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The Influence of Carbon Emission and Monetary Instruments on Economic Growth in Indonesia

Atika Fatimah and Ismadiyanti Purwaning Astuti
Universitas Amikom Yogyakarta, Indonesia
Corresponding author: atika.fatimah@amikom.ac.id

Abstract

Over the past three decades, Indonesia's economic growth has been quite fluctuating, with two major crises causing deep recessions and severe economic contractions. This study aimed to examine the effects of carbon emissions and monetary policy instruments on Indonesia's economic growth, proxied by Gross National Income (GNI) growth data. The carbon emission variable consisted of emissions from waste, emissions from transportation, and electricity generation from renewable energy, while the monetary policy variable comprised two independent variables, namely lending interest rates and portfolio investments. This study used secondary time-series data obtained from the World Bank and Statistics Indonesia (BPS), covering the period from 1994 to 2023. The analysis method was the Error Correction Model (ECM). The results of the long-run study found that carbon emissions from waste and lending interest rates had a negative and significant influence on economic growth, while carbon emissions from transportation, electricity generation from renewable energy, and portfolio investments had no effect on economic growth. If the government aims to promote economic growth, carbon emissions from waste and lending interest rates should be reduced. Reduced carbon emissions from waste will reduce pollution, thereby improving the quality of health and human resources, increasing productivity, and ultimately fostering economic growth. In the short run, the results of the study indicated that portfolio investments had a positive and significant effect on economic growth, while lending interest rates had a negative and significant effect on economic growth. On the other hand, carbon emissions from waste, carbon emissions from transportation and electricity generation from renewable energy did not have an effect on economic growth. An increase in carbon emissions from transportation may reflect that people in developing countries such as Indonesia use vehicles for productive activities, thereby fostering economic growth. Similarly, higher portfolio investments increase access to capital, which will increase profits, thereby fostering economic growth. On the other hand, lower lending interest rates in the short run encourage borrowing for both consumption and production, thereby fostering economic growth.

Keywords: carbon emission; monetary instruments; economic growth; error correction model
JEL Classification: E52; O44; Q43

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A. INTRODUCTION

Economic growth reflects the continuous improvement in the economic performance of a country. It is an increase in a country's ability to produce goods and services over a certain period of time. Over the past three decades, Indonesia's economic growth has been quite fluctuating, with two major crises causing deep recessions and severe contractions.

As shown in Figure 1, Indonesia's economic growth contracted by 13.13% in 1998 during the monetary crisis and by 1.72% in 2020 due to the pandemic. Overall, Indonesia has experienced four economic phases during 1994–2023: the pre-crisis and monetary crisis phase (1994–1999), the recovery and commodity phase (2000–2014), the stable growth and COVID-19 pandemic phase (2015–2020), and the post-pandemic phase (2021–2023).

During 1994–1996, Indonesia's economy grew rapidly, exceeding 7% annually, supported by strong foreign investments and exports. However, in 1998,

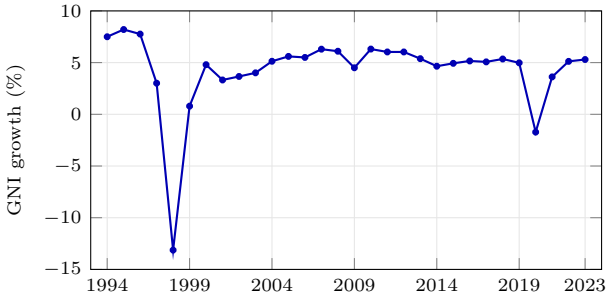

Figure 1. Indonesia's Economic Growth Chart in 1994–2023

Source: BPS, 2024.

the economy severely contracted by 13.13% due to the collapse of the rupiah during the monetary crisis. This was the deepest contraction in Indonesia's modern economic history.

In the 2000s, the economic growth returned to stability at around 4% to 6% annually. Under the administration of President Susilo Bambang Yudhoyono, the economic growth reached 6.35% in 2007. When the global financial crisis hit in 2008–2009, Indonesia still experienced a positive growth of above 4.5% because of strong domestic consumption.

From 2015 to 2019, Indonesia's economic growth remained relatively stable at around 5% annually. Unfortunately, mobility restrictions due to the pandemic pushed Indonesia into a second recession, with growth contracting by 1.72% due to the spread of COVID-19 and the implementation of the large-scale mobility restriction policy, which disrupted economic activities across sectors.

As an economic recovery effort, the Indonesian government introduced a number of economic policies, which resulted in economic growth in the second quarter of 2021, reaching 7.08%. However, growth declined in the third quarter of 2021 to 3.53% due to geopolitical tensions, inflation risks, and climate change. In fact, Indonesia's economic growth continued to experience a slowdown. Even by the fourth quarter of 2023, the economic growth rate was 5.04%, but it was still considered insufficient to reflect good performance. According to the Director of the Center of Economic and Law Studies (CELIOS), Bhima Yudhistira, household consumption has not made a maximum contribution to GDP even though the government has revoked the Enforcement of Community Activity Restrictions (PPKM). This indicates several obstacles to household spending, including high inflation in the first quarter of 2023, an increase in lending interest rates, and uncertainty in the global economy (Madrim, 2023).

Many factors have contributed to Indonesia's fluctuating economic growth performance over the past three decades, including government policies, particularly economic and environmental policies. Economic policies are divided into two, namely fiscal and monetary policy. Fiscal policy is a government policy related to state revenues and expenditures as outlined in the State Budget (APBN). One of its purposes is to control economic conditions to help achieve certain goals, such as fostering economic growth.

