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An Analysis of the Factors Influencing Carbon Emissions in Indonesia

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Abstract

Indonesia's high carbon emissions pose a major challenge to achieving sustainable development amid rapid economic growth. This research explores the determinants of total carbon emissions in Indonesia, focusing on per capita value added of the manufacturing industry, population density, and the Gross Regional Domestic Product (GRDP) of the mining and quarrying sector. The analysis employs panel data from ten provinces with the highest carbon emissions over the 2018-2023 period and applies a Fixed Effect Model (FEM) to control for unobserved provincial heterogeneity. The results indicate that per capita manufacturing value added and population density have a positive and statistically significant effect on carbon emissions, whereas the mining sector's GRDP does not show a significant impact. These findings suggest that industrial expansion in high-emission provinces remains energy-intensive and that demographic pressure substantially amplifies environmental stress. From a policy perspective, the study highlights the need for targeted emission control strategies, including the promotion of low-carbon technologies and energy efficiency in the manufacturing sector, sustainable urban planning to manage population density, and the strengthening of environmental regulations to support Indonesia's transition toward low-carbon and sustainable development.

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INTRODUCTION

Climate change is increasingly being felt globally, with 2023 standing out as the year with the most extreme heat on record with temperature anomalies reaching +1.45°C relative to pre-industrial levels (BMKG, 2023). According to estimates from the World Bank, climate change is expected to cause economic losses of 2.5 to 7 percent of Indonesia's Gross Domestic Product (GDP) by 2100 (Karunia et al., 2023). Carbon emissions are one of the main drivers of climate change, which have emerged as a priority global issue in the SDGs, calling for urgent climate action and supporting the transition to low-carbon development (UNDP Indonesia, 2022; United Nations, 2015).

Carbon emissions come from anthropogenic activities such as fossil fuel combustion, deforestation, agriculture, and industrial production processes (Putri & Serly, 2024; Soehaditama et al., 2024; Suwandi et al., 2022). Carbon emissions consist six main gases, including SF_6 which has a global warming potential up to 22,200 times greater than CO_2 (Ratnawati, 2016). Excessive release of emissions accelerates global warming and climate change (Hariswan et al., 2022; Kurniawan et al., 2022). In Indonesia, total carbon emissions continue to show an increasing trend. According to data provided by he Ministry of Environment and Forestry (KLHK, 2024) national emissions increased from 535,781.48 Gg CO2 in 2022 to 613,331.61 Gg CO2 in 2023. However, their geographical distribution remains uneven. Environmental pressures and carbon emission contributions are concentrated in regions with different economic structures (Chantika, 2024; Wahyudi et al., 2025).

Table 1. Provinces with the Largest Total Carbon Emissions in Indonesia in 2023

No	Province	Total Carbon Emissions (Gg CO2)
1	South Kalimantan	450.606,15
2	Riau	273.697,29
3	Central Kalimantan	194.588,76
4	South Sumatra	179.896,30
5	Central Java	118.738,90
6	West Java	92.890,89
7	Riau Islands	78.005,62
8	Lampung	74.435,90
9	DKI Jakarta	64.330,84
10	North Sumatra	46.042,21

Source: Sighmart KLHK (2025), processed by the author.

The discharge of carbon emissions contributing to climate change are a consequence of environmentally unfriendly economic activities. This phenomenon is explained by the Environmental Kuznets Curve (EKC) theory, which illustrates the link between economic growth and income inequality through U-shaped pattern, in which ecological degradation typically intensifies during the initial phases of economic expansion but gradually declines after income surpasses a certain threshold (Grossman & Krueger, 1991). The Environmental Kuznets Curve (EKC) is divided into three stages. First, in the earliest stage of economic development (pre-industrial economy), economic growth is typically accompanied by environmental degradation. Second, during the industrial economy stage, environmental pressure continues as industrialization accelerates. Third, in the post-industrial economy stage, environmental degradation begins to decline along with rising income levels, greater environmental awareness, and the adoption of more environmentally friendly technologies (Panayotou, 2003). This pattern is especially relevant for developing countries like Indonesia, which much balance economic expansion with environmental sustainability (Prasetyanto & Sari, 2021; Wang et al., 2024).

