use policy shifts may generate clustered disturbances. In this context, inference based on robust or clustered standard errors is more appropriate than relying solely on conventional OLS precision (Cameron & Miller 2015). As reported in **Table 3**, the two-way fixed effects regression results show that economic growth and the contribution of the agricultural sector have positive and statistically significant effects on deforestation, whereas per capita income and poverty are not statistically significant, and the mining coefficient should be interpreted cautiously.

Table 3. Two-Way Fixed Effects Regression Results

Independent variable	Coefficient	p-value	Direction	Interpretation
Economic growth	1275.351	0.042	Positive	Significant at 5%
Per capita income	9187.932	0.892	Positive	Not significant
Poverty rate	1698.784	0.503	Positive	Not significant
Agricultural sector contribution	1283.734	0.039	Positive	Significant at 5%
Mining sector contribution	-1283.426	0.080	Negative	Significant at 10%

Sources: Analysis Results

Substantively, the two-way fixed effects results reinforce the idea that deforestation in West Kalimantan is shaped by a combination of place-specific structural conditions and broader temporal forces. This is consistent with comparative work showing that tropical forest loss is rarely explained by a single factor; rather, it emerges from interactions among land rents, trade demand, infrastructure, institutions, and changing development trajectories (DeFries *et al*. 2010). The significance of year effects is particularly important because it suggests that province-wide or national shocks, including commodity-price cycles, climatic anomalies, and regulatory interventions, likely influenced all districts simultaneously, even if the magnitude of their impact differed across local contexts.

Economic Growth and Deforestation

Economic growth has a positive and statistically significant association with deforestation (coefficient = 1275.351; p = 0.042). Within the same district/city over time, and after controlling for district and year effects, higher growth tends to be accompanied by greater forest loss. This finding should not be read as proof that growth mechanically causes deforestation, but as evidence of a positive within-panel relationship consistent with land-based development pressure.

The result suggests that regional expansion in West Kalimantan has not yet been fully decoupled from forest conversion. In many tropical regions, growth can increase land rents, infrastructure demand, and incentives for plantation or commercial land conversion, especially when output expansion depends more on land acquisition than productivity improvement (Barbier 1997; Benhin 2006; Laurance *et al*. 2014). In this study, those mechanisms are theoretically informed inferences rather than directly observed causal channels.

Accordingly, the policy implication concerns the quality of growth. Economic growth is more likely to become forest-compatible when additional output is generated through productivity improvement, degraded-land rehabilitation, stronger spatial governance, and tighter control over

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frontier expansion. Evidence from Indonesia also shows that forest loss has often followed phases of commercial expansion and changing political-economic incentives, which supports a cautious interpretation of the positive growth coefficient (Tsujino *et al*. 2016; Putra & Gunarto 2023).

Per Capita Income and Deforestation

Per capita income shows a positive coefficient (9187.932) but is not statistically significant (p = 0.892). This indicates that average income does not independently explain deforestation after district/city and year effects are controlled. The environmental meaning of income therefore depends more on how income is generated, distributed, and connected to land-based sectors than on the average income indicator itself.

This result is consistent with the Environmental Kuznets Curve debate, which emphasizes that income is not a direct land-use variable and that environmental improvement depends on institutional quality, technology, and structural transformation (Stern 1998; Panayotou 1997). For West Kalimantan, the non-significant coefficient should be read as a cautious conceptual indication rather than evidence of a forest-transition pathway. The model does not directly estimate income thresholds or test forest-transition dynamics; it only shows that higher per capita income is not independently associated with lower deforestation in this specification (Rudel *et al*. 2005; Margono *et al*. 2014).

Poverty Rate and Deforestation

Poverty has a positive but non-significant coefficient (1698.784; p = 0.503), indicating that poverty incidence is not the dominant explanation of deforestation variation in the estimated model. This does not mean poverty is irrelevant to forest governance. Rather, district-level poverty rates may be too aggregated to capture household livelihood strategies, tenure insecurity, labor migration, and dependence on extensive land use.

