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Research Article

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The Vector Error Correction Model (VECM) in Analyzing the Impact of Economic Growth, Population Growth, and Carbon Emissions in Indonesia

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Abstract: *Managing carbon emissions is a pivotal challenge in Indonesia due to its significant impact on climate change and environmental sustainability. This study aims to examine the dynamic relationships between economic growth, primary energy consumption, and carbon emissions in Indonesia, employing the Vector Error Correction Model (VECM) approach. Using annual data from 1996 to 2023 sourced from the World Bank, the analysis investigates both short-term and long-term effects of the independent variables on carbon emissions. The findings reveal that primary energy consumption exerts a substantial and consistent impact on increasing carbon emissions across both time horizons, whereas the influence of economic growth appears more variable and less pronounced. The Impulse Response Function (IRF) analysis demonstrates a persistent upward trend in carbon emissions following shocks from primary energy consumption. Moreover, the Variance Decomposition analysis highlights that by the 25th period, primary energy consumption accounts for 23.79% of the variance in carbon emissions, whereas economic growth contributes only 4.09%. These results underscore the urgent need for Indonesia to prioritize energy transition policies that promote the adoption of renewable energy sources and improve energy efficiency. Such measures are essential to mitigate carbon emissions and support the country's commitment to sustainable development and environmental preservation.*

Keywords*: Carbon Emissions, Economic Growth, Primary Energy Consumption.*

Introduction

The urgency of addressing carbon emissions has become a critical concern for the Indonesian government due to its impact on climate change. Indonesia has taken concrete measures to tackle carbon emissions and mitigate climate change. One of the key policies implemented is the suppression of forest and land fires (Karhutla). The government has intensified monitoring, law enforcement, and public awareness campaigns to reduce forest and peatland fires, which are significant sources of carbon emissions. Additionally, the government has enforced a moratorium on the expansion of palm oil plantations to reduce deforestation and protect forest areas. Other initiatives include the rehabilitation of forests, peatlands, and mangrove ecosystems, as well as the promotion of biodiesel and electric vehicles as environmentally friendly alternatives (Trihusodo, 2021).

Carbon emissions in Indonesia have shown a significant upward trend from 1990 to 2023. In 1990, carbon emissions were recorded at 155.08 million tons. This figure has continued to rise over time, with some minor fluctuations in certain years. By 2000, carbon emissions had increased to 281.33 million tons, indicating a substantial rise compared to previous years. The upward trend persisted, reaching 445.81 million tons in 2010. By 2020, carbon emissions had grown to 608.22 million tons, and by 2023, the figure had reached 733.22 million tons. The primary drivers of this increase are rapid economic growth and the country's primary energy consumption.

Economic growth plays a pivotal role in a nation's economy. Economic activities such as industrial processes, daily transportation, and manufacturing contribute to increased carbon dioxide emissions. To achieve an improved standard of living, higher production of goods and services is required, reflecting economic growth. However, this increase in production also leads to a rise in carbon emissions (Tahir et al., 2021). Several theories explain the relationship between economic growth and carbon emissions, one of which is the Environmental Kuznets Curve (EKC). The EKC suggests that environmental degradation increases at the early stages of economic growth but begins to decline after reaching a certain peak, forming an inverted U-shaped curve (Juliani et al., 2021). Initially, an increase in per capita income results in higher pollution levels, but after a certain threshold, pollution decreases as per capita income continues to rise (Ssekibaala et al., 2022).

Indonesia's economic growth has experienced fluctuations from 1990 to 2023. In 1990, economic growth was recorded at 7.24%. This figure experienced both increases and decreases over the years. By 2000, economic growth had declined to 4.92%. The fluctuations continued, with growth recorded at 6.22% in 2010. However, in 2020, economic growth dropped to -2.07% due to the impact of the COVID-19 pandemic. By 2023, economic growth rebounded to 5.05%. These fluctuations reflect both global and domestic economic dynamics, including changes in economic policies, investments, and market conditions.

Primary energy refers to naturally occurring, unprocessed energy sources such as crude oil, natural gas, coal, solar, wind, hydropower, and other renewable energy sources (Kementerian ESDM, 2014). Primary energy consumption plays a crucial role in national development, as energy is a vital resource that supports economic activities (Sugiyanto et al., 2017).. In Indonesia, the largest share of primary energy consumption comes from fossil fuels such as crude oil and coal (Husna, 2019). However, excessive use of fossil fuels can have adverse environmental effects, such as increasing carbon emissions, which contribute to climate change. Therefore, transitioning to renewable energy sources is essential to achieve sustainable development and reduce environmental impacts (Solikah & Bramastia, 2024).