In addition, the IPAT model (Ehrlich & Holdren, 1971) asserts that environmental stress is the result of interactions between population, prosperity, and technology (Nurrahmawati & Kusumawardani, 2021). According to (York et al., 2003). The IPAT framework explains that environmental impact is the result of the interaction of three main components, namely population size, prosperity levels reflected in consumption or production at the per capita level, and technology that represents the magnitude of impact per unit of output and consumption. The relationship between these three factors is formulated in the equation $I = P \times A \times T$. General welfare is generally proxied by GDP per capita, so $P \times A$ is mathematically equivalent to GDP. Consequently, technology can be expressed as $T = I / GDP$, which reflects the intensity of the environmental impact of economic activity (York et al., 2003). In a microeconomic perspective, this situation reflects negative externalities, which harm society because the pollution it generates can cause environmental damage (Alfin & Qomariah, 2024). Externalities were first developed by Arthur Cecil Pigou (1920), the environmental impact of economic activity is often not reflected in production costs (Maghfirani et al., 2022).

The complexity of this situation cannot be separated from the various factors that trigger carbon emissions, one of which is the manufacturing industry, which contributes greatly to the Indonesian economy through the Gross Domestic Product (Setiawan et al., 2021). This sector includes the oil and gas industry along with various non-oil and gas industries, such as textiles, chemicals, and forestry products, which in the long term are projected to experience an increase in annual growth from 5.2% to 5.7%. (Asmara, 2018; Harahap et al., 2023; Yusuf, 2021). However, as industrialization progresses, carbon emissions also increase sharply as the sector uses around 70% of fossil-based energy (Nastiti & Hardiningsih, 2022; Zhang et al., 2021). Environmentally unfriendly production processes, such as pollution, intensive production and waste, are major contributors to carbon emissions (Mehmood et al., 2024), therefore the connection between industrial activities and carbon emissions is a crucial aspect that cannot be ignored in future industrial development (Baratta et al., 2023).

In addition, population density also drives increased emissions through pressure on resources, increased energy consumption, and land conversion (Han et al., 2021; Shunfa et al., 2022). Sadly, when economic activity increases to meet needs, environmental concerns tend to be ignored, resulting in negative impacts such as global warming and environmental degradation (Khan et al., 2020). In addition, the mining sector, which includes exploration and utilization of resources such as coal, oil, and minerals, also contributes high emissions, especially in areas with a mining-based economy (Ivanova et al., 2022; Saputra et al., 2023). Despite the rapid growth of this sector, its high emissions make reducing environmental externalities a crucial facilitating the shift to a sustainable economy (Basyith & Fadillah, 2019; Ulrich et al., 2022).

According to the reviewed literature, although extensive studies has been conducted on the association between carbon emissions and economic growth, most studies have not specifically distinguished the contribution of sectors such as the manufacturing industry (Prinadi et al., 2022; Yusuf, 2021; Zhang et al., 2021). In addition, the majority of studies use population size as a demographic indicator, which does not accurately represent spatial pressure (Adrian, 2023; Sari & Karimi, 2023; Widyawati et al., 2021). Population density variables, which reflect the intensity of human activity per unit area, are more relevant for explaining variations in carbon emissions between regions. The mining sector is also rarely studied simultaneously with other sectoral and demographic variables (Hariswan et al., 2022).

In response to the research background and gaps previously identified, this study is conducted to evaluate the effect of manufacturing industry value added per capita, population density, and the Gross Regional Domestic Product (GRDP) of the mining sector on total carbon emissions in Indonesia, emphasizing specifically on the ten provinces with the greatest carbon emissions. The novelty of this study is evident in the analytical perspective used to analyze the determinants of carbon emissions at the provincial level in Indonesia. Specifically, this study explicitly incorporates manufacturing industry value added per capita as a representation of the industrial sector's contribution to carbon emissions, uses population density as an indicator of demographic pressure that more accurately reflects the intensity of human activities than total population size, and integrates the mining sector alongside other sectoral and demographic variables within a panel data analytical framework. This approach is expected to provide a deeper insight into the main determinants influencing carbon emissions in Indonesia.

This study is anticipated to provide several significant contributions. Empirically, it enriches the environmental economics literature by offering recent empirical findings on the determinants of carbon emissions at the provincial level in Indonesia, while simultaneously accounting for sectoral and demographic variables. Methodologically, this study applies the Fixed Effects Model allows for a more accurate analysis of structural differences across provinces. Practically, the findings are expected to provide a foundation for developing more targeted carbon emission control policies that are tailored to regional economic characteristics Practically, the results are expected to form a foundation for developing more targeted carbon emission control policies that are tailored to regional economic characteristics.

