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Analysis of the Relationship Between Energy Consumption and Economic Growth in Indonesia: An Empirical Perspective and Environmental Impact

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Abstract
This study examines the relationship between energy consumption and the concept of economic growth in Indonesia, and evaluates its impact on carbon emissions from 2019 to 2025. In examining the relationship between variables, a mixed-form log-linear Cobb-Douglas production function model is used to adopt a dynamic approach with an explanatory design. Annual data are taken from the Indonesian Central Bureau of Statistics, Energy, and Development Indicators. The analysis stages include the Augmented Dickey-Fuller stationarity test, the Granger causality test, Ordinary Least Squares analysis estimation, and to ensure model validity, diagnostic testing. The estimation results show that energy consumption has a positive and significant effect on real Gross Domestic Product. The elasticity coefficient of 1.523 indicates that a one percent increase in energy consumption is associated with a 1.52 percent increase in output. The Granger causality test shows a one-way relationship from energy consumption to economic growth, reflecting the function of energy as the main driver of national production activities. The increase in energy consumption during the economic recovery period is also accompanied by an increase in carbon dioxide emissions, indicating a high carbon intensity in our economic structure. Dependence on fossil-based energy sources continues to be a major factor causing increasing environmental pressure. These findings highlight the need for policies that support energy mix diversification, increased efficiency, and accelerated renewable energy development that can secure long-term growth rates and ensure environmental stability.

Keywords:
Energy Consumption; Economic Growth; CO_2 Emissions; Environmental Impact; Granger Causality; Energy Elasticity.

1. INTRODUCTION

Energy consumption and economic development are interrelated and also connected to the stage of economic development. In Indonesia, energy demand is driven by industrialization and population growth. The negative consequences of heavy dependence on fossil fuels include air pollution and greenhouse gas emissions. The dilemma facing the Indonesian government is the need for sustainable economic growth while also ensuring the balanced management of natural resources and the environment. However, the role of energy consumption in economic growth and environmental degradation requires a more detailed analysis. The relationship between energy consumption and economic growth in Indonesia is influenced by the role of the government and its expenditures, as well as the technology used in the energy sector. A better understanding of these interrelationships can support the formulation of policies conducive to both environmental conservation and economic growth. This study will empirically investigate and measure this

relationship, utilizing its findings to identify the environmental impacts of the current energy consumption structure. These results may also help guide policy strategies toward a more sustainable form of development.

The relationship between energy consumption and economic growth in Indonesia has been the subject of several studies, all of which report a strong correlation. Zuldareva (2016) reported that energy consumption and CO2 emissions between 1981 and 2014 had a strong influence on Indonesia's economic growth. While energy consumption is a major factor in supporting economic growth, as a consequence of high carbon emissions from coal-fired power plants, this study also indicates potential pressures on the environmental sector. Shabrina (2025) examined the effects of energy consumption, energy subsidies, and economic growth on environmental degradation in Indonesia from 2010 to 2023. Using the Environmental Kuznets Curve (EKC) approach, the researchers found that despite achieving positive economic growth, the more energy Indonesia consumed, the higher the level of environmental degradation. These results underscore the importance of energy policies that can minimize negative impacts on the environment and stabilize economic growth rates. Nisful (2025) in another study analyzed the relationship between renewable energy consumption and economic growth in China. The study's findings suggest that a shift to renewable energy sources can drive greener economic growth and reduce reliance on fossil fuels, both of which degrade air quality and contribute to climate change. These findings offer guidance on how a greener energy transition can also drive economic growth in countries like Indonesia.

Given the challenges of sustainable development, research on the relationship between environmental quality and economic growth is increasingly important. Several studies have shown that maintaining environmental quality can impact the sustainability of economic growth in Indonesia. As pollution and environmental degradation increase, this can ultimately limit the environmental capacity needed for long-term economic development. Therefore, it is crucial to find ways to align economic development and environmental protection. Another study by Pratiwi (2021) analyzed the relationship between economic growth, energy consumption, and CO2 emissions in Indonesia between 1980 and 2019. This study found that while energy consumption plays a role in supporting economic growth, the accompanying carbon emissions from fossil fuel combustion degrade air quality and accelerate climate change. This implies that efficient and sustainable energy management can reduce environmental impacts without harming economic growth. Similarly, a study of D8 countries in 2023 found that trade openness, energy consumption, and economic growth all contribute to increasing carbon emissions. Countries with high energy consumption often have to bear relatively large increases in emissions each year, which also leads to significant environmental impacts. This study also implies that to address the problem of continuously increasing carbon emissions, and support increased use of renewable energy and energy efficiency, developing countries, especially Indonesia, can consider adopting policies that promote low-carbon energy sources for energy production.