Indonesia's primary energy consumption has increased significantly from 1990 to 2023. In 1990, primary energy consumption was recorded at 600.18 TWh. This figure continued to rise over time, with minor fluctuations in certain years. By 2000, primary energy consumption had increased to 1,163.52 TWh, reflecting substantial growth compared to previous years. The upward trend persisted, reaching 1,738.33 TWh in 2010. By 2020, primary energy consumption had reached 2,163.75 TWh, and by 2023, it rose further to 2,807.73 TWh. This increase is mainly driven by rapid economic growth, urbanization, and population growth. Additionally, increased access to energy and the development of energy infrastructure contribute to higher primary energy consumption in Indonesia. However, this trend highlights the need for energy diversification and efficiency improvements to reduce dependence on fossil fuels and mitigate environmental impacts.

The Vector Error Correction Model (VECM) is a widely used statistical method in time-series research, particularly in the fields of economics, business, and finance. The primary objective of this method is to determine causal relationships between variables in both the short and long term. VECM was first introduced by Granger and Engle to address imbalances between long-term and short-term dynamics. This method accounts for data fluctuations in long-term trends and analyzes discrepancies in dependent variables caused by imbalances among various factors (Ekananda, 2016).

Based on the background presented above, the objectives of this study are as follows:

1. To analyze the short-term and long-term influence of economic growth on carbon emissions in Indonesia.

2. To analyze the short-term and long-term influence of primary energy consumption on carbon emissions in Indonesia.

Literature Review

Carbon Emissions

Carbon emissions are the dependent variable used as a proxy for environmental degradation. Carbon emissions are a major pollutant in the composition of greenhouse gases and are measured in tons. These emissions are primarily generated from the use of fossil fuels and deforestation. High levels of carbon emissions can damage the atmosphere and disrupt economic activities, while also being a significant cause of environmental quality deterioration. The calculation of emissions includes the industrial, transportation, building, and other combustion sectors.

Economic Growth

According to the World Bank, the annual growth rate of GDP is calculated based on market prices with constant local currency, using constant 2015 prices expressed in US dollars. GDP includes the gross value added by all producers in the economy, plus product taxes, minus subsidies, without any deduction for depreciation of assets or degradation of natural resources. Economic growth is measured by changes in the volume of output or real income. The 2008 United Nations System of National Accounts provides three indicators for calculating growth: GDP volume, real gross domestic income, and real gross national income.

Primary Energy Consumption

Primary energy consumption, according to the World Bank, is measured as the total amount of energy used by a country or region over a specific period, including energy used for electricity generation, transportation, industry, and other sectors. Primary energy includes various sources such as petroleum, natural gas, coal, as well as renewable energy sources like solar, wind, and hydroelectric power. The purpose is to understand the energy needs of a country and how that energy is used across different economic sectors.

The Impact of Economic Growth on Carbon Emissions

Empirical reviews indicate varying results regarding the relationship between economic growth and carbon emissions. Based on the research by Mikayilov et al., (2018), the results show that the Environmental Kuznets Curve (EKC) hypothesis does not apply to Azerbaijan, and economic growth has a positive and significant impact on carbon emissions in the long term. Additionally, research by oleh Osadume (2021) found that economic growth has a positive and significant impact on carbon emissions in the short term, but not in the long term. This indicates that there is no EKC relationship between economic growth and carbon emissions in the region. Meanwhile, research by Espoir et al. (2023) concluded that economic growth has a negative effect on carbon dioxide emissions in the short term. This aligns with the findings by Kamanda et al. (2021), where economic growth and carbon emissions do not follow the same trend, supporting the EKC hypothesis. Furthermore, according to Acheampong (2018), except for global and Caribbean-Latin American regions, economic growth does not have a causal impact on carbon emissions.

The Impact of Primary Energy Consumption on Carbon Emissions

Empirical studies show varying results regarding the relationship between primary energy consumption, economic growth, and carbon emissions. Based on research by Afriyanti et al. (2021), primary energy consumption has a significant positive effect on economic growth in Indonesia. A 1 percent increase in primary energy consumption leads to a 0.85 percent increase in economic growth. A similar finding was presented in research by Solikah & Bramastia (2024), where primary energy consumption in Indonesia contributes to the increase in carbon emissions. On the other hand, research by Yudiartono et al. (2022) shows differing results, where in some industrial sectors, primary energy consumption does not have a significant relationship with carbon emissions.