METHOD

Data for this study were collected from the official publications of the Central Statistics Agency (BPS) and the Ministry of Environment and Forestry (KLHK). The data utilized include the total amount of carbon emissions, value added of the manufacturing industry sector, population density, and the Gross Regional Domestic Product (GRDP) of the mining and quarrying sector.

The dataset is structured as panel data, covering 10 provinces with the largest carbon emission levels in Indonesia in 2023, namely South Kalimantan, Riau, Central Kalimantan, South Sumatra, Central Java, West Java, Riau Islands, Lampung, DKI Jakarta, and North Sumatra, over the period 2018–2023. Consequently, the study comprises 60 observations. The selection of high emission provinces aims to enable a deeper focused examination of the key factors of carbon emissions in regions experiencing the greatest environmental pressure.

Table 2. Variable Operational Table

Variable		Description	Unit	Source
Total Carbon Emissions	CO_2	The total amount of greenhouse gases (GHG) produced by human activities or natural processes.	Gg Co_2	Ministry of Environment and Forestry
Added of Manufacturing Industry Sector per Capita	MAN	This indicator measures the share of manufacturing value added to GDP per capita as a reflection of national industrialization progress.	Thousand Rupiah	Central Bureau of Statistics

Population Density per square kilometer	DENS	Average population per 1 square kilometer	Km^2	Central Bureau of Statistics
GRDP at constant 2010 prices Mining and Quarrying Sector	MIN	Value indicating the value added of goods and services from the mining and quarrying sector calculated using prices prevailing in 2010.	Billion Rupiah	Central Bureau of Statistics

This research adopts a quantitative method by applying panel data analysis techniques. Panel regression analysis employs both time series and cross-sectional data to investigate how independent variables affect the dependent variable over a specific timeframe across multiple units of observation. It begins with determining the relevant dependent and independent variables. Each variable is log-transformed to equalize units and reduce data dispersion.

The empirical model employed in this study in defined as follows:

$$ln\ CO_{2it} = \alpha + \beta_1\ ln\ MAN_{it} + \beta_2\ ln\ DENS_{it} + \beta_3\ ln\ MIN_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

Where i denotes the province and t denotes the year; *MAN*, *DENS*, and *MIN* represent the independent variables as defined in the operational variable table; μ_i captures province-specific effects, and ε_{it} is the error term. The parameters are estimated through Ordinary Least Squares (OLS) method within the Fixed Effect framework. In panel data analysis, three methodological approaches commonly applied are the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM) (Bertiani et al., 2024; Dzogovic & Bajrami, 2023).

This study employs the Fixed Effect Model (FEM) to control for unobserved, time-invariant heterogeneity across provinces. The choice of FEM is based on the assumption that province-specific characteristics, such as regional policies and industrial capacity, influence carbon emissions and may be correlated with the explanatory variables. The analysis includes descriptive statistics, panel regression estimation, and statistical testing. Classical assumption tests comprise test of normality, heteroskedasticity, autocorrelation, and multicollinearity tests (Dewayanti & Utami, 2021). Hypothesis testing was conducted using the F-test to examine the simultaneous effect of independent variables, the t-test to examine the partial effect, and the coefficient of determination (R^2) to assess the model's ability to explain the dependent variable (Rohman et al., 2023).

RESULT AND DISCUSSION

This research adopts the Fixed Effect Model for panel data regression analysis. In the use of the Fixed Effect Model (FEM), this study uses industrial value added, population density and mining sector GRDP as independent variables, and total carbon emissions as the dependent variable. The Fixed Effect Model in panel data accounts for the impact of individual cross-sectional units on estimation outcomes.

Table 3. Model Specification Test

Variables	Model Specification Test
Log of Manufacturing Industry Value Added (X1)	2.096**
	(0.862)
Log Population Density (X2)	6.021***
	(2.028)
Log GRDP Mining Sector (X3)	0.100

	(0.219)
_cons	-43.08***
	(13.86)
Observations	60
Number of id	10
R-squared	0.684451
Chow Test (F-stat)	11.33417
p-value Chow	0.000006
Lagrange MultiplierTest (Chi2)	3.244931
p-value LM	0.028582
Hausman Test (Chi2)	8.495566
p-value Hasman	0.000000

