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Economic Growth and Environmental Quality in Java and Sumatra: A Panel Data Analysis of GRDP, Population Density, and Poverty

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Abstract

Environmental quality is a key indicator of sustainable development, yet the impacts of economic growth, population density, and poverty remain inconclusive. This study examines the effects of Gross Regional Domestic Product (GRDP), population density, and the poverty severity index on the Environmental Quality Index (EQI) across 16 provinces in Java and Sumatra during 2015–2024. Using a quantitative approach with balanced panel data (160 observations), the analysis applies panel regression, with the Fixed Effect Model (FEM) selected through the Chow and Hausman tests. Cluster-robust standard errors were employed to address heteroskedasticity. The findings reveal that GRDP has a positive and significant effect on EQI, while population density and poverty severity have no significant effects. Collectively, the three variables significantly influence environmental quality. The results are conceptually consistent with the Environmental Kuznets Curve (EKC), although the hypothesis cannot be empirically confirmed because the model excludes the squared GRDP ($GRDP^2$) term.

Keywords: Panel Data, Population Density, EQI, Poverty Severity Index, GRDP.

INTRODUCTION

Economic development is one of the primary objectives of developing countries, including Indonesia. The success of economic development is commonly measured by Gross Regional Domestic Product (GRDP), which reflects the level of economic activity within a region. Increased economic activity is expected to improve social welfare through

job creation, income growth, and more equitable regional development. However, intensified economic activities are often accompanied by adverse environmental consequences, including increased greenhouse gas emissions, air and water pollution, deforestation, and greater volumes of solid waste (Tolksdorf et al., 2020); (Zang et al., 2022). A study conducted by Febriana et al. (2019) in East Java further demonstrated that economic growth may exert pressure on environmental quality when it is not supported by adequate environmental management policies. These conditions indicate that the success of development should not be assessed solely through economic indicators but must also consider environmental sustainability as an essential component of sustainable development.

Java and Sumatra are the two largest contributors to Indonesia's economy. According to Statistics Indonesia (Badan Pusat Statistik, 2025), Java contributes approximately 57% of the national Gross Domestic Product, while Sumatra accounts for around 22%. Despite their strategic roles in the national economy, these two islands exhibit distinct development characteristics and environmental pressures. Java is characterized by high population density, rapid urbanization, and the concentration of industrial and transportation activities. In contrast, environmental degradation in Sumatra is largely driven by mining activities, deforestation, and the expansion of large-scale plantations (Indriana et al., 2021). These differences suggest that the determinants of environmental quality may vary across regions.

In addition to economic factors, social and demographic conditions also play a significant role in determining environmental quality. High population density increases the demand for land, energy, transportation, and residential infrastructure, thereby intensifying environmental pressure (Ulucak & Khan, 2020); (Nathaniel et al., 2020). Likewise, poverty severity may adversely affect environmental quality due to limited access to adequate sanitation, environmentally friendly technologies, and sustainable natural resource management practices (Sinaga, 2020); (Ehigiamusoe et al., 2022). Consequently, environmental quality is influenced not only by economic growth but also by the demographic and social characteristics of the population.

Previous studies have extensively examined the relationships between economic growth, population density, poverty, and environmental quality. However, most of these studies have investigated these variables separately or focused on only one particular aspect. Studies simultaneously examining the effects of Gross Regional Domestic Product (GRDP), population density, and the Poverty Severity Index on the Environmental Quality Index (EQI) at the provincial level in Indonesia, particularly in Java

and Sumatra, remain relatively limited (Rahmi et al., 2025); (Kondolele & Mustari, 2023). Moreover, only a few studies have compared these two major regions of Indonesia, which differ substantially in terms of economic development, demographic characteristics, and ecological conditions. This gap highlights the need for further research to better understand the combined effects of economic, social, and demographic factors on environmental quality at the regional level.

Based on these considerations, this study aims to examine the effects of Gross Regional Domestic Product (GRDP), population density, and the Poverty Severity Index on the Environmental Quality Index (EQI) across 16 provinces in Java and Sumatra during the 2015–2024 period. The findings are expected to provide empirical evidence to support the formulation of sustainable regional development policies by integrating economic, social, and environmental dimensions (Zafar et al., 2020); (Tolksdorf et al., 2020).

The novelty of this study lies in its simultaneous examination of the effects of GRDP, population density, and the Poverty Severity Index on the Environmental Quality Index using panel data from the two largest economic regions in Indonesia, which exhibit distinct development characteristics and environmental pressures. This approach is expected to provide a more comprehensive understanding of the heterogeneity of factors influencing environmental quality at the regional level.

