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The Relationship between Gross Domestic Product, Energy Consumption, and Carbon Gas Emissions in the Implementation of a Sustainable Economy in Indonesia

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Abstract

Current economic activities cannot be avoided from the use of natural resources, especially natural resources that produce energy. The use or consumption of energy is a means to drive the industrialization of the economy as well as a means of accumulating development capital either complementary or substitute in producing outputs in the economy. The purpose of this research is to see the relationship and influence between the linkages of economic growth, energy consumption, carbon gas emissions in the implementation of a sustainable economy in Indonesia with a time frame of 1990 - 2020. The type of research used is descriptive quantitative, which is a descriptive approach with a quantitative approach. The data used is secondary data, this research is time series data research using the Vector Error Correction Model (VECM) analysis method assisted by the Eviews 12.0 analysis tool. The results found that energy consumption and carbon gas emissions have a negative effect on short-term relationships but have a positive effect and a long term relationship on Gross Domestic Product in Indonesia.

Keywords: Gross Domestic Product; Energy Consumption; Carbon Gas Emissions

1. Introduction

Environmental degradation is a very classic topic that has been discussed since the 20th century. The increasing rate of global carbon emissions is considered the main determinant of the worsening environmental quality [1]. According to environmental and climate economists, global CO2 emissions increased dramatically by 58% from 1990 to 2014. During the same period, global trade transactions also surged by 42,5%. Trade not only drives Gross Domestic Product (GDP), but also corrects market failures, strengthens environmental instruments, improves quality of life, and boosts industrial production in many countries. Indonesia's energy consumption has shown a continuously increasing trend year by year. In fact, Indonesia's total primary energy consumption grew by 16% between 2010 and 2020. In 2022, Indonesia's energy consumption reached 9.102 quadrillion BTU/trillions.

The high energy consumption in Indonesia is caused by the increasing energy demand over time. Moreover, in economic development, energy is crucial for driving sectors related to the movement of the economy in Indonesia. According to [2], energy is an input resource that supports and enhances other inputs through various processes that result in outputs. As a natural resource, energy must be utilized to the fullest extent for the prosperity of society, and its management should adhere to the principles of sustainable development. Environmentally conscious development serves as the foundation for achieving sustainable development. The high energy consumption in Indonesia can have negative impacts on the environment. At least three aspects are required for sustainable development: maintaining or increasing all forms of manufactured capital (factories and machinery), human capital (skills and experience), and environmental capital (forests, as well as air, water, and soil quality). From the energy consumption data, we can see that fuel consumption is the highest compared to other types of energy consumption. The increased use of fuel has led to a rise in CO2 emissions in Indonesia.

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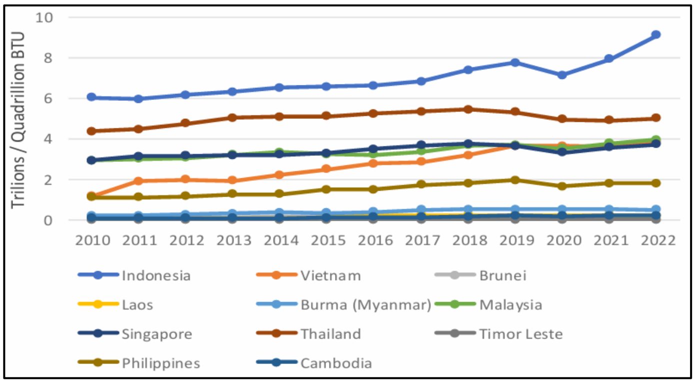

Figure 1. Energy Consumption of ASEAN Countries 2010-2022

In Figure 1, Indonesia ranks highest in CO2 emissions from energy consumption. In 2022, Indonesia's total CO2 emissions reached 685 MM tons, according to the Energy Information Administration (EIA). This figure makes Indonesia the largest CO2 emitter compared to other ASEAN countries. Looking at the impact of energy on Gross Domestic Product (GDP) highlights the importance of energy in Indonesia. According to Stern (2003), energy is also an essential component of production. If energy is considered a part of the production process, any government policy that restricts the energy supply will inevitably have a negative impact on Gross Domestic Product (GDP). Indonesia has recognized the importance of sustainable growth. This is reflected in its approach to sustainable development. The implementation of Law No. 32 of 2009 serves as the government's legal foundation for environmental conservation efforts.