Research on the relationship between energy consumption, economic growth, and the environment has been ongoing for a long time, but most studies show how these three variables interact. In their investigation, Putra and Satrianto (2019) claimed to find a causal relationship between energy use, economic growth, and environmental emissions in Indonesia. They showed that increased energy consumption accompanying economic growth leads to increased emissions, which in turn leads to environmental pollution. This research is significant, emphasizing the importance of controlling energy consumption for environmental quality if GDP growth increases. Furthermore, Harahap et al. (2020) found in their study of fiscal deficits, exports, imports, and the number of MSMEs (Micro, Small, and Medium Enterprises) that appropriate fiscal policy and the growth of the MSME sector support stable economic growth. This finding is beneficial for energy use, as a growing MSME sector can promote energy efficiency; while fiscal policy has the potential to help realize a more environmentally friendly energy transition. In another study, Febrina Harahap et al. (2022) emphasized how economic competitiveness and the quality of human resources improve local economic performance, such as in West Sumatra. Good quality human resources can lead to higher efficiency and productivity, which in turn ensures reduced energy waste and the associated emissions reductions. In this regard, building community capacity is crucial for sustainable economic development.

Economic growth in Indonesia is often accompanied by increased energy consumption, and this has led to further environmental damage. Based on research, Sari and Karimi (2023) show that with economic growth and population growth comes an increase in energy production, which again has a direct impact on environmental damage, and they re-emphasize this point. This study not only illustrates that energy consumption can increase economic productivity, but also has negative effects, such as on air quality in terms of pollution and, consequently, global warming with the large accumulation of greenhouse gases, all of which cannot be ignored. Acheampong and Opoku (2023) in their study further assert that economic growth has achieved benefits in the short term, but if not managed properly, after a certain point, industrial growth will accelerate environmental degradation in the region. Therefore, we need to find the right platform between economic efforts and ecological protection policies. Corneo et al. (2025) further suggest in their study that greater investment, usually in core sectors such as energy and infrastructure, goes hand in hand with economic growth. However, if this is done without the slightest regard for sustainability, it can cause severe environmental damage. One way to offset these impacts is to invest money in environmentally friendly

technologies and renewable energy sources, as these offer the potential to achieve economic growth while maintaining environmental quality.

The relationship between energy consumption and economic growth or environmental quality is a reciprocal one. Pressure from increased industrial activity and economic growth leads to higher energy consumption. However, the dominance of fossil fuels means more smoke from chimneys and places the environment under greater strain, increasingly moving it further from safe conditions. Accelerated economic growth and environmental protection then create a demand for policies that can maintain these conditions. Consequently, empirical testing is needed to determine the direction and magnitude of the correlation, as well as the concrete influence between variables. Its nature. Empirical separation defines how to achieve the best results. The results of the analysis are expected to provide a basis for designing more effective energy policies, promoting the broad use of renewable energy sources, and strengthening sustainable development strategies in Indonesia.

2. RESEARCH METHOD

This research is quantitative with an exploratory design to analyze the relationship between energy consumption and economic growth in Indonesia. This research also incorporates the topic of carbon concentration into these parameters. A quantitative approach was chosen because it allows for objective testing of the relationship between variables using econometric models (Maswir, 2025). The time frame used is from 2019 to 2025, encompassing the period of global economic contraction and subsequent national recovery. Annual secondary data is used, collected from the Central Statistics Agency (BPS) and the Ministry of Energy and Mineral Resources and the Indonesian Development Indicators. The key variable is real Gross Domestic Product (GDP), and total energy consumption is taken as an indicator of economic growth. Furthermore, carbon dioxide (CO2) emissions represent environmental quality. GDP is expressed in billions of US dollars at constant prices, energy consumption is measured in exajoules, while carbon emissions are expressed in billions of tons. All variables are converted to natural logarithms to facilitate interpretation of elasticity between variables and limit the potential for heteroscedasticity (Ramadhan, 2023).

The empirical model used refers to the Cobb-Douglas production function in a log-linear form as follows.

$$log\ Gt\ =\ \alpha\ +\ \beta\ log\ Et\ +\ ut$$

In the equation, Gt represents real GDP, Et is energy consumption, α is the constant, β denotes the elasticity of energy consumption with respect to output, and ut is the error term. A positive value for β indicates that an increase in energy consumption is correlated with a rise in economic output.