Objectives

The objectives of this study are :

1. Examine the effect of Gross Regional Domestic Product (GRDP) on the Environmental Quality Index (EQI).
2. Analyze the effect of population density on the Environmental Quality Index (EQI).
3. Investigate the effect of the Poverty Severity Index on the Environmental Quality Index (EQI).

Examine the simultaneous effects of Gross Regional Domestic Product (GRDP), population density, and the Poverty Severity Index on the Environmental Quality Index (EQI).

Explain the relationship between the empirical findings and the Environmental Kuznets Curve (EKC) concept.

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THEORETICAL FOUNDATION

Environmental Kuznets Curve (EKC)

Environmental quality is a key indicator of sustainable development because it reflects the balance between economic activities, social conditions, and environmental carrying capacity. Economic growth, commonly measured by Gross Regional Domestic Product (GRDP), plays an essential role in improving social welfare by increasing income and economic opportunities. However, economic expansion may also exert considerable pressure on the environment through higher energy consumption, industrialization, natural resource exploitation, and land-use change (Tolksdorf et al., 2020).

The relationship between economic growth and environmental quality is explained by the Environmental Kuznets Curve (EKC) hypothesis. This concept originated from the work of Kuznets (1955) on the structural transformation of the economy from the agricultural sector to the industrial and service sectors. The EKC proposes that environmental degradation tends to increase during the early stages of economic development due to expanding production activities and intensive exploitation of natural resources. However, once income reaches a certain threshold (*turning point*), environmental quality gradually improves as a result of technological progress, increased environmental awareness, and stronger environmental regulations (Anwar et al., 2022).

Nevertheless, empirical studies have shown that the relationship between economic growth and environmental quality does not always follow the inverted U-shaped pattern proposed by the EKC hypothesis. These differences are influenced by regional variations in economic structure, energy composition, institutional quality, and the effectiveness of environmental policies (Indriana et al., 2021); (Zeng & Bao, 2024). Therefore, further empirical investigation across regions with different socioeconomic and environmental characteristics is required to provide a more comprehensive understanding of the relationship between economic development and environmental quality.

Gross Regional Domestic Product (GRDP)

Gross Regional Domestic Product (GRDP) represents the level of economic activity within a region and serves as the primary indicator of regional economic growth. Higher GRDP may contribute positively to environmental quality by increasing investment capacity, promoting the adoption of cleaner and more efficient technologies, and strengthening governments' ability to provide environmental infrastructure and implement

effective environmental management policies (Tolksdorf et al., 2020); (Zeng & Bao, 2024).

Conversely, economic expansion may also intensify environmental degradation when growth remains dependent on the intensive exploitation of natural resources and fossil fuel consumption (Indriana et al., 2021); (Tolksdorf et al., 2020). Consequently, the impact of GRDP on environmental quality depends largely on the stage of economic development, industrial structure, and the effectiveness of environmental governance and policy implementation (Anwar et al., 2022); (Zeng & Bao, 2024).

Population Density

Population density is an important demographic factor influencing environmental quality. According to Malthusian population theory (Malthus, 1789), population growth that exceeds the capacity of available resources may increase environmental pressure unless accompanied by technological innovation and effective resource management. High population density increases demand for land, energy, transportation, and housing infrastructure while simultaneously generating larger volumes of waste, thereby accelerating environmental degradation.

However, modern economic theory suggests that these adverse effects can be mitigated through improvements in human capital, technological innovation, and sustainable development governance (Krugman, 1991); (Abdali et al., 2024). Therefore, the environmental impact of population density depends not only on the size of the population but also on the effectiveness of environmental management and regional development policies.

Poverty Severity

Poverty severity is closely associated with environmental quality through the concept of the poverty environment nexus. Households experiencing severe poverty generally have limited access to adequate sanitation, environmentally friendly technologies, and sustainable natural resource management practices. Consequently, they tend to rely more heavily on natural resource exploitation to meet their basic needs. This condition creates a reciprocal relationship in which poverty accelerates environmental degradation, while environmental deterioration further worsens the socioeconomic conditions of vulnerable communities (Ehigiamusoe et al., 2022).

Therefore, improving environmental quality depends not only on economic growth but also on policies that effectively reduce poverty and promote inclusive social welfare (Sinaga, 2020).