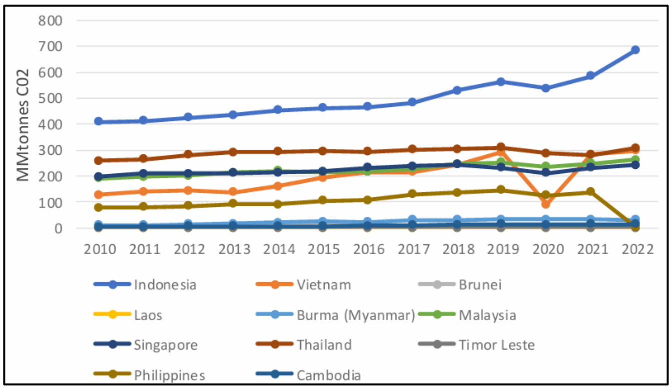

Figure 1. Total CO2 Emissions from Energy Consumption in ASEAN Countries 2010–2022

In 2023, it can be concluded that only around 32% of the 282 poor families in Sukamaju village were designated as beneficiary families. On the other hand, the remaining 68% are families that cannot be designated as Beneficiary Families due to poor families who do not meet the requirements or poor families who have received social assistance outside the Expected Family Program. According to [3], Indonesia's Gross Domestic Product (GDP) has always been positive and very stable, remaining above 5%. This figure consistently ranks among the top five GDPs in the Group of Twenty (G20) members, although this growth condition has not yet met the planned growth targets outlined in the National Budget Law. One way to measure and evaluate the impact of Gross Domestic Product (GDP) on society in the future is by internalizing the concept of green growth. The idea of "green growth" is appropriate as it refers to increasing economic activity while maintaining the efficiency of natural resource consumption and minimizing the harmful effects of economic activities on the environment (World Bank, 2012).

According to data from the Ministry of Environment and Forestry (KLHK), Indonesia's Environmental Quality Index (IKLH) score in 2023 reached 72.54. This score increased by 0.12 points compared to 2022, which stood at 72.42 points. It also surpassed the 2023 target of 69.48 points. However, based on data analysis by The Environmental Performance Index (EPI) 2022, Indonesia ranked 9th among Southeast Asian countries and 164th out of 180 countries surveyed, with a score of 28.20 points.

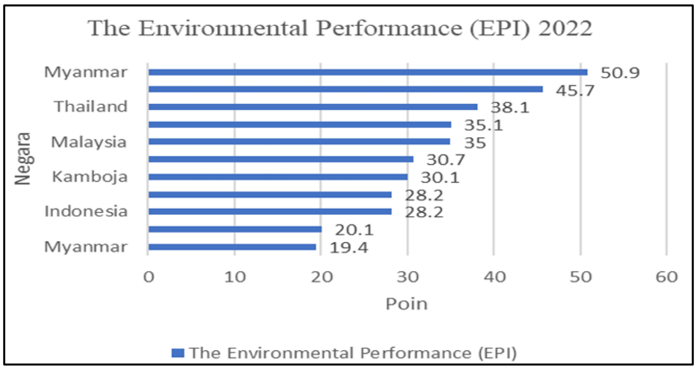

Figure 2. Environmental Index of ASEAN Countries

2. Literature Review

The term "Green Economy" was first used in 1989 in the report "Blueprint for a Green Economy," which was created by a group of leading environmental economists for the UK government. The United Nations, through one of its organizations, the United Nations Environment Programme (UNEP), has proposed the concept of "Green Economy" to support efforts to reduce greenhouse gas emissions [4]. The idea of a green economy aims to provide significant opportunities for utilizing the concept of green economy in supporting the implementation of development focused on environmental and ecosystem aspects. Regarding the green economy, there are two main objectives to achieve, according to [4]. First, the green economy seeks to create an economic concept that not only considers macroeconomic issues, particularly investments in sectors producing environmentally friendly products and services, but also focuses on the contributions of these green investments to the production of goods and services and the growth of jobs in environmentally friendly fields (green jobs). Second, the green economy aims to prepare guidelines for pro-poor green investment, which can help alleviate poverty. The primary goal is to encourage policymakers to ensure that all levels of government and the private sector participate in supporting the increase of green investments. According to Cato (Directorate of Environmental Affairs, 2013), the economy within a green economy is not aimed at continuous growth and development but rather at achieving a steady-state economy, where society becomes friendly and does not threaten other species or the planet itself. So far, there is no internationally agreed-upon definition of a green economy; however, several definitions and perspectives have been proposed by various parties. Most of them follow the definition put forward by the United Nations Environment Programme (UNEP).