The finding suggests that deforestation in West Kalimantan is better understood as a structural land-use problem than as a simple outcome of household deprivation. Large changes in forest cover are often linked to commercial land conversion, concessions, infrastructure, and market-oriented agricultural expansion, which may operate independently of short-run changes in poverty incidence (Angelsen & Kaimowitz 1999; Hosonuma *et al*. 2012; Miyamoto 2020). Poverty reduction remains important, but its forest-protective effect depends on whether it creates non-land-extensive livelihoods, secure rights, and sustainable rural welfare.

Agricultural Sector Contribution and Deforestation

The agricultural sector contribution is positive and statistically significant (coefficient = 1283.734; p = 0.039), making it one of the clearest findings of the study. Within the same district/city over time, a larger agricultural contribution to Gross Regional Domestic Product (GRDP) tends to be associated with higher forest loss, particularly where agricultural growth remains linked to land expansion rather than productivity improvement on existing cultivated land.

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This interpretation requires qualification. The agricultural contribution to GRDP should not be equated entirely with oil palm expansion or direct forest clearing. Agricultural value added may reflect productivity gains, commodity-price movements, harvested-area expansion, smallholder plantations, large-scale estates, food crops, horticulture, livestock, and other subsectors. Therefore, the coefficient indicates a structural association between agriculture-led development and deforestation, not direct evidence that every increase in agricultural output originates from forest conversion.

The finding is nevertheless consistent with broader evidence that agricultural and plantation expansion have contributed substantially to tropical forest loss, including in Indonesia and Kalimantan (Gibbs *et al*. 2010; Austin *et al*. 2015; Gaveau *et al*. 2022). It supports a policy strategy that distinguishes between agricultural growth based on productivity and agricultural growth based on frontier expansion. Intensification on existing land, restoration of degraded areas, stronger permit control, and protection of high-carbon and high-conservation-value landscapes are therefore central to forest-compatible regional development.

Mining Sector Contribution and Deforestation

The mining sector contribution has a negative coefficient (-1283.426) and is only weakly significant at the 10 percent level ($p = 0.080$). This result should therefore be treated as indicative rather than as a principal conclusion. It suggests that a higher mining share in district GRDP is not consistently accompanied by higher deforestation within the same district and year, but it should not be interpreted as evidence that mining has no ecological consequences.

The key issue is measurement. Mining contribution to GRDP records value added, not the physical footprint of extraction, haul roads, waste disposal, supporting infrastructure, or indirect land-use change. A district may record a higher mining share because of commodity prices, productivity improvements, higher mineral quality, or increased output from existing sites without new clearing in the same year. Conversely, mining-related impacts may occur through roads, settlements, and transport corridors that are only partly reflected in sectoral output shares (Sonter *et al*. 2017; Lo *et al*. 2024).

For this reason, the mining coefficient points more to the limitation of a sectoral-share proxy than to a forest-sparing mining economy. Future research should include land-use-sensitive indicators such as concession area, active mine footprint, road expansion, ore transport infrastructure, and proximity to forest frontiers. Until such measures are incorporated, the coefficient should be read as suggestive and should not be used to claim that extractive activity is environmentally benign (Abood *et al*. 2015; Curtis *et al*. 2018; Werner *et al*. 2023).

Synthesis of Findings and Implications for Forest-Compatible Growth

Taken together, the findings show that the central issue in West Kalimantan is not growth in the abstract, but the composition and territorial organization of growth. The significant coefficients on economic growth and agriculture, combined with the weak explanatory power of income and

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poverty, indicate that forest loss is more closely associated with land-extensive production structures than with welfare indicators alone. This pattern is consistent with wider evidence that forests are most vulnerable where land rents, commodity demand, infrastructure access, and institutional weaknesses reinforce one another (Balboni *et al*. 2023).