Conceptual Relationships among Variables

The Environmental Quality Index (EQI) is a composite indicator developed by the Indonesian Ministry of Environment and Forestry to assess environmental conditions based on several dimensions, including air quality, water quality, land cover, and ecosystem carrying capacity (Kementerian Lingkungan Hidup, 2024). Based on the theoretical foundations and previous empirical studies, environmental quality is influenced by the interaction of economic, demographic, and social factors.

GRDP represents the level of economic activity that may positively influence environmental quality by stimulating investment, technological innovation, and government capacity in environmental management. However, it may also increase environmental pressure when economic development is not accompanied by sustainable development policies. Population density contributes to ecological pressure through increasing demand for land, energy, transportation, and waste generation. Meanwhile, poverty severity affects environmental quality because limited access to sanitation, clean technologies, and sustainable resource management practices encourages unsustainable exploitation of natural resources. Collectively, these factors are expected to determine variations in environmental quality across regions.

RESEARCH METHODOLOGY

Data and Data Sources

This study employed a quantitative approach using balanced panel secondary data covering 16 provinces in Java and Sumatra during the 2015–2024 period, resulting in 160 observations. Panel data analysis was selected because it combines cross-sectional and time-series data, thereby providing more efficient estimates while accounting for unobserved heterogeneity across provinces (Baltagi, 2008); (Gujarati, 2012).

The Environmental Quality Index (EQI) data were obtained from the Ministry of Environment and Forestry of the Republic of Indonesia, whereas data on Gross Regional Domestic Product (GRDP), population density, and the Poverty Severity Index were obtained from Statistics Indonesia (BPS).

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Data Collection Method

Data were collected using the documentation method through official publications issued by Statistics Indonesia (BPS) and the Ministry of Environment and Forestry (KLHK). The collected data were verified, organized into a balanced panel dataset, and processed using STATA statistical software.

Operational Definitions and Measurement of Variables

This study employed one dependent variable, namely the Environmental Quality Index (EQI), and three independent variables consisting of Gross Regional Domestic Product (GRDP), population density, and the Poverty Severity Index. The operational definitions and measurements of all variables were based on the standards established by the Ministry of Environment and Forestry and Statistics Indonesia, as presented in Table 1.

Table 1. Operational Definitions and Measurement of Variables

Variable	Symbol	Operational Definition	Measurement	Source
Environmental Quality Index	EQI	A composite indicator measuring environmental quality based on water quality, air quality, and land cover quality.	EQI Index	Ministry of Environment and Forestry (2025)
Gross Regional Domestic Product	GRDP	The total gross value added generated by all economic activities within a province at constant prices.	Billion Rupiah (Constant Prices)	Statistics Indonesia (2025)
Population Density	PD	The ratio of the total population to	Persons/km²	Statistics Indonesia (2025)

Variable	Symbol	Operational Definition	Measurement	Source
		the land area of a province.		
Poverty Severity Index	PSI	An index measuring the distribution of expenditure among the poor relative to the poverty line.	Poverty Severity Index (P2)	Statistics Indonesia (2025)

Data Analysis Method

Panel data regression analysis was employed to examine the effects of Gross Regional Domestic Product (GRDP), population density, and the Poverty Severity Index on the Environmental Quality Index (EQI). The empirical model is specified as follows:

$$EQI_{it}=\beta_0+\beta_1 GRDP_{it}+\beta_2 PD_{it}+\beta_3 PSI_{it}+\varepsilon_{it}$$

where:

EQI : Environmental Quality Index;
GRDP : Gross Regional Domestic Product;
PD : Population Density;
PSI : Poverty Severity Index;
i : province;
t : observation year; and
ε : error term.

The appropriate panel data model was determined using the Chow test to select between the Common Effect Model (CEM) and the Fixed Effect Model (FEM), followed by the Hausman test to determine the most appropriate model between the Fixed Effect Model (FEM) and the Random Effect Model (REM) (Baltagi, 2008); (Wooldridge, 2010). Multicollinearity was assessed using the Variance Inflation Factor (VIF), while heteroskedasticity was examined using the Modified Wald Test. Since heteroskedasticity was detected, the final estimation employed the Fixed Effect Model with cluster-robust standard errors to ensure consistent and efficient parameter estimates (Wooldridge,

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2010). Hypothesis testing was conducted using the t-test for partial effects, the F-test for simultaneous effects, and the coefficient of determination (R^2) at a 5% significance level.