Gross Domestic Product is an effort to increase production capacity to achieve additional output, measured using GDP and Regional Gross Domestic Product (RGDP) within a specific area. GDP represents the long-term increase in per capita output. The emphasis is on three aspects: the process, per capita output, and the long term. The Solow-Swan growth model indicates that sustainable growth must stem from technological advancement, which is considered an exogenous change. In the Solow-Swan model, this is merely assumed. Therefore, we need to move beyond the Solow-Swan model and utilize models outside of it, commonly referred to as endogenous growth theory. One of the fundamental models in endogenous growth theory is the AK growth model, introduced by Sergio Rebelo (1991). This theory begins with a simple production function: Yt = AKt. Where Y is output, K is the capital stock, and A is a constant that measures the amount of output produced per unit of capital, or can be considered the level of technology. This production function does not exhibit diminishing returns to capital. An additional unit of capital produces an extra A units of output, regardless of the amount of existing capital. The absence of diminishing returns to capital is a key difference between endogenous and neoclassical models. According to [5], in economic analysis, there are only two factors of production: labor (L) and capital (K). The Cobb-Douglas production function, also known as the "CD production function," was first proposed by Paul Douglas and Charles Cobb. Based on the simple CD production function, the Cobb-Douglas production function is: $EG = AK^{(\propto 1)} EC^{(\propto 2)}$. Where EG is the GDP index developed with PCA and consists of six indicators. A is represents total factor productivity, K is denotes labor capital. EC is the portion of total energy consumption used by fossil fuels. Since energy is a necessary input for GDP, EC is included in the basic Cobb-Douglas production function as an element of energy production within the relationship.

The Theory of Energy Consumption is a fundamental concept in the field of energy studies. This theory is based on the belief that energy is a limited resource, and efficient use of energy is crucial for sustainable development. It also examines how individuals or organizations utilize energy and the factors that influence energy consumption patterns. According to [6], alongside Gross Domestic Product (GDP), industries develop, and production processes become more energy-intensive. For instance, the manufacturing sector requires a significant amount of energy for processes such as production, transportation, and logistics. As a result, Gross Domestic Product (GDP) often leads to increased energy consumption. According to [7], economic variables such as energy costs have a significant impact on energy consumption patterns.

The concept of sustainable development began to emerge and was discussed by the World Commission on Environment & Development (WCED) in 1987. It was driven by concerns and the growing awareness of the public regarding the environmental impacts caused by economic development. Ultimately, the idea of sustainable development sparked discussions on environmental issues, which were no longer considered minor topics for discussion and marked a turning point in the economic actors' concern for environmental improvement. Sustainable development is a development process that encompasses social, environmental, and economic aspects, with the principle of striving to meet present needs without compromising the ability to meet the needs of future generations. Sustainable development can also be interpreted as four important values: economic sustainability, environmental sustainability, social sustainability, and sustainable development itself. From a development perspective, there are two main elements related to economic sustainability. The goals of the other sustainability elements are closely interconnected. The three main components of macroeconomic sustainability are economic efficiency, sustained economic well-being, and the enhancement of equity and welfare through structural and national reforms that ensure sustainable economic progress.

According to [1], their research indicates that the relationship between Gross Domestic Product (GDP) and environmental pollution has been analyzed using another pervasive approach known as the Environmental Kuznets Curve (EKC) theory. The EKC theory claims that environmental pollutants initially increase at early stages of Gross Domestic Product (GDP) but tend to reverse beyond a certain level of per capita income. This suggests an inverted U-shaped relationship between environmental degradation and other economic variables. According to [6], the increase in energy consumption has a positive impact on Gross Domestic Product (GDP) and a negative impact on carbon emissions. However, the impact of energy consumption on Gross Domestic Product (GDP) is greater than its adverse effects on the environment. According to [8], observed that most developed countries have decoupled their CO2 emissions from their Gross Domestic Product (GDP) and found that the relationship between CO2 emissions and energy consumption is increasing, suggesting that these countries maintain a consumption pattern that is still carbon-intensive.