Standard errors in parentheless. ***p<0.01, **p<0.05, *p<0.1

Source: Processed Data, 2025

Table 4. Fixed Effect Model Regression Results

Variables	FEM
Log of Manufacturing Industry Value Added (X1)	2.096**
	(0.862)
Log Population Density (X2)	6.021***
	(2.028)
Log GRDP Mining Sector (X3)	0.100
	(0.219)
_cons	-43.08***
	(13.86)
Observations	60
Number of id	10
R-squared	0.684

Standard errors in parentheless

***p<0.01, **p<0.05, *p<0.1

Source: Processed Data, 2025

Based on the results from table 4, the following estimation model can be obtained:

$$Y_{it} = -43.08 + 2.096\, X1_{it} + 6.021\, X2_{it} + 0.100\, X3_{it} + \varepsilon_{it} \quad (2)$$

The panel data estimation results using the Fixed Effect Method (cross-section fixed) indicate that the intercept (C) is -43.08028. This indicates that when all independent variables (Log Value Added of Manufacturing Industry Sector per Capita, Log Population Density and Log GRDP of Mining Sector) are zero, the log of the dependent variable (Log Total Carbon Emissions) is -43.08028. This value is the basic logarithmic level of Log (Y) without in the absence of the explanatory variables Log (X1), Log (X2), and Log (X3). The negative constant does not imply negative carbon emissions in real terms, rather within the Fixed Effect framework, it reflects the baseline level of emissions after controlling for province-specific, time-invariant characteristics. Thus, the negative intercept is primarily a statistical artifact of the log-linear specification and fixed effects transformation, and it does not carry a direct economic interpretation.

The variable Log (Value Added of Manufacturing Industry Sector per Capita) (Log(X1)) has a coefficient of 2.095962 which means that every 1% increase in the value added of the manufacturing industry sector per capita will increase the log of total carbon emissions by 2.095962. Statistically, this variable is significant at the 5% level (p-value = 0.0190), indicating that the manufacturing industry sector contributes positively and significantly to increases in carbon emissions. Economically, this coefficient suggests a high elasticity of emissions with respect to industrial expansion, implying that industrial growth in high-emission provinces is still strongly energy-intensive and reliant on carbon-based production processes. These results are consistent with the Environmental Kuznets Curve (EKC) theory, which states that in the early to middle stages of economic growth, industrialization tends to intensify environmental degradation due to increased energy use and insufficient adoption of clean technology.

The Log X2 (Population Density) variable has a coefficient of 6.021155 with a probability of 0.0047. This implies that a 1% rise in population density would lead to a substantial rise of approximately 6.021155 in the logarithmic value of total carbon emissions. In other words, the population density variable exerts a strong and positive influence on the rise in carbon emissions. This large coefficient indicates that demographic pressure is a dominant driver of carbon emissions, reflecting intensified transportation demand, residential energy consumption, and economic activities in densely populated areas. From a theoretical perspective, this result supports the population–environment nexus theory, which explains that population concentration amplifies environmental pressure through scale effects and increased resource consumption.

The Log X3 (mining) variable has a coefficient of 0.100065 with a probability of 0.6496, meaning that if the mining sector GRDP at constant 2010 prices increases by 1%, the log of total carbon emissions will increase by 0.100065. However, the result is not statistically significant as the p-value is 0.6496 which is more than 0.05. This result suggests that variations in mining sector output do not significantly explain differences in carbon emissions across provinces during the study period. One possible explanation is that emissions from mining activities are either indirectly captured through other sectors or mitigated by technological efficiency and environmental regulations, resulting in an insignificant net effect at the regional level.

The coefficient of determination or R-squared (R2) of 0.6845 demonstrates that approximately 68.45% of the variation in the log total carbon emissions can be explained by the three independent variables used in this model and the remaining 31.55% of the variation is attributable to factors not captured by the model. The R-squared (R2) value represents the proportion of variance in the data accounted for by the model. The F-test result, with a p-value of 0.0000, confirms that the independent variables together have a statistically significant impact on carbon emissions. Overall, the results indicate that manufacturing value added per capita and population density are the primary determinants of carbon emissions in Indonesia from 2018 to 2023, while the mining and quarrying sector has no significant direct impact. These findings reinforce both theoretical expectations and previous empirical studies, highlighting that industrial expansion and demographic pressure remain critical challenges for environmental sustainability in high-emission provinces.