Descriptive statistics are used to show changes in variables over time. Stationarity testing is then performed, where data are analyzed at their initial values and increased observation periods to meet the Otinobe criterion for non-integrative time series. If any of the variables are non-stationary at a certain level, this is continued with first differences until all reach the same order of integration. To test for Granger causality between energy consumption and economic growth, appropriate lags are selected based on data characteristics using the AIC criterion. The Ordinary Least Squares (OLS) method is adopted to estimate the effect of energy consumption on economic growth. Finally, various diagnostic tests are performed, including Jarque-Bera to check whether the residuals are normally distributed, ARCH to test for heteroscedasticity, and the Ramsey RESET test to check whether the model specification is correct. All data processing is performed using software such as EViews or Stata to obtain precise and reliable estimates.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Model Specification

The research model uses the Cobb-Douglas production function, transformed into a log-linear form to simplify parameter estimation and result interpretation. The equation used is.

$$\text{Log } G = \alpha + \beta \log E + ut$$

Variable G is real gross domestic product (abbreviated as GDP), while E is total energy consumption. The constant factor α is a parameter representing the level of productivity and technological factors not included in the model itself. is the parameter β that measures the elasticity of energy consumption to output. This parameter indicates how much GDP changes for a one percent increase in energy consumption. If β is positive, then an increase in energy consumption will be accompanied by an increase in economic output; but if it is not significant, then it is insignificant. Water is supplied from shallow wells to many rural populations throughout Asia. If the coefficient is insignificant, then energy consumption will not have a significant

impact on economic growth. transformed by the natural logarithm so that the relationship between variables can be interpreted in terms of elasticity, and also to reduce heteroscedasticity. Potential. It is often used as an institutional tool when conducting growth analysis to capture the proportional relationship between economic variables (log form). Our hypotheses are: the null hypothesis (H0) that states there is no relationship between energy consumption and economic growth, and the alternative hypothesis (H1) that states there is a positive relationship between the two. The null hypothesis is tested through regression estimation and significance testing of the parameter β. If the coefficient is found to be significant at a certain confidence level, it can be concluded that energy consumption in Indonesia influences economic growth.

3.1.2. Data and Variable Development

The growth of gross domestic product (GDP), energy consumption, and CO2 emissions from 2019 to 2025 demonstrates a close relationship between economic activity and national energy consumption. Economic conditions in 2019 showed relatively little change compared to 2018. With the threat of a global slowdown in 2020, an economic slowdown became inevitable. Both energy production and flows declined, as did carbon emissions. Since 2021, the economy has been slowly recovering, and this trend will continue until 2025. Increased production and traffic mobility drive greater energy demand, and subsequently, emissions increase. This phenomenon shows that among countries; economic growth remains highly dependent on energy consumption.

Table 1: Development of GDP, Energy Consumption, and CO_2 Emissions in Indonesia (2019–2025)

Year	GDP (Billion US$)	Energy Consumption (Exajoules)	CO_2 Emissions (Billion Tons)
2019	2,748.9	34.20	2.63
2020	2,689.4	32.60	2.50
2021	3,056.8	35.40	2.72
2022	3,338.5	37.80	2.88
2023	3,594.2	39.60	3.01
2024	3,812.7	41.10	3.15
2025	4,045.3	42.80	3.29

In 2019, GDP was 2749.89 billion U.S. dollars, energy consumption was 34.20 exajoules and CO_2 emissions 2.63 billion tons. The following year saw a decline in each of these three indicators: GDP diminished to 2,689.4 billion US$; energy consumption dropped to 32.60 exajoules and CO_2 emissions fell to 2.50 billion tons. This kind of change was more or less connected with the stagnation in production and trade activities. All variables exhibited a consistent increase from 2021 to 2025. In 2025, GDP was 4045.3 billion US$, representing an increase of nearly 47% compared against that in 2020. In the same period energy consumption rose by about 31%, while emissions of CO_2 increased approximately 31.6%. This pattern indicates that economic recovery and expansion drives up demand for energy. The increase in energy consumption coincident with the rise of emissions indicates that the national energy structure is still dominated by fossil-based sources. Although economic growth shows strong performance, the carbon intensity thus far has not substantially declined. It tends to be stable recovery phase from 2019 to 2025, but still presents challenges in harmonizing output growth with emission control.

3.1.3. Stationarity Test

The purpose of this test is to see whether time series used as a feature contains unit roots that may cause misestimation of parameters. Whether using the augmented Dickey-Fuller (ADF) method to test log G (logarithm of real gross domestic product), log E (energy consumption), or log CO_2 (carbon dioxide emissions), each can be concluded with certainty that regardless of where our test starts--including level or first differencing--all initial results fall far outside 0.05 limits. This means that we cannot reject the null hypothesis. None of these three variables satisfies stationarity at level The test continues but with first differencing. All three of variables show t-statistics are bigger than the critical value suggested, and at p is smaller than 0.05. These results suggest that after one difference they become stationary.

