

Research Article

The Impact of Renewable Energy, Energy Consumption, and Gross Domestic Product (GDP) on Carbon Dioxide (CO₂) Emissions in Indonesia

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Abstract: This study aims to analyze the effect of renewable energy, energy consumption, and Gross Domestic Product (GDP) per capita on carbon dioxide (CO₂) emissions in Indonesia for the period 1995-2024. This study uses secondary data over time (time series) with the Ordinary Least Square (OLS) multiple linear regression analysis method corrected using the Newey-West Heteroskedasticity and Autocorrelation Consistent (HAC) approach. The results show that renewable energy does not have a significant effect on CO₂ emissions, which is caused by the still low share of renewable energy in the national energy mix which only reaches 10.95% in 2024. Energy consumption has a positive and significant effect on CO₂ emissions, where every 1% increase in energy consumption increases CO₂ emissions by 84.23%. Gross Domestic Product (GDP) per capita has a positive and significant effect on CO₂ emissions. Every 1% increase in GDP per capita increases CO₂ emissions by 35.03%, indicating that Indonesia remains on the EKC curve. Simultaneously, all three variables have a significant effect, with an adjusted R-squared value of 53.63%. This finding confirms that Indonesia's energy mix, still dominated by fossil fuels, is a major factor in high carbon emissions. Comprehensive energy efficiency policies, accelerated renewable energy transitions, and greener and more sustainable economic growth strategies are needed.

Keywords: CO₂ Emissions; Energy Consumption; Environmental Kuznets Curve; Gross Domestic Product; Renewable Energy.

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1. Introduction

Carbon dioxide (CO₂) emissions refer to the total amount of CO₂ gas released into the atmosphere as a result of fossil fuel combustion associated with production, transportation, and distribution of fossil fuels, as well as emissions from industrial processes. CO₂ is one of the main greenhouse gases contributing significantly to global warming and climate change, generated from transportation, industry, energy generation, and other fossil fuel dependent activities (Kaparang et al., 2023).

Climate change has become one of the most pressing challenges facing the world, with consequences threatening not only ecosystems but also international economic stability. According to the Swiss Re Institute, if global temperatures rise beyond 3°C, the global economy could experience an 18% decline in GDP (Re, 2021). The primary cause of climate change is the increasing concentration of greenhouse gases, especially CO₂ from fossil fuel combustion in the energy, industrial, and transportation sectors (Kaparang et al., 2023). CO₂ accounts for nearly 64% of total greenhouse gas impact since the industrial era (Dunn et al., 2025).

Indonesia ranks among the top ten CO₂ emitting countries globally and is the highest emitter in ASEAN, facing serious challenges in controlling carbon emissions while undergoing economic development. Based on Global Carbon Budget (2025) data, CO₂ emissions

in Indonesia increased from 222,23 million tons in 1995 to 812,22 million tons in 2024 (Ritchie et al., 2023). Without structured emissions control, economic growth risks being overshadowed by long-term economic losses from climate disasters and declining productivity (World Bank, 2023).

This study identifies three key independent variables: (1) renewable energy, the share of energy from renewable sources (solar, wind, hydro, biomass) in total national consumption; (2) energy consumption, total primary energy use; and (3) Gross Domestic Product per capita, representing economic growth. Based on the Environmental Kuznets Curve (EKC) theory, emissions generally increase in the early stages of industrialization and decline after a country reaches a certain income level (Ardiana & Naylah, 2024). Given the substantial research gaps in studying these three variables simultaneously for Indonesia using the latest data (1995-2024), this study aims to fill that gap with robust time series economics analysis (I. Turyandi et al. 2025; Chengxuan Wang et al. 2026).

The research objectives are: (1) to analyze the impact of renewable energy on CO₂ emissions in Indonesia; (2) to analyze the impact of energy consumption on CO₂ emissions; (3) to analyze the impact of Gross Domestic Product per capita on CO₂ emissions in Indonesia.