RESULTS

Panel Data Regression Estimation Results

The panel data model selection indicated that the Fixed Effect Model (FEM) was the most appropriate approach for examining the effects of Gross Regional Domestic Product (GRDP), population density, and the Poverty Severity Index on the Environmental Quality Index (EQI) across 16 provinces in Java and Sumatra during the 2015–2024 period. The selection was based on the results of the Chow test and the Hausman test, both of which confirmed that the Fixed Effect Model was more appropriate than the Common Effect Model (CEM) and the Random Effect Model (REM). Furthermore, the classical assumption tests revealed the presence of heteroskedasticity; therefore, the final estimation was conducted using the Fixed Effect Model with cluster-robust standard errors to ensure consistent parameter estimates and valid statistical inference.

Prior to estimating the regression model, several diagnostic tests were performed. The multicollinearity test yielded a Variance Inflation Factor (VIF) of 1.50, indicating that no multicollinearity existed among the independent variables. The Modified Wald test for heteroskedasticity produced a probability value of 0.0000, confirming the presence of heteroskedasticity. Meanwhile, the autocorrelation test generated a probability value of 0.1445, indicating that the model was free from autocorrelation. Consequently, the cluster-robust standard error approach was employed in the final estimation to correct for heteroskedasticity and to obtain reliable statistical estimates.

The estimation results of the Fixed Effect Model (FEM) with cluster-robust standard errors are presented in Table 2.

Table 2. Fixed Effect Model (FEM) Estimation Results

Variable	Coefficient	Robust Std. Error	t-statistic	p-value
Constant	45.98529	2.576342	17.85	0.000
Gross Regional Domestic Product (GRDP)	0.0000253	0.00000487	5.21	0.000
Population Density	0.0045682	0.0037399	1.22	0.241
Poverty Severity Index	–1.345902	4.680872	–0.29	0.778

Source: STATA output, 2026.

Based on the estimation results, the panel regression equation can be expressed as follows:

$$EQI=45.98529+0.0000253(GRDP)+0.0045682(PD)-1.345902(PSI)+\varepsilon$$

The estimated equation indicates that the constant term is 45.98529, implying that, holding all independent variables constant, the Environmental Quality Index (EQI) is expected to be 45.98529.

The coefficient of Gross Regional Domestic Product (GRDP) is 0.0000253, indicating a positive relationship with environmental quality. The corresponding t-statistic of 5.21 and p-value of 0.000 demonstrate that GRDP has a positive and statistically significant effect on the Environmental Quality Index at the 5% significance level. These findings suggest that higher levels of regional economic activity, as reflected by increases in GRDP, are associated with improvements in environmental quality across the provinces of Java and Sumatra during the study period.

The coefficient of population density is 0.0045682, indicating a positive relationship with the Environmental Quality Index. However, the estimated t-statistic of 1.22 and p-value of 0.241 indicate that this relationship is not statistically significant at the 5% significance level. Therefore, variations in population density do not significantly explain differences in environmental quality across the study area.

The Poverty Severity Index has an estimated coefficient of –1.345902, indicating a negative relationship with the Environmental Quality Index. Nevertheless, the t-statistic of –0.29 and p-value of 0.778 reveal that the effect is statistically insignificant. Accordingly, the severity of poverty does not constitute a statistically significant determinant of environmental quality across the 16 provinces included in this study.

The overall regression results indicate that the estimated model is statistically significant, implying that Gross Regional Domestic Product, population density, and the Poverty Severity Index jointly explain variations in the Environmental Quality Index. Using a balanced panel dataset consisting of 160 observations from 16 provinces over the 2015–2024 period, the Fixed Effect Model effectively captures province-specific heterogeneity, thereby providing more reliable and representative estimates than alternative panel data models.

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DISCUSSION

Effect of Gross Regional Domestic Product (GRDP) on the Environmental Quality Index (EQI)

The findings indicate that Gross Regional Domestic Product (GRDP) has a positive and statistically significant effect on the Environmental Quality Index (EQI) across 16 provinces in Java and Sumatra during the 2015–2024 period. This result suggests that economic growth does not necessarily lead to environmental degradation; instead, it can be accompanied by improvements in environmental quality when supported by sustainable development policies.

These findings are consistent with Kuznets (1955), who argued that economic growth enhances institutional capacity and governments' ability to provide public services, including environmental management. The results also support the Scale Effect, Composition Effect, and Technique Effect proposed by Grossman and Krueger (1995), which explain that rising income levels promote structural transformation toward more efficient economic sectors and encourage the adoption of cleaner technologies, thereby reducing environmental pressure.