The results may be interpreted conceptually as suggesting that West Kalimantan has not yet shown a clear movement toward a forest-transition dynamic in which economic restructuring and policy intervention systematically reduce pressure on remaining forests. However, this statement should remain cautious because the model does not directly test a formal forest-transition process. The findings instead support a development strategy that moves from frontier expansion toward productivity improvement, restoration, stricter spatial control, and stronger integration between regional economic planning and forest governance (Tsujino *et al*. 2016; Rudel *et al*. 2020).

Temporal Heterogeneity, Commodity Cycles, and Policy Shocks

The significance of year effects indicates that deforestation in West Kalimantan is shaped not only by district characteristics, but also by broader factors operating across the province at the same time. These year effects should be interpreted as indicators of shared temporal conditions, such as commodity-price cycles, export demand, national regulatory shifts, and climatic anomalies. Because these factors are not directly included in the model, the interpretation remains inferential rather than causal (Leblois *et al*. 2017).

This temporal dimension means that the growth coefficient should be read together with annual shocks. When commodity demand strengthens or dry conditions interact with disturbed peat and forest landscapes, incentives and ecological vulnerability may rise simultaneously. Indonesian fire episodes and land-use disturbances show that climatic conditions can magnify ecological damage, but the present model does not directly measure drought, fire intensity, or peat exposure. The year effects therefore plausibly absorb part of this volatility, without proving a specific market or climate mechanism (Huijnen *et al*. 2016; Field *et al*. 2016; Baccini *et al*. 2017).

Territorial Heterogeneity and Uneven District Development Pathways

District fixed effects show that deforestation in West Kalimantan is territorially uneven in ways that persist over time. In a two-way fixed effects model, however, these effects capture unobserved heterogeneity rather than directly measured variables. Factors such as forest endowment, accessibility, settlement history, institutional quality, land-tenure arrangements, and connectivity to frontier expansion are therefore plausible explanatory factors, not mechanisms directly estimated by the model (DeFries *et al*. 2010; Lim *et al*. 2017).

The province should consequently be understood as a mosaic of district development pathways. Some districts may face stronger agricultural-frontier pressure, others may be exposed to peat degradation, road expansion, mining corridors, or urban-linked demand. Policy should therefore avoid a one-size-fits-all interpretation and instead combine district-level evidence on land cover, permits, roads, tenure, peat exposure, and governance capacity. Forest-compatible

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development is most effective when interventions are calibrated to territorial differences (Robinson *et al*. 2014; Santika *et al*. 2019).

Rethinking Growth, Income, and Poverty in a Political-Economy Perspective

The contrast between significant growth and agriculture variables and statistically weak income and poverty variables suggests that deforestation is more closely connected to production organization, land rents, and access to land-based opportunities than to average welfare indicators alone. The political-economy perspective is used here as an interpretative framework for reading the regression results, not as a separate mechanism fully tested by the model. From this perspective, forest conversion is often shaped by actors and institutions with access to capital, permits, infrastructure, and market channels, not only by poor households clearing land for subsistence (Busch & Ferretti-Gallon 2017; Krishna *et al*. 2017).

The non-significant income coefficient can be interpreted through the lens of uneven structural transformation. In this article, structural transformation refers to a shift from land-extensive primary activities toward more diversified, productive, and less forest-dependent growth. Incomplete structural transition means that income growth has not yet been accompanied by sufficient productivity upgrading, diversification, and land-use governance to reduce forest pressure. By contrast, ecological modernisation refers to growth that becomes progressively decoupled from environmental degradation through cleaner technology, stronger regulation, and more efficient resource use (Culas 2007; Koop & Tole 1999).

The poverty coefficient should be read similarly. Its lack of significance does not mean poverty is unimportant, but that district poverty rates do not directly capture tenure insecurity, livelihood options, market access, or local dependence on extensive land use. Social inclusion remains part of a forest-compatible development strategy when it improves education, extension support, livelihood diversification, local value addition, and tenure clarity. Welfare improvements become forest-protective when they alter incentives and reduce the attractiveness of frontier conversion (Miyamoto 2020; Brockhaus *et al*. 2021).