According to [9], it was found that there is only a unidirectional relationship between GDP and CO2, meaning that GDP serves as a control variable for CO2, although the overall relationship is positive. Based on [10], it is shown that Gross Domestic Product (GDP) increases alongside CO2 emissions up to a certain threshold level, after which CO2 emissions decline. According to [9], it was found that there is a bidirectional and positive relationship between energy consumption and GDP. Kuznetsova & Kravchenko (2020), who studied the energy conditions in China, also indicated a strong relationship between a country's economy and its energy consumption. However, what distinguishes them is the pattern and form of consumption, whether it focuses on internal consumption or promotes energy production for external consumption, or in other words, exports to other countries.

3. Methods

The type of research used is quantitative research with an associative approach, the purpose of this research is to analyze the relationship and impact between energy consumption (EC) and carbon dioxide (CO2) emissions on Gross Domestic Product (GDP) in Indonesia over the period from 1990 to 2020. The exogenous variables in this study include Energy Consumption (EC) and Carbon Dioxide Emissions (CO2), while the endogenous variable in this research is Gross Domestic Product (GDP). This study uses secondary data, which was obtained from the Central Statistics Agency (BPS), the World Bank, the Energy Information Administration (EIA), Our World in Data, and several other websites that support this research. This study is a time series research using the Vector Error Correction Model (VECM) analysis technique, assisted by Eviews 12.0 analysis software.

4. Results and Discussion

The first stage that must be undertaken to obtain VECM estimates is the stationarity test of each variable, both exogenous and endogenous variables. As explained above, stationary data is needed to influence the results of the VECM estimation test. A regression equation with non-stationary variables will produce what is called a spurious regression. In this study, to detect whether each variable's data is stationary or not, the ADF test (Augmented Dickey Fuller) is used. The stationarity test results of each variable can be shown in the following table.

Table 1. Unit Root Test

Variable	Level		First Difference	
	ADF	Prob	ADF	Prob
GDP	1.900037	0.9997	-2.993656	0.0473
EC	-0.504342	0.8769	-5.667554	0.0001
CO2	-0.428512	0.8917	-4.55836	0.0011

Source: Researcher Processed Data (2024)

Based on table 1, shows the results of the unit root test for three variables: GDP, energy consumption (EC), and carbon dioxide emissions (CO2). For the GDP variable, the ADF value is 1.900037 with a probability of 0.9997. This probability is very high, well above the significance level of 0.05, which means the null hypothesis is rejected that GDP has a unit root at level. This indicates that GDP is not stationary at level. The energy consumption (EC) and carbon dioxide emissions (CO2) variables also exhibit non-stationarity at the level. After taking the first difference of these variables, the test results show significant changes. From the unit root test results, it can be concluded that the three variables (GDP, energy consumption, and carbon dioxide emissions) are not stationary at their original level. However, after first differencing, these three variables become stationary. This means that the econometric model involving these variables should consider using the first difference to ensure that the data used in the analysis is stationary, in order to obtain valid results.

A common problem in stationarity tests is determining the optimal lag. In both VAR and VECM approaches, the length of the lag used can be sensitive. The determination of the lag length is intended to understand the duration of the influence of one variable on the past and other endogenous variables for making new policy decisions.

In the table 2, it can be seen that the lag test provides different lags. It shows that with the criteria of LR, FPE, AIC, SC, and HQ, the suggested candidate is lag 1, as indicated by the asterisk. Therefore, the recommended optimal lag is lag 1. The determination of lag 1 is because the lag or delay is the time span involved in economic policy-making, specifically the time between a 1-year delay from the initial policy to determine new policies for detecting economic problems, implementing solutions, and realizing outcomes in the economy.

Table 2. Optimal Lag Test

Lag	Logl	LR	FPE	AIC	SC	HQ
0	-665.6469	NA	3.42e+19	53.49175	53.63802	53.53232
1	-578.6819	146.1012*	6.73e+16*	47.25455*	47.83961*	47.41682*
2	-576.2334	3.525824	3.18e+17	47.77867	48.80253	48.06265
3	-574.3002	2.319854	2.29e+17	48.34402	49.80667	48.74969
4	-570.5948	3.557195	4.25e+17	48.76758	50.66903	49.29496
5	-577.6772	9.300629	4.51e+17	48.45418	50.79442	49.10326
6	-535.9419	10.43294	3.30e+17	47.43536	50.21439	48.20614

Source: Researcher Processed Data (2024)

The model stability test is considered stable if the modulus value is less than one. In this research data, the modulus values of all roots are less than one, which results in the model being stable at that lag.