Furthermore, the findings are consistent with the concepts of Green Growth (OECD, 2011), Natural Capital (P. Dasgupta, 2021), and (Nordhaus, 2019), which emphasize that economic growth and environmental protection can be achieved simultaneously through technological innovation, green investment, and effective environmental policies. The results are also in line with Ulucak and Khan (2020) but differ from those of Febriana et al. (2019); Indriana et al. (2021); and Kondolele & Mustari (2023) who reported that economic growth increases environmental pressure. These differences may be attributed to variations in regional characteristics, environmental indicators, and the effectiveness of environmental policies. Additional evidence from Prawira et al., (2023) shows that GRDP is positively associated with capital utilization in East Java, indicating that stronger regional economic performance can enhance investment capacity and support environmental improvement through greater access to resources, technology, and infrastructure.

Overall, the findings demonstrate that GRDP is an important determinant of environmental quality improvement in the provinces of Java and Sumatra. Moreover, the results provide conceptual support for the Environmental Kuznets Curve (EKC) hypothesis, although the nonlinear relationship cannot be empirically confirmed because the regression model does not include the quadratic term of GRDP ($GRDP^2$).

Effect of Population Density on the Environmental Quality Index (EQI)

The results indicate that population density has no statistically significant effect on the Environmental Quality Index (EQI), suggesting that population size is not the primary determinant of environmental quality across the provinces of Java and Sumatra. Instead, the environmental impacts of demographic pressure depend largely on governments' capacity to manage development and natural resources effectively.

These findings are not entirely consistent with Malthusian theory (Malthus, 1789), which argues that population growth increases pressure on natural resources and environmental quality. Instead, they provide stronger support for Boserup (1965) Population Pressure Theory, which suggests that population growth can stimulate technological innovation and improve resource-use efficiency. The results are further supported by Kuznets (1955), Ecological Modernization Theory (Huber, 1982); (Mol & Sonnenfeld, 2000), and the STIRPAT framework (Dietz & Rosa, 1997) all of which emphasize that environmental outcomes are shaped by the interaction among technology, economic development, institutional quality, and population dynamics.

The findings differ from those reported by Indriana et al. (2021) and Kondolele & Mustari (2023), who found a negative relationship between population density and environmental quality. This discrepancy may be explained by differences in regional characteristics and the use of the Fixed Effect Model (FEM), which controls for province-specific heterogeneity.

The insignificant effect of population density also suggests that EQI, as a composite environmental indicator, is influenced more by the effectiveness of environmental management than by demographic pressure alone. This finding is consistent with the concepts of Green Growth (OECD, 2011), Natural Capital (P. Dasgupta, 2021); (Nordhaus, 2019); (Beretta, 2023), all of which highlight the importance of institutional quality and environmental governance in improving environmental quality. Consequently, environmental improvement depends more on effective governance than on population control.

Effect of the Poverty Severity Index on the Environmental Quality Index (EQI)

The results reveal that the Poverty Severity Index has a negative but statistically insignificant effect on the Environmental Quality Index (EQI). This finding suggests that poverty severity is not a primary determinant of environmental quality across the provinces of Java and Sumatra.

The relationship between poverty and environmental quality is commonly explained by the Poverty Environment Nexus (S. Dasgupta et al., 2005), which argues that poverty and environmental degradation are mutually reinforcing. However, this relationship is strongly influenced by institutional capacity, public policy, and natural resource management. The findings are further supported by the concept of Natural Capital (P. Dasgupta, 2021), which emphasizes that environmental sustainability depends on governments' ability to manage natural resources as productive assets.

The findings differ from those of Febriana et al. (2019) and Indriana et al. (2021), who found a significant relationship between poverty and environmental quality. These differences may reflect variations in regional characteristics, environmental indicators, and analytical approaches.

The insignificant effect of poverty further indicates that environmental quality is influenced more by effective environmental policies than by socioeconomic conditions alone. This finding supports the Three Pillars of Sustainability (Purvis et al., 2019), as well as the perspectives of (Nordhaus, 2019) and (Beretta, 2023), which emphasize that environmental improvement requires synergy among economic development, social welfare, and effective environmental governance.