2. Method

This study employs a quantitative method using annual time series data covering the period 1995-2024. Secondary data were obtained from official publications of the Energy Institute Statistical Review, World Bank Open Data, and the Global Carbon Budget. The dependent variable is CO₂ emissions (million tonnes), whilst the independent variables include the share of renewable energy (%), primary energy consumption (TWh), and Gross Domestic Product per capita (constant LCU).

Table 1. Variables, Symbols, Units, and Data Sources

Variable	Symbol	Unit	Data Sources
CO ₂ Emissions	CO	Million Ton	Global Carbon Budget
Renewable Energy	ET	Percent (%)	Energy Institute
Energy Consumption	KE	TWh	Energy Institute
Gross Domestic Product per capita	PDB	Billion IDR	World Bank

The data analysis method employed multiple linear regression using the Ordinary Least Squares (OLS) approach. Estimation was carried out using Eviews 12 software. OLS was chosen as it is the most efficient estimation technique, providing Best Linear Unbiased Estimation (BLUE) result when classical assumptions are met. To address the issue of autocorrelation, which is common in time series data, this study employs the Newey-West HAC (Heteroscedasticity and Autocorrelation Consistent) standard error approach, which ensures that the estimates remain valid even in the presence of violations of the assumptions of autocorrelation and heteroscedasticity (Widarjono, 2018).

All variables were transformed into natural logarithms (ln) to stabilise data variation and facilitate the interpretation of coefficients as elasticities. As the variables were non-stationary at the level and only stationary at the first difference (I(1)), estimation was performed on the first difference data. The regression equation model used:

$$D_lnCO_2 = \alpha + \beta_1 D_lnET + \beta_2 D_lnKE + \beta_3 D_lnPDB + \epsilon_t$$

Where:

D_lnCO_2 = Change in CO₂ emissions (%)

α = Constant

$\beta_1, \beta_2, \beta_3$ = Regression coefficients

D_lnET = Change in renewable energy (%)

D_lnKE = Change in energy consumption (%)

D_lnPDB = Change in Gross Domestic Product per capita (%)

ϵ_t = Error term.

The analysis stages include: (1) descriptive statistical analysis; (2) classical assumption tests, including a normality test using the Jarque-Bera test, a multicollinearity test using the Variance Inflation Factor (VIF), a heteroscedasticity test using the Breusch-Pagan-Godfrey test,

and an autocorrelation test; (4) hypothesis testing using the F-test for simultaneous testing and the t-test for partial testing; and (5) analysis of the coefficient of determination (R^2).

3. Result and Discussion

Descriptive Statistics

Descriptive statistics provide an overview of the characteristics of the data used in this study for the period 1995-2024. The variables were analysed in the form of first differences (D) following natural logarithmic transformation.

Table 2. Descriptive Statistics Results.

	D_CO	D_ET	D_KE	D_PDB
Mean	0.043660	0.038985	0.044010	0.041931
Median	0.035590	0.027854	0.044477	0.049095
Maximum	0.180318	0.472551	0.223904	0.078996
Minimum	-0.135239	-0.330624	-0.062615	-0.140720
Std. Dev.	0.074993	0.171416	0.053497	0.038832
Skewness	-0.194738	0.573011	0.776537	-3.745853
Kurtosis	2.576925	3.715827	5.889067	17.78479
Jarque-Bera	0.413355	2.282219	13.44843	343.3946
Probability	0.813282	0.319464	0.001201	0.000000
Sum	1.309787	1.169564	1.320286	1.257915
Sum Sq. Dev.	0.163095	0.852121	0.082996	0.043729
Observations	30	30	30	30

Source: Output Eviews 12

The change in CO₂ emissions (D_CO) has a mean of 0,043660 with standard deviation of 0,074993, and is normally distributed (probability > 0,05). The change in renewable energy (D_ET) has a mean of 0,038985 with a standard deviation of 0,171416, indicating the highest variation compared to other variables, and is also normally distributed. Meanwhile, the change in energy consumption (D_KE) has a mean of 0,044010 with a standard deviation of 0,053497, but is not normally distributed. The change in Gross Domestic Product (D_PDB) has a mean of 0,041931 with a standard deviation of 0,038832, with a highly skewed distribution and is also not normally distributed.