The Fixed Effect Model (FEM) estimation using panel data from 10 provinces over the 2018–2023 period indicates that manufacturing industry sector value added per capita (X1) and population density (X2) exert a considerable influence in increasing total carbon emissions. Meanwhile, the GRDP of the mining and quarrying sector (X3) did not show a significant influence on carbon emissions during the study period.

More specifically, higher manufacturing value added per capita is associated with a statistically significant rise in carbon emissions, which implies that industrial growth in the observed provinces remains largely dependent on energy-intensive production processes. This suggests that the expansion of the industrial sector drives increased energy consumption and production activities that generate greenhouse gas emissions. This consistency is reinforced by various empirical studies, such as Dong et al., (2020), who through the STIRPAT found a direct relationship between the increase in industrial value added and higher carbon emissions, and Majeed & Asghar (2021), who highlighted the negative impact of high energy consumption in the manufacturing sector on the environment. Liu et al., (2021) also revealed that the industry's energy structure and capital inputs hinder the carbon decoupling process. Furthermore, Adrian (2023) and Farhan (2021) found that increasing industrialization in Southeast Asia increases carbon emissions. Although Pratama (Pratama, 2022) found a negative effect in Indonesia, the current trend still shows that industrial expansion remains a major contributor to carbon emissions in various regions.

Higher population concentration increases the intensity of human activities, including energy consumption for transportation, electricity use, industrial activities, and land conversion, which collectively contribute to higher carbon emissions when not accompanied by environmentally sustainable practices. This mechanism aligns with previous studies, such as Prinadi et al., (2022), who identified population pressure as a major driver of rising carbon emissions in ASEAN countries, including Indonesia. Similar evidence is reported by Zarco-Periñán et al., (2021) for Spain and Han et al., (2021) for China, showing that densely populated areas tend to experience higher energy consumption and increasingly carbon-intensive lifestyles.

The relatively weak role of the mining and quarrying sector in explaining variations in carbon emissions reflects the effectiveness of Indonesia's environmental governance in the mining sector. The enforcement of Law No. 3 of 2020 which amends Law No. 4 of 2009 on Mineral and Coal Mining, along with its adjustment under the Job Creation Law, has strengthened environmental management by mandating reclamation and post-mining obligations and imposing stricter administrative and criminal sanctions for environmental violations (Darongke et al., 2022). This regulatory framework limits emission-intensive practices in mining activities, thereby reducing the direct contribution of the sector to recorded carbon emissions. This interpretation is consistent with Insani & Robertus (2024) and Nazra (2023), who highlight the role of regulatory quality and technological efficiency in shaping the environmental impact of mining activities. Furthermore, Mervine et al., (2025) highlight that nickel mining activities, particularly through land clearing, generate large amounts of carbon emissions that have not been fully captured in official reporting systems, and thus their contribution to national emissions is often underestimated.

The results of this study underscore the necessity for targeted policy interventions to mitigate carbon emissions in provinces with high emission levels. Sustainable industrial development can be achieved by promoting low-carbon technologies, enhancing energy efficiency, and rigorously enforcing emission standards for each unit of production. Meanwhile, pressures from dense populations call for sustainable urban planning, expansion of public transportation, and the implementation of energy-efficient building regulations. In the mining sector, maintaining and strengthening environmental governance, including reclamation and post-mining obligations ensures responsible resource extraction and minimizes environmental impact. Collectively, these measures can support economic development while achieving measurable and sustainable reductions in carbon emissions.

CONCLUSSION AND RECOMMENDATION

The research investigates how per capita value added from the manufacturing sector, population density, and the GRDP of the mining and quarrying sector impact total carbon emissions in Indonesia, utilizing panel data from ten provinces over the 2018–2023 period. Through estimation using the Fixed Effect Model, the analysis reveals that both the manufacturing sector's value added per capita and population density have a statistically significant and positive association with carbon emission levels. These findings indicate that increased industrial activity and higher population concentration contribute to increased energy consumption and production patterns that exacerbate greenhouse gas emissions.

Meanwhile, the GDRP variable for the mining and quarrying sector does not show a strong influence in increasing the amount of carbon emissions. This insignificance could be due to differences in the intensities: and operational technology of the mining sector in each province, or because some mining activities have not produced high direct emissions. In addition, environmental regulation and supervision in the sector may also affect the amount of contribution to carbon emissions.

Thus, efforts to control carbon emissions in Indonesia need to focus on strengthening policies in the industrial sector and managing population density, as well as improving environmentally friendly technology to support sustainable development.

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