Simultaneous Effects of Gross Regional Domestic Product, Population Density, and the Poverty Severity Index on the Environmental Quality Index

The simultaneous test indicates that GRDP, population density, and the Poverty Severity Index jointly have a statistically significant effect on the Environmental Quality Index. Although only GRDP is individually significant, these findings suggest that environmental quality is shaped by the interaction of economic, social, and demographic factors.

The findings support the concept of sustainable development proposed by the World Commission on Environment and Development (1987) and the Three Pillars of Sustainability (Purvis et al., 2019), which emphasize that sustainable development requires a balance among economic, social, and environmental dimensions. The results are also consistent with the concepts of Green Growth (OECD, 2011), Natural Capital (P. Dasgupta, 2021), Ecological Modernization Theory (Huber, 1982); (Mol & Sonnenfeld, 2000); (Nordhaus, 2019), all of which argue that economic growth, poverty reduction, and environmental protection can be achieved simultaneously through technological innovation, institutional strengthening, and effective public policies.

Overall, these findings demonstrate that environmental quality depends more on the integration of economic, social, and environmental policies than on any single factor in isolation. Therefore, strengthening environmental governance is essential for achieving sustainable development.

Relationship between the Empirical Findings and the Environmental Kuznets Curve (EKC)

The results show that GRDP has a positive and statistically significant effect on the Environmental Quality Index, indicating that higher levels of economic activity in the provinces of Java and Sumatra are associated with improvements in environmental quality. These findings are consistent with Kuznets (1955) and the Environmental Kuznets Curve (EKC) hypothesis developed by (Grossman & Krueger, 1995), which proposes that, beyond a certain income threshold, economic growth contributes to environmental improvement through structural transformation, technological progress, and stronger environmental regulations.

The findings further support the Scale Effect, Composition Effect, and Technique Effect, and are consistent with Stern (2004), who argued that the relationship between economic growth and environmental quality depends on institutional quality, economic structure, technological progress, and environmental policies. The concepts of Green Growth (OECD, 2011); Natural Capital Dasgupta (2021), and Nordhaus (2019) further reinforce the view that economic development and environmental protection can progress simultaneously when supported by effective governance.

However, this study cannot empirically confirm the EKC hypothesis because the regression model does not include the quadratic term of GRDP ($GRDP^2$), which is required to test the hypothesized nonlinear relationship. Therefore, the findings provide conceptual rather than empirical support for the EKC hypothesis while contributing to the literature on the relationship between economic growth and environmental quality at the regional level in Indonesia. Future studies are encouraged to incorporate $GRDP^2$, carbon emissions, energy consumption, urbanization, institutional quality, and government environmental expenditure to provide a more comprehensive assessment of the nonlinear relationship proposed by the EKC hypothesis.

CONCLUSION

This study concludes that Gross Regional Domestic Product (GRDP) has a positive and statistically significant effect on the Environmental Quality Index (EQI) across

16 provinces in Java and Sumatra during the 2015–2024 period, whereas population density and the Poverty Severity Index do not have significant effects. Nevertheless, the three variables jointly exert a significant influence on environmental quality, indicating that environmental conditions are shaped by the interaction of economic, social, and demographic factors. These findings suggest that economic growth does not inevitably lead to environmental degradation; instead, it can contribute to improvements in environmental quality when supported by effective environmental governance, technological advancement, and sustainable development policies. This study also extends the empirical literature on the relationship between economic growth and environmental quality at the regional level in Indonesia by simultaneously examining the effects of GRDP, population density, and poverty severity across the two largest economic regions, Java and Sumatra, which exhibit distinct development patterns and environmental pressures. The findings are consistent with Kuznets' (1955) proposition that economic growth accompanied by structural transformation alters the relationship between economic development and various dimensions of social welfare, including environmental quality (Kuznets, 1955).

From a conceptual perspective, the results exhibit a tendency consistent with the Environmental Kuznets Curve (EKC) hypothesis, although the existence of the EKC cannot be empirically confirmed because the model does not include the quadratic term of GRDP ($GRDP^2$). Therefore, policymakers should strengthen the integration of economic and environmental policies through greater investment in green technologies, the adoption of low-carbon development strategies, improved environmental governance, and sustainable natural resource management to ensure that economic growth is aligned with environmental sustainability. Future research is encouraged to incorporate the quadratic term of GRDP ($GRDP^2$), carbon emissions, energy consumption, urbanization, institutional quality, and government environmental expenditure to provide a more comprehensive assessment of the nonlinear relationship hypothesized by Kuznets (1955) and further developed in the Environmental Kuznets Curve literature (Stern, 2004).

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