Stationary Testing***Unit Root Test*****Table 3.** Augmented Dickey-Fuller Unit Root Test Results at Level.

Variable	ADF Test Value	Mackinnon Critical Value	Probability	Description
CO	-0.477287	1% level	0.8824	Non-stationary
		5% level		
		10% level		
ET	-0.277327	1% level	0.9171	Non-stationary
		5% level		
		10% level		
KE	-0.802106	1% level	0.8041	Non-stationary
		5% level		
		10% level		
PDB	0.518297	1% level	0.9758	Non-stationary
		5% level		
		10% level		

Source: Output Eviews12

Based on the results of the Augmented Dickey-Fuller unit root test at level, it can be concluded that the variables CO, ET, KE, and PDB are non-stationary at the level. All variables contain unit roots and do not meet the conditions for stationarity. Therefore, further transformation via differentiation is required to achieve stationarity.

Degree of Integration Test**Table 3.** Augmented Dickey-Fuller Unit Root Test Results on First Difference.

Variable	ADF Test Value	Mackinnon Critical Value	Probability	Description
CO	-8.680905	1% level	0.0000	Stationary
		5% level		
		10% level		
ET	-7.566168	1% level	0.0000	Stationary
		5% level		
		10% level		
KE	-6.036519	1% level	0.0000	Stationary
		5% level		
		10% level		
PDB	-4.232414	1% level	0.0021	Stationary
		5% level		
		10% level		

Source: Output Eviews12

Based on the results of the Augmented Dickey-Fuller unit root test at the first difference level, it can be concluded that the variables CO, ET, KE, and PDB are stationary at the first difference level.

Classical Assumption Testing

Normality Test

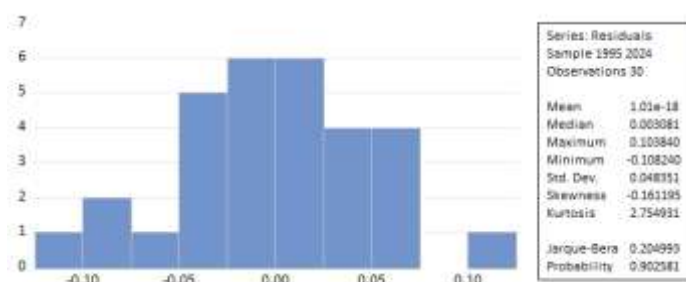


Figure 1. Normality Test Results

Source: Output Eviews12

Based on the results of the normality test, a Jarque-Bera statistic of 0.204993 was obtained, with a probability value of 0.902581 (> 0.05), it can therefore be concluded that the residuals are normally distributed.

Multicollinearity Test

Table 4. Multicollinearity Test Results

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	0.000317	3.649268	NA
D_ET	0.004438	1.527960	1.450354
D_KE	0.039195	2.120914	1.247525
D_PDB	0.079039	2.924213	1.325464

Source: Output Eviews12

Based on the results of the multicollinearity test, the Centred Variance Inflation Factor (VIF) values for the variables ‘change in renewable energy (ET)’, ‘change in energy consumption (KE)’, and ‘change in Gross Domestic Product (GDP)’ are well below the general threshold of 10. This indicates that there is no evidence of multicollinearity in this study.

Heteroscedasticity Test

Table 5. Heteroscedasticity Test Results.

F-statistic	0.571498	Prob. F(3,26)	0.6388
Obs*R-squared	1.855880	Prob. Chi-Square(3)	0.6029
Scaled explained SS	1.223162	Prob. Chi-Square(3)	0.7475

Source: Output Eviews12

Based on the results of the heteroscedasticity test, the probability value for Obs*R-squared was found to be 0.6029 (> 0.05). It can therefore be concluded that the model does not suffer from heteroscedasticity.