Table 3 Model Stability Test

Root	Modulus
0.337367	0.227367
0.020304 – 0.035194i	0.040630
0.020304 + 0.035194i	0.040630

Source: Researcher Processed Data (2024)

In the model stability estimation test, it is indicated that Gross Domestic Product (GDP) and the influencing variables have a strong modeling and impact in both the short and long term. A properly stabilized model will yield strong predictions and forecasts due to the feedback effects when the variables experience increases or decreases, and it is hoped that the predictions and forecasts will remain valid in the future. Thus, the results can provide a valid analysis of the Impulse Response Function (IRF) and Variance Decomposition (VDC).

The next test that needs to be conducted is the cointegration test. The cointegration test is performed to determine the long-term equilibrium among the variables being

Table 4 Cointegrattion Test

Hypothesized No. of CE (s)	Eigenvalue	Trace Satastic	0.05 Critical Value	Prob.**
None*	0.415466	32.83354	29.79707	0.0217
At most 1*	0.379343	17.79918	15.49471	0.0221
At most 2*	0.146785	4.443858	3.841465	0.0350

Source: Researcher Processed Data (2024)

The results of the cointegration test for lag one, based on the table above, indicate that the trace statistic value is greater than the critical value at a significance level of 0.05, and it can be seen that the probability values are less than 0.05, namely 0.0217, 0.0221, and 0.0350. Therefore, the results of this cointegration test show that the analysis used for this study is VECM.

The Granger causality test is intended to determine the cause-and-effect relationship between each exogenous variable and the endogenous variable. In this study, the causality test is more focused on the interrelationship between Gross Domestic Product (GDP), energy consumption, and carbon emissions. The significance level used in this Granger causality test is set at a confidence level of 0.05 (5 percent), with a lag length of up to the second lag, according to the optimal lag length testing that has been conducted. The results of the Granger causality test are shown in the table as follows.

The probability values in the Granger causality study need to be carefully considered. If the probability value is greater than 0.05 or the significance level is 5 percent, it can be concluded that there is no causality between the variables. Conversely, if the probability value is less than 0.05 or the significance level is 5 percent, it indicates that there is a relationship and influence. From the results of the Granger causality test above, it can be seen that none of the variables have a causal relationship among them. This occurs in Indonesia, where Gross Domestic Product (GDP), energy consumption, and carbon emissions do not have any influence or causal relationship.

Table 5 Causality Test

Null Hypothesis:	Obs	F-Statistic	Prob.
EC does not Granger Cause GDP GDP does not Granger Cause EC	30	0.02094 1.90442	0.8860 0.1789
CO2 does not Granger Cause GDP GDP does not Granger Cause CO2	30	2.65354 1.32033	0.1149 0.2606
CO2 does not Granger Cause EC EC does not Granger Cause CO2	30	2.78690 2.23745	0.1066 0.1463

Source: Researcher Processed Data (2024)

After finding a cointegration relationship among the five variables, if a cointegration relationship exists among the research variables, the estimation is conducted using VECM. Conversely, if there is no cointegration among the five variables, the estimation is carried out using VAR. An important procedure in estimating the VECM equations is the selection of the optimum lag. The lag length test indicates that the optimum lag obtained is lag 1; therefore, the estimated equation is VECM using lag 1.

Table 6 Short Term

Variabel	Koefisien	t-statistik	t-tabel	Ket
CoinEq1	0.161137	1.35136	2.048407	Tidak sig
D(GDP(-1),2)	-0.512665	-1.33481	2.048407	Tidak sig
D(EC(-1),2)	-538E+09	-1.52372	2.048407	Tidak sig
D(CO2(-1),2)	-7.09E+11	-1.40093	2.048407	Tidak sig

Source: Researcher Processed Data (2024)