Method

This research adopts a descriptive design with a quantitative approach to analyze the effects and forecast the relationship between Economic Growth, Primary Energy Consumption, and Carbon Emissions in Indonesia. The study leverages time-series data spanning from 1965 to 2023, allowing for a comprehensive analysis of the variables under consideration, based on the availability of adequate data. In this investigation, the independent variables examined are Economic Growth and Primary Energy Consumption, while Carbon Emissions serve as the dependent variable under analysis. This approach aims to provide valuable insights into the dynamics between these key factors within the context of Indonesia's economic and environmental landscape.

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

Variables	Symbol	Units	Data Sources
Economic Growth	ECOGR	Percent	World Bank
Primary Energy Consumption	PRIMARY	TWh	World Bank
Carbon Emissions	EMISSION	Million Ton	World Bank

Estimation will be conducted using two approaches: VAR (Vector Autoregression) and VECM (Vector Error Correction Model). VAR is employed when the cointegration test indicates no long-term relationship between the variables or when the data is not cointegrated. In contrast, if cointegration is detected, the VECM model will be applied. Generally, the estimation of the influence and relationship between the variables in this study can be interpreted as follows:

$$EMISSION_t = \beta_0 + \beta_1 ECOGR_t + \beta_2 PRIMARY_t \, \epsilon t$$

where:
$EMISSION_t$ = Carbon Emission (Million Ton)
$ECOGR_t$ = Economic Growth (Percentage)
$PRIMARY_t$ = Primary Energy Consumption (Tera-Watt Hour)
β0 = Constanta
β1,β2, β3, β4, β5 = Coefficient
ϵt = Error Term

Results and Discussion

To analyze the results of a study on a specific subject, one of the approaches applied is descriptive statistical analysis. This approach includes calculating the mean, minimum value, maximum value, and standard deviation. In this study, carbon emissions serve as the dependent variable, while the influencing variables include economic growth, population growth, and primary energy consumption. Below is a table showing data related to Carbon Emissions, Economic Growth, and Primary Energy Consumption.

Table 2. Descriptive Statistics

Variables	Co2 Emission (Y)	Economic Growth (X1)	Primary Energy Consumption (X3)
Mean	264,46	5,31	981,31
Max	737,07	10,92	2.807,73
Min	23,37	(13,13)	82,90
Std Dev	206,39	3,29	779,40

VECM Result

The cointegration equation represents the long-term relationship between the variables in the model, namely Carbon Emissions (D(Y)), Economic Growth (X1), and Primary Energy Consumption (D(X2)). Based on the results, the cointegration equation can be formulated as follows:

$$D(Y) = -0{,}004471 * X1(-1) + 0{,}543950 * D(X2(-1)) - 0{,}057729$$

Based on the analysis, the results reveal that economic growth in the previous period exhibits a negative coefficient of -0.004471, suggesting that economic growth tends to reduce carbon emissions in the long term. Conversely, primary energy consumption in the previous period has a positive coefficient of 0.543950, indicating that an increase in primary energy consumption leads to higher carbon emissions in the long run. The cointegration analysis highlights a significant long-term relationship between carbon emissions, economic growth, and primary energy consumption.

In the short-term dynamic relationship, changes in carbon emissions are influenced by various variables within the model. The estimation results demonstrate that carbon emissions in the previous period have a positive and significant effect on current carbon emissions, with a coefficient of 0.58323 and a t-statistic of 1.90356. This suggests that an increase in past carbon emissions tends to induce a rise in carbon emissions in the short term. Additionally, primary energy consumption in the previous period also has a positive and significant impact on current carbon emissions, with a coefficient of 0.724346 and a t-statistic of 1.96548. This indicates that an increase in primary energy consumption in the preceding period will contribute to higher carbon emissions in the short term.

Furthermore, changes in economic growth in the short term are influenced by carbon emissions in the previous period. The results show that past carbon emissions have a positive and significant effect on economic growth, with a coefficient of 96.62628 and a t-statistic of 2.13864. This suggests that past increases in carbon emissions can potentially stimulate economic growth in the short term. However, for primary energy consumption, the estimation results reveal that most variables influencing it in the short term are not statistically significant. For example, economic growth in the previous period has a negative coefficient of -0.003532 and a t-statistic of -1.59479, indicating that changes in past economic growth do not have a significant effect on primary energy consumption in the short term.

In summary, the short-term relationships indicate that carbon emissions are primarily influenced by past carbon emissions and primary energy consumption, while economic growth is largely driven by past carbon emissions. However, the influence of economic growth on primary energy consumption in the short term is found to be statistically insignificant, suggesting that the relationship between these two variables is more pronounced in the long run.