Autocorrelation Test

Table 6. Autocorrelation Test Results

F-statistic	5.518359	Prob. F(s,24)	0.0107
Obs*R-squared	9.450130	Prob. Chi-Square(2)	0.0089

Source: Output Eviews12

Based on the results of the autocorrelation test, the probability value for Obs*R-squared was found to be 0.0089 (< 0.05). It can be concluded that there is a problem of autocorrelation in the regression model. As the model is indicated to suffer from autocorrelation, the researcher made corrections using the Heteroskedasticity and Autocorrelation Consistent (HAC) method with the Newey-West approach.

Autocorrelation Test with the Newey-West HAC Method

Based on the results of the autocorrelation test using the Heteroscedasticity and Autocorrelation Consistent (HAC) approach, a Durbin-Watson value of 3.010 ($DW > 2$) indicates a tendency for autocorrelation in the model. To address this issue, the researcher employed

the Heteroscedasticity and Autocorrelation Consistent (HAC) approach using the Newey-West and Berlett Kernel methods. The HAC method does not alter the regression coefficient values but corrects the standard errors to make them robust against autocorrelation and heteroscedasticity (Widarjono, 2018). Consequently, the t-statistics and probabilities obtained have been corrected and can be used for hypothesis testing.

OLS Multiple Linear Regression with Heteroskedasticity and Autocorrelation Consistent (HAC) Approach

Table 8. OLS Multiple Linear Regression with HAC Approach.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.005624	0.010188	-0.552006	0.5857
D_ET	-0.063511	0.047730	-1.330631	0.1949
D_KE	0.842348	0.145913	5.772958	0.0000
D_PDB	0.350291	0.121974	2.871848	0.0080
R-squared				0.584307
Adjusted R-squared				0.536343
F-statistic				12.18208
Prob (F-statistic)				0.000036
Durbin-Watson stat				3.010391

Source: Output Eviews12

Based on this regression model, the constant value of -0.005624 indicates that if all independent variables—namely the change in Renewable Energy (D_ET), the change in Energy Consumption (D_KE), and changes in Gross Domestic Product (D_GDP) are assumed to remain unchanged or equal to zero, then the change in CO₂ emissions (D_CO) is estimated to be -0.005624. A negative constant indicates that, in the absence of changes to the independent variables, the change in CO₂ emissions tends to decrease only very slightly.

Hypothesis Testing

Simultaneous Significance Testing (F-Test)

Table 7. F-Test Results.

F-Statistic	12.18208
Prob. (F-Statistic)	0.000036

Source: Output Eviews12

Based on the results of the simultaneous significance test (F-test), it was found that changes in energy consumption (D_KE) and changes in gross domestic product (D_GDP) simultaneously influence changes in CO₂ emissions (D_CO) in Indonesia between 1995 and 2024.

Coefficient of Determination (R²)

Table 8. Results of the Coefficient of Determination (R²) Test.

R-squared	0.584307
Adjusted R-squared	0.536343

Source: Output Eviews12

Based on the coefficient of determination (R²) test, the adjusted R-squared value of 0.536343 indicates that, after adjusting for the number of variables and the number of observations, the model's ability to explain the variation in CO₂ emissions is 53.63%. It can therefore be concluded that approximately 46.37% of the variation in CO₂ emissions is influenced by other factors outside the model that were not investigated.

Partial Significance Test (t-Test)**Table 9.** t-Test Results.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.005624	0.010188	-0.552006	0.5857
D_ET	-0.063511	0.047730	-1.330631	0.1949
D_KE	0.842348	0.145913	5.772958	0.0000
D_PDB	0.350291	0.121974	2.871848	0.0080

Source: Output Eviews12

The results of the partial tests indicate that changes in Renewable Energy (D_ET) do not have a significant effect on CO₂ emissions. Meanwhile, changes in Energy Consumption (D_KE) and Gross Domestic Product (D_GDP) have a positive and significant effect on CO₂ emissions, with the greater contribution to this effect coming from energy consumption.