Based on Table 6, it can be explained that the estimation of energy consumption has a negative but insignificant effect. In the short-term estimation, it shows a t-statistic of -1.52372, which is less than the t-table value of 2.048407 at a 5 percent significance level, with a coefficient value of -538E+09. The results of the short-term estimation indicate that there is an indication of a negative effect of energy consumption on GDP, but this effect is not statistically significant. This suggests that in the short term, energy consumption may not be a good indicator of Gross Domestic Product (GDP), as it is influenced by many other factors and short-term fluctuations. The estimation of carbon emissions has a negative and insignificant effect. In the short-term estimation, it shows a t-statistic of -1.40093, which is less than the t-table value of 2.048407, with a coefficient of -7.90E+11. Carbon emissions may not directly reflect Gross Domestic Product (GDP) in this short period, as industries may adjust their production or technology to reduce carbon emissions, which can temporarily lower emissions without significantly reducing GDP.

Table 7 Long Term

Variabel	Koefisien	t-statistik	t-tabel	Ket
D(EC(-1))	4.17E+10	3.90083	2.048407	Sig
D(CO2(-1))	4.81E+12	4.41870	2.048407	Sig

Source: Researcher Processed Data (2024)

Based on Table 7, it can be explained that the long-term estimation results for the energy consumption variable have a positive and significant effect on the GDP variable at a significance level of 5 percent, with a t-statistic of 3.90083, which is greater than the t-table value of 2.048407, and a coefficient of 4.17E+10. This means that every one-unit increase in energy consumption in the long term will increase GDP by 4.17E+10. This indicates a direct relationship where an increase in energy consumption contributes to an increase in GDP. Overall, the long-term estimation results suggest that energy consumption plays a very important role in determining the level of GDP to promote sustainable Gross Domestic Product (GDP). This is also consistent with several previous studies that found that energy consumption and GDP have a positive influence on future Gross Domestic Product (GDP). Furthermore, the endogenous growth theory states that investments in energy infrastructure and energy technologies can enhance productivity and innovation, which in turn drives Gross Domestic Product (GDP). Expenditures for research and development in the energy sector can also lead to innovations that improve efficiency and reduce production costs.

The long-term estimation results for the carbon emissions variable indicate a positive and significant effect on the GDP variable at a significance level of 5 percent, with a t-statistic of 4.41870, which is greater than the t-table value of 2.048407, and a coefficient of 4.481E+12. This means that every one-unit increase in carbon emissions will increase GDP by 4.481E+12. This suggests a direct relationship where an increase in carbon emissions contributes to an increase in GDP. This finding is also consistent with endogenous growth theory, which posits that investments in energy infrastructure and industries that generate carbon emissions can enhance productivity and innovation, thereby driving Gross Domestic Product (GDP).

The results of this test are presented in a graph, where the response graph indicates the positive or negative responses of the variables used. The results of IRF can be seen as follows:

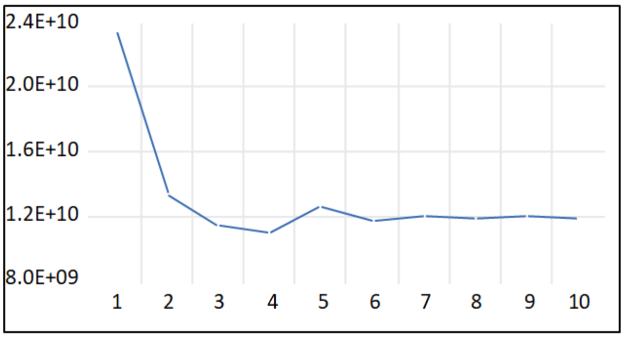

Figure 4. IRF of GDP to Shock GDP

The interpretation of the Impulse Response Function (IRF) graph for GDP above the horizontal line shows a fluctuating nature that has a positive impact. In the first period, it stands at 2.35E+10, then declines in the second period to 1.35E+10. In the third period, it experiences a slight decrease to a level of 1.15E+10, followed by a recovery to 1.26E+10 in the fifth period. By the tenth period, the IHSG reaches its own equilibrium point in response to the given shock. This is because GDP influences itself, allowing it to control the impact it generates.