Methodological Reflections and Robustness of the Findings

Methodologically, the two-way fixed effects specification gives the results a stronger interpretive foundation than pooled correlation because it estimates within-district temporal associations after controlling for time-invariant district characteristics and common year shocks (Arellano 2003; Greene 2012). Thus, the model does not merely compare high-deforestation districts with low-deforestation districts; it examines whether changes within the same district/city over time are associated with changes in deforestation.

Even so, the fixed effects model does not establish full causality. It reduces some bias from persistent territorial differences and shared annual shocks, but it does not fully address spatial dependence, lagged effects, reverse causality, or time-varying omitted variables. Deforestation may be affected by roads, concession dynamics, enforcement intensity, commodity prices, fire events,

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peat exposure, and political cycles that are not included in the specification. Therefore, the coefficients should be interpreted as theoretically informed empirical associations rather than definitive causal estimates (Wooldridge 2010; Elhorst 2014).

The diagnostic results also support cautious inference. Heteroskedasticity and non-normal residuals indicate that deforestation shocks are uneven and episodic, so robust or clustered standard errors are more defensible than conventional homoskedastic inference (Cameron & Trivedi 2005; Cameron & Miller 2015). Future research would be strengthened by spatial panel models, dynamic specifications, instrumental variables where feasible, and remote-sensing covariates that capture roads, concessions, peat, plantations, and active mine footprints more directly (Sonter *et al*. 2017; Werner *et al*. 2023).

Implication for Model and Policy

The policy meaning of the model is not that growth should be suppressed, but that the organization of growth must be redesigned. The significant association of economic growth and agricultural contribution with deforestation, together with the weaker role of welfare indicators, points to a forest-compatible regional development model in which output expansion is evaluated against land-use efficiency, forest-risk exposure, and natural-capital loss.

Such a model requires a shift from area expansion to land-efficiency logic. Agricultural policy should prioritize intensification, extension services, smallholder productivity, and value addition on already cultivated land, while new plantation, food-crop, and infrastructure programs are screened against forest and peatland conversion risks. This approach retains development objectives while reducing dependence on frontier expansion (Austin *et al*. 2017; Gaveau *et al*. 2022).

Regional planning should also treat forests as productive natural capital rather than residual land available for conversion. District and provincial plans should combine GRDP targets with indicators such as deforestation intensity per unit of GRDP, restoration achievement, peat and watershed protection, land-use efficiency, and the proportion of expansion redirected to degraded or already-cleared land. These indicators would make development accounting more consistent with the long-term ecological costs of forest loss (Pendrill *et al*. 2019; Kastner *et al*. 2021).

Finally, policy must be territorially differentiated. Agricultural-frontier districts require stricter permit screening, zoning, and monitoring of conversion risks, while mining, logistics, and urban-linked districts require attention to indirect land-use effects through roads, settlements, and market corridors. The practical goal is higher-quality growth that increases output without reinforcing forest conversion, supported by livelihood diversification, tenure clarification, rehabilitation of degraded land, and community-based forest management where appropriate (Santika *et al*. 2019; Brockhaus *et al*. 2021).

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CONCLUSION

Deforestation in West Kalimantan during 2015–2024 is more closely related to the structure of regional economic growth than to welfare indicators alone. The two-way fixed effects model indicates that economic growth and the contribution of the agricultural sector are positively and significantly associated with deforestation, whereas per capita income and poverty do not show significant effects, and the mining coefficient should be interpreted cautiously. This interpretation should be understood as evidence of statistically grounded associations rather than as a definitive causal claim. Overall, the results underline the need for a higher-quality growth path in which regional development is decoupled from continued forest conversion. These results indicate that the main policy challenge lies not in suppressing growth, but in changing the sectoral composition and spatial footprint of that growth. Therefore, future regional development in West Kalimantan should be evaluated not only by how much output it generates, but also by how effectively it reduces dependence on frontier expansion and protects forest-based natural capital.

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