Discussion of Research Results***The Impact of Renewable Energy on Carbon Dioxide (CO₂) Emissions***

The results of the study indicate that changes in renewable energy had no significant effect on CO₂ emissions in Indonesia during the period 1995–2024 (t-statistic < t-table = -1,33 < 1,706; Prob. > α = 0,1949 > 0,05). This is due to the low share of renewable energy, which reached only 10,95% in 2024, whilst fossil fuels still dominated 89,05% of the national energy mix (Energy Institute, 2025). This finding is consistent with energy transition theory, which emphasises that the transition to clean energy is gradual and requires a critical mass to have a significant impact (Smil, 2010; Sovacool, 2016). Although not statistically significant, these results underscore the urgency of accelerating the increase in the share of renewable energy through policy, investment incentives, and regulatory reforms to support the 2060 net-zero emissions target.

The Impact of Energy Consumption on Carbon Dioxide (CO₂) Emissions

Changes in energy consumption have a positive and significant impact on changes in CO₂ emissions, with every 1% increase in energy consumption leading to an 84.23% increase in CO₂ emissions. This confirms that Indonesia's energy mix, which remains heavily reliant on fossil fuels such as coal, oil and natural gas, directly contributes to high carbon emissions (Hannah et al., 2020). The drastic rise in energy consumption in Indonesia, from 869.43 TWh in 1995 to 2,990.65 TWh in 2024, shows a pattern consistent with the increase in CO₂ emissions, which reached 812.22 million tonnes in 2024 (Ritchie et al., 2023). This finding supports the Energy Demand Theory, which suggests that increased energy consumption, particularly of fossil fuels, is directly linked to rising carbon emissions (Ahmat et al., 2025; Bohi, 2013). This reflects the fact that, during this period, efforts to reduce CO₂ emissions in Indonesia have remained hampered by the dominance of fossil fuels.

The Impact of GDP per capita on Carbon Dioxide (CO₂) Emissions

Changes in GDP per capita also have a positive impact on changes in CO₂ emissions, with every 1% increase in GDP per capita leading to a 35.03% rise in CO₂ emissions. This finding indicates that economic growth, as measured by GDP per capita, remains closely correlated with rising emissions in Indonesia. Indonesia remains on the left-hand side of the Environmental Kuznets Curve (EKC), where, in the early stages of development, economic growth is accompanied by rising carbon emissions (Ashraf et al., 2019; Noor & Saputra, 2020). Increased productivity, industrial sector expansion, and rapid urbanisation exacerbate energy consumption and, in turn, increase carbon emissions (Destiarsono, 2025; International & Agency, 2024; Nugraha & Osman, 2019). This study supports the EKC theory, which states that in the early stages of industrialisation, emissions will continue to rise in tandem with economic growth.

4. Conclusion

This study shows that changes in renewable energy have no significant impact on changes in CO₂ emissions in Indonesia, as its share remains low, whereas changes in energy consumption and changes in Gross Domestic Product (GDP) per capita have a positive and significant impact on CO₂ emissions, indicating that economic growth and the use of fossil

fuels remain the primary drivers of emissions. Collectively, these three variables account for more than half of the variation in CO₂ emissions, underscoring the crucial role of energy consumption and GDP per capita in national emissions dynamics. These findings confirm that Indonesia remains in the early stages of the Environmental Kuznets Curve (EKC) and requires more targeted policy strategies to curb emissions.

Suggestion

Based on the research findings, it is recommended that the government strengthen energy efficiency policies in the industrial and transport sectors, accelerate the transition to renewable energy through investment incentives, infrastructure development and regulatory reform, and implement a strategy to decouple economic growth from carbon emissions by promoting the development of clean-technology-based economic sectors and strengthening environmental regulations. These measures are in line with the 2022 Enhanced NDC emission reduction targets and the 2060 net-zero emissions vision, and serve as key instruments for achieving sustainable economic development whilst reducing national emissions. For future research, it is recommended to expand the scope of independent variables, given that approximately 41.53% of CO₂ emission variation remains unexplained by the model in this study.

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