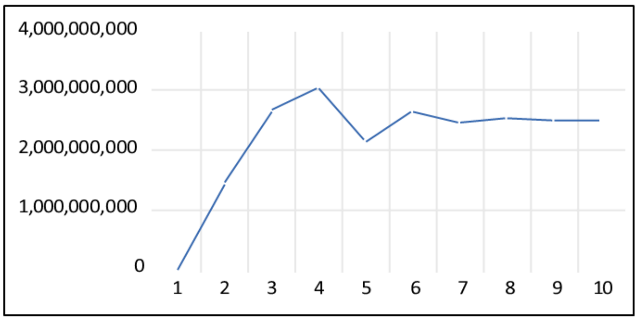

Figure 5. IRF of GDP to Shock EC

The analysis of the graph above indicates that the trend of the shock from the energy consumption (EC) variable is positively impactful. In the second period, the shock is recorded at 1.46E+09, meaning that an increase of one unit in energy consumption results in an increase in GDP of 1.46E+09. This represents the lowest point of the shock. In the fourth period, the shock reaches its highest point at 3.06E+09. Subsequently, from the fifth to the tenth period, the shocks are positioned at a positive equilibrium level. This can be observed as the line is above the horizontal line, with an average shock of 2.47E+09. The analysis of the graph above indicates that the trend of the shock from the carbon emissions (CO2) variable is positively impactful. In the second period, the shock recorded is 5.87E+08, meaning that an increase of one unit in carbon emissions results in an increase in GDP of

5.87E+08. In the third period, the shock reaches its highest point at 5.97E+09. Subsequently, from the fourth to the tenth period, the shocks are positioned at a permanently positive equilibrium level. This is evident as the line is above the horizontal line, with an average shock of 3.67E+09.

The Variance Decomposition model is used to provide a detailed explanation of how changes in one variable are influenced by changes in other variables. The changes occurring in the variables are indicated by changes in error variance. The results of the Variance Decomposition test can be seen in the Table 8.

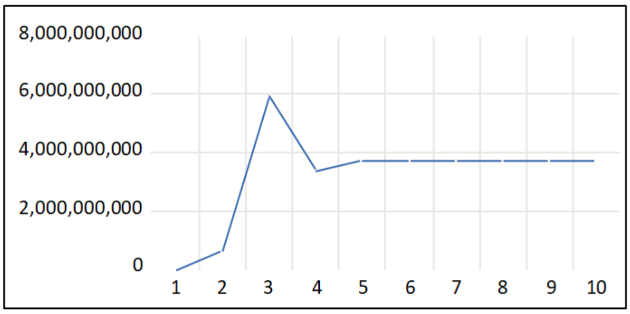

Figure 6. IRF of GDP to Shock CO2

Table 8 Variance Decomposition of GDP

Period	S.E.	D(GDP)	D(EC)	D(CO2)
1	2.35E+10	100.0000	0.000000	0.000000
2	2.71E+10	99.66454	0.288580	0.046883
3	3.01E+10	94.99905	1.033639	3.967309
4	3.24E+10	93.73415	1.781384	4.484470
5	3.51E+10	93.12911	1.899801	4.971092
6	3.73E+10	92.43340	2.187273	5.379328
7	3.95E+10	91.95247	2.340757	5.706778
8	4.15E+10	91.53086	2.494417	5.974723
9	4.34E+10	91.20482	2.608227	6.186955
10	4.53E+10	90.92170	2.708092	6.370208

Source: Researcher Processed Data (2024)

From table 8, it can be explained that in the first period, GDP is significantly influenced by the shock of GDP itself, accounting for 100 percent. In the second period, the energy consumption (EC) variable contributes 0.2%, while in the fourth period, its contribution increases to 1.7%. In the following periods up to the tenth period, this contribution continues to rise annually, with the tenth period providing a contribution of 2.7%. The analysis of the Variance Decomposition shows that in the second period, the carbon emissions (CO_2) variable contributes 0.04%. In the third period, its contribution increases to 3.9%. This upward trend continues in the subsequent periods up to the tenth period, where the contribution reaches 6.3%.

5. Results

Based on the research results, the following conclusions can be drawn: According to the short-term VECM test, the estimated energy consumption variable has a negative but insignificant effect. In contrast, the long-term estimation results indicate that the energy consumption variable has a positive and significant effect on the Gross Domestic Product (GDP). Similarly, the short-term estimation results for the carbon emissions variable show a negative but insignificant effect; however, the long-term estimation reveals that carbon emissions have a positive and significant impact on GDP. Furthermore, the Impulse Response Function (IRF) test, which examines shocks to each variable, demonstrates that both energy consumption and carbon emissions maintain a permanent positive impact from period 1 to period 10.

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