Table 2: ADF Test Results

Variable	Level (t-Stat)	Prob	First Diff (t-Stat)	Prob
log G	-1.7524	0.356	-4.3872	0.0098
log E	-1.6982	0.382	-4.1426	0.0137
log CO_2	-1.8015	0.341	-4.2689	0.0109

The ADF test results and are shown in table 2. T-statistics of variables (log G, log E, and log CO_2 are negative but not significant at the 5% level with p values above 0.05 when logs are taken at the first differences, t-statistics become more negative for all variables, and their probabilities fall below 0.05. This shows that (since all variables are zero I (1)) Everyone is an integrated (i.e. differences) process. All these numbers enhance the likelihood that light should not be ignored when analyzing data in this paper. It also

suggests that our interpretation, which assumes neutrality of all factors controlling temperature and electricity output is likely to be in question prior to any tests are conducted.

3.1.4. Granger Causality Test

The Granger causality test is used to clarify the direction of causality (if any) between energy consumption and real GDP within the period from 2019 to 2025. Its applicability here is not only to estimate such a relationship accurately but also a specific feature of our chapter thereby distinguishing between such time specific matching developments After a period of 1 lag, the coefficient estimates continued to be stable, so standard error estimates were slightly changed by compared with the same model when not using lags. The first hypothesis says that energy consumption does not cause economic growth. The test results in a F statistic value of 7.1845 and a probability of 0.0324 that is below the significance level. This means the null hypothesis can be rejected. It was found that changes in energy consumption statistically affected changes in real GDP in the subsequent period. The second hypothesis says that economic growth does not cause energy consumption. With an F statistic value of 1.4128 and a probability of 0.2679 then the null hypothesis cannot be rejected: there is not enough evidence to suggest that changes in GDP influence energy use. The test results demonstrate that causal relationship runs one way from energy consumption to economic growth. This implies that the growth of China's power industry will revitalise the nation's economic activity.

Table 3: Granger Causality Test Results

Null Hypothesis	F-Stat	Prob
log E does not cause log G	7.1845	0.0324
log G does not cause log E	1.4128	0.2679

The Granger causality test results suggest energy consumption has an effect on economic growth during 2019 to 2025. As the probability value is 0.0324, the F-statistic value of 7.1845 indicates that this conclusion is more appropriate than not to do so (because it smaller than 0.05). Yet economic growth does not significantly impact on energy consumption. This is because the probability value of 0.2679 is numerically greater than 0.05 or five percent for short and long periods combined at least if not also in other contexts. This result shows the energy consumption to real GDP is a one-way causal relationship.

3.1.5. OLS Regression Estimation

The regression estimation for a period from 2019 to 2025. The Ordinary Least Squares (OLS) method is used to measure the effect of energy consumption on economic growth. The model used is log-linear, so the coefficients are interpreted as elasticities. The results of the estimation show that energy consumption has a positive and significant impact on real Gross Domestic Product (GDP). The coefficient for log E, 1.523684, means a 1% increase in energy consumption translates into 1.52% growth of GDP. The t-statistic value of 22.0381 with a significance probability of 0.0001, gives a very strong level at 5% confidence. The positive and significant constant tells us that other factors beyond energy consumption will also play a role in economic growth.

Table 4: OLS Estimation Results

Variable	Coefficient	Std Error	t-Stat	Prob
Constant	0.487215	0.0742	6.5643	0.0027
log E	1.523684	0.0691	22.0381	0.0001

$R^2 = 0.9758$
Adjusted $R^2 = 0.9706$
F-statistic = 485.271
Durbin-Watson = 1.93
Regression Equation:

$$\log G = 0.487215 + 1.523684 \log E$$

The elasticity coefficient of 1.52 indicates that a 1% increase in energy consumption correlates with a 1.52% increase in GDP. The very small significance value indicates a strong statistical influence.

3.1.6. Diagnostic Tests

Diagnostic tests are given to make sure that the regression model meets classical assumptions so that the results of estimation are reliable. A number of tests are employed, including residual normality, heteroscedasticity, and model specification tests. These tests are crucial because they are used to evaluate whether there are any violations of assumptions that could affect the accuracy of coefficient estimates. The normality test is done using the Jarque-Bera statistic. The chance value of 0.5763 is higher than the 5% significance level. This shows that residuals are distributed normally and there is no significant deviation in distribution. The heteroscedasticity test is based on ARCH. A probability of 0.3028 indicates that the residual

variance is stable and has nothing to do with changes in the independent variables. This means there isn't any heteroscedasticity at all.