Impulse Response Function (IRF)

Based on the results of the Impulse Response Function (IRF) test, the following findings were obtained:

Table 2. IRF Table

Response of D(Y): Period	D(Y)	X1	D(X2)
1	0.036022	0.000000	0.000000
2	-0.015899	-0.004972	-0.014275
3	0.002264	0.006036	0.012222
4	0.003960	-0.006158	-0.011492
5	0.013790	-8.30E-05	-0.003603
6	-0.000741	-0.003536	-0.005880
7	0.004554	-0.001771	0.001444
8	0.010975	-1.45E-05	-0.004343
9	0.008558	0.002066	-0.006700
10	-0.002391	-0.000404	-0.003299
11	0.004911	-0.001051	0.001550
12	0.008941	-0.002696	-0.005727
13	0.005052	-0.001166	-0.005407
14	0.000268	-0.001089	-0.002782
15	0.006911	-0.001759	-0.001871
16	0.010253	-0.000784	-0.004738
17	0.004730	0.000150	-0.004819
18	0.001679	-0.000311	-0.001850
19	0.006023	-0.000722	-0.002118
20	0.007153	-0.001351	-0.005046
21	0.003431	-0.001310	-0.003992
22	0.003293	-0.001513	-0.002297
23	0.007323	-0.001477	-0.003298
24	0.007182	-0.000616	-0.004708
25	0.003952	-0.000349	-0.003632

Based on the table above, carbon emissions exhibit a significant impact on themselves in the short term, although the effect diminishes over time. Shocks to economic growth tend to result in a slight decrease in carbon emissions in the short term, although the magnitude of this effect is relatively small. Primary energy consumption shows a fluctuating impact on carbon emissions in the short term, but generally tends to reduce carbon emissions in subsequent periods. The negative response observed from primary energy

consumption may be attributed to a shift towards cleaner energy sources, which could result in a reduction in overall carbon emissions. However, the impact of economic growth and energy consumption on carbon emissions warrants further analysis to confirm the consistency of these patterns in the long term.

These findings underscore the importance of continued investigation into the relationship between economic growth, energy consumption, and carbon emissions, particularly as shifts in energy sources and economic structures may alter the dynamics of these variables over extended periods.

Variance Decomposition (VD)

Based on the Variance Decomposition analysis of carbon emissions, economic growth, and primary energy consumption, it is observed that in the initial period, the variation in carbon emissions is entirely influenced by its own shocks. However, over time, the contribution of carbon emissions to its own variance decreases from 100% in the first period to approximately 72.12% in the 25th period. On the other hand, economic growth provides a relatively small contribution to the variation in carbon emissions, at around 4.09% in the 25th period. Meanwhile, the contribution of primary energy consumption to the variation in carbon emissions increases significantly, rising from approximately 11.46% in the second period to about 23.79% in the 25th period. It is important to note that the standard error also increases over time, indicating a rise in the uncertainty of predicting the variance of carbon emissions. In conclusion, in the long run, the variation in carbon emissions is predominantly influenced by carbon emissions themselves and primary energy consumption, with a smaller influence from economic growth.

Conclusion

In the long term, carbon emissions are significantly influenced by economic growth and primary energy consumption. Economic growth exhibits a negative relationship with carbon emissions, suggesting that economic growth tends to reduce carbon emissions over time. Conversely, primary energy consumption has a positive and significant impact on carbon emissions, meaning that an increase in primary energy consumption will lead to higher carbon emissions in the long run.

In the short-term dynamic relationship, the estimation results indicate that past carbon emissions play a crucial role in determining current carbon emission levels. Primary energy consumption also has a positive impact on changes in carbon emissions in the short term, while economic growth does not show a significant influence on carbon emissions in the short term. Additionally, past changes in carbon emissions affect economic growth in the short term, but economic growth does not have a significant impact on primary energy consumption.

In conclusion, in the long term, the variation in carbon emissions is more strongly influenced by primary energy consumption than by economic growth. Carbon emissions are also highly dependent on their historical behavior, suggesting that efforts to reduce carbon emissions should focus on reducing primary energy consumption and transitioning to renewable energy sources. While economic growth has a smaller impact on carbon emissions, economic policies that promote the use of clean energy and energy efficiency remain critical for mitigating environmental impacts in the long term. Furthermore, the increase in standard error observed in the Variance Decomposition analysis indicates rising uncertainty in predicting the variance of carbon emissions, highlighting the need for adaptive and responsive policies that can address changing environmental conditions and energy consumption patterns.

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