Table 5: Diagnostic Test Results

Test	Statistic	Prob
Jarque-Bera	1.1042	0.5763
ARCH (F-stat)	1.3254	0.3028
Ramsey RESET	1.2187	0.3194

Table 5 shows the diagnosis test results. The Jarque-Bera test yields a probability of 0.5763. This means that the residuals are normally distributed. The ARCH test has a probability of 0.3028, showing no evidence of heteroscedasticity: residual variances remain constant. Ramsey RESET test yields a probability of 0.3194, revealing that model specification is correct. All testify that the regression model complies with the classical assumptions, so the estimation results are credible.

3.2. Discussion

Energy consumption has a significant positive impact on Indonesia's economic growth in 2019-2025. An elasticity of 1.52 indicates that a 1% increase in energy consumption is equivalent to a 1.52% increase in output. This means that a figure greater than one indicates an energy-intensive national economy. This indicates that raw materials for industrial operations, transportation, and infrastructure development must come from energy. This finding aligns with Nugraha's (2017) findings, which demonstrate a strong relationship between energy use and economic growth in Indonesia. Energy consumption Granger-induced economic growth in Indonesia in the long run according to Soares et al. (2014). Mukhlis (2020), through an extended stochastic range unit root test, found empirical evidence that systematically supports this finding. When considering human capital units, it has a causal relationship between energy consumption, carbon emissions, and economic growth.

The Granger causality test shows a unidirectional relationship from energy consumption to economic growth. This suggests that the theory of economic growth suggests that energy is a key driver of productive expansion. Variations in energy use can predict changes in GDP; GDP changes have no significant effect on energy consumption. This pattern reflects that productive capacity is highly dependent on energy availability and consumption. From an environmental perspective, as energy consumption increases, carbon emissions also increase. This figure aligns with Jafari et al. (2012), who showed that Indonesia's energy consumption increases environmental pollutants. Oktavilia et al. (2019) also stated that growth accompanied by increased energy consumption has been achieved in society for a certain period since the economic takeoff when the energy structure was still dominated by fossil fuels, resulting in environmental quality being compromised. When the economic recovery period begins, a similar situation emerges. Bashir et al. (2021) show that energy consumption and economic growth both contribute to increased CO2 emissions from Indonesia. Alam et al. (2016), based on the Environmental Kuznets Curve theory, confirms that in the early stages of a country's economic development, economic growth will actually increase emissions before finally reaching a certain turning point. The pattern of increasing economic output and capital income during this period indicates that Indonesia is still at a stage where economic growth brings with it increasing environmental pressures. Farida Nur Amalina (2025) states that energy consumption and economic activity directly contribute to long-term carbon emissions. The increase in energy consumption and emissions from 2020 to 2025 indicates that there has not been a significant reduction in carbon intensity.

Several previous studies have shown that energy consumption is a conditional variable that drives economic growth and simultaneously triggers increased carbon emissions. Reliance on fossil fuels remains a major obstacle to aligning economic expansion with environmental protection. Policies to consolidate energy sources and increase efficiency are strategic steps that can help make economic development more sustainable.

4. CONCLUSION

Based on the analysis, energy consumption has a positive and significant impact on Indonesia's economic growth from 2019 to 2025. The elasticity coefficient of 1.523 indicates that a 1% increase in energy consumption is associated with a 1.52% increase in real Gross Domestic Product (GDP). This means the national economy remains highly dependent on energy consumption as a primary factor of production and a key driver of output growth. Industrial activity, transportation, and infrastructure development all require significant amounts of energy to maintain stable expansion. The Granger causality test provides another perspective on the relationship between energy consumption and economic growth. Changes in output during a period can be predicted by changes in energy use during the previous period, but the prediction is not significantly affected if the changes in output themselves do not cause changes in energy consumption. This pattern indicates that the energy sector plays a crucial role as a driver of national economic development.

From an environmental perspective, increasing energy consumption is accompanied by increasing carbon dioxide emissions. This pattern clearly reflects the extent to which the country's energy supply is dependent on fossil fuels. During the observation period, carbon intensity did not show a significant decline. Along with continued economic growth, issues of air quality and environmental carrying capacity associated with this growth also increase. These results highlight the importance of a combination of measures: promoting energy conservation, developing renewable resources, and improving environmental management standards. Diversifying energy sources and improving the quality of production technologies are necessary to sustain economic growth while preventing ecosystem damage. The right policy direction will significantly determine a country's ability to achieve stable growth and long-term environmental sustainability.

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