On the other hand, monetary policy is a policy carried out by the Central Bank to regulate the money supply and interest rates. Effective regulation of money supply is crucial because excessive liquidity can significantly increase purchasing power. Unless it is accompanied by sufficient productive capacity (supply), goods will become scarce, thereby triggering inflation. Rising inflation then reduces people's purchasing power and slows economic growth. Therefore, monetary policy is crucial to maintain a balance between the money supply, demand, and availability of goods or services so the economy remains healthy and stable.

There are two types of monetary policy: expansionary monetary policy (easy money policy) and contractionary monetary policy (tight money policy). Expansionary monetary policy aims to increase the money supply in the economy. Its main objectives are to foster economic growth, stimulate business activities, and reduce unemployment by lowering interest rates and buying securities such as bonds. However, this policy may also increase inflation, so this policy is implemented when the economy is sluggish, such as during a recession, to stimulate economic activities. On the other hand, contractionary monetary policy aims to reduce the money supply to control inflation by raising interest rates and selling securities (Lianovanda, 2025). When the money supply is limited, the demand for goods and services declines, thereby stabilizing the prices of goods or services and preventing inflation.

In Indonesia, monetary policy has undergone a structural transformation in response to various crises over the past three decades. There are three phases of monetary policy evolution in Indonesia: the crisis response and inflation targeting phase (1990s–2000s), the policy mix and sustainable finance phase (2010s), and the green macroprudential and modern monetary policy phase (2020s).

Following the 1997 crisis, Bank Indonesia focused entirely on restoring rupiah exchange rate stability and controlling inflation through the implementation of the Inflation Targeting Framework (ITF). Monetary policy purely used conventional instruments, including the BI rate, open market operation, and minimum reserve requirements. However, environmental issues had not yet been integrated into the central bank's policy framework.

In 2010, Bank Indonesia recognized that climate change could pose systemic risks to financial stability through physical risks (such as disasters) and transition risks. Bank Indonesia started aligning its policies with those of the Financial Services Authority (OJK), which introduced phase I of its Sustainable Finance Roadmap in 2014 to encourage banks to channel environmentally friendly financing (green banking).

In 2020, Bank Indonesia introduced a green policy

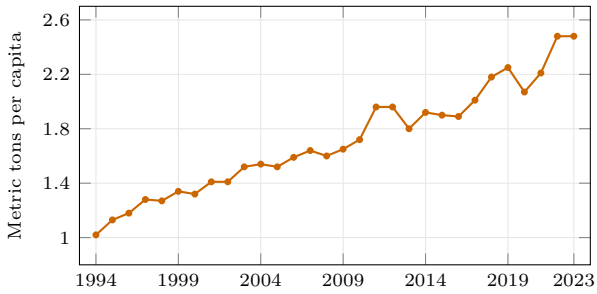

Figure 2. Carbon Emissions (Metric Tons Per Capita)

Source: My Data Jungle, 2023.

mix which focused on three main pillars: strengthening green macroprudential policies, deepening green financial markets, and developing green MSMEs. The concrete instruments implemented included loan-to-value (LTV/FTV) relaxation, macroprudential liquidity policy, financial market deepening, and real-sector support initiatives. Under the LTV/FTV relaxation mechanism, down payments were eliminated of up to 0% for electric vehicle and green property loans to accelerate the transition to low-emission transportation and housing. Macroprudential liquidity policy is a banking liquidity incentive that channels credit to the green downstream sector and green MSMEs. Financial market deepening provides assistance for the issuance of Green Bonds and Green Sukuk as alternative low-cost financing instruments for green infrastructure projects. The real-sector support initiative includes the launch of a green calculator application to help corporations and MSMEs measure their carbon footprints.

The next factor is carbon emissions, which serve as a proxy indicator of environmental conditions because they are one of the largest contributors to air pollution and are dangerous if left unaddressed. Carbon emissions refer to the release of carbon dioxide or exhaust gases into the atmosphere, which contribute to climate change due to fossil fuel combustion and global warming (Farah, 2024). There are several types of carbon emissions. One type is carbon emissions from waste in the form of greenhouse gases that are released into the atmosphere through waste management and disposal activities. The next type is carbon emissions from transportation, which are generated by fossil fuel combustion in vehicles such as cars, motorcycles, planes, and ships, contributing to climate change and air pollution. These emissions include CO_2, NO_x, and fine particles that negatively impact health and the environment.

Since the 1990s, carbon emissions in Indonesia have generally shown an increasing trend due to economic growth and an increase in fossil fuel consumption.

The evolution of Indonesia's carbon emissions can be divided into three main phases: the 1990s (early industrialization), the 2000s–2010s (commodity boom and deforestation), and the 2020s (energy transition). At the beginning of industrialization, fossil fuel consumption began to increase steadily from around 1,000 TWh, along with the rapid growth of the manufacturing sector before the 1997 crisis. During this phase, emissions were dominated by land-use change and the growing dependence on coal.

Emissions have increased significantly due to deforestation and periodic forest fires. In 2019, emissions from the fossil fuel sector alone reached 581 $MtCO_2$. According to EDGAR data, Indonesia ranks seventh among the world's largest greenhouse gas emitters, with total emissions of around 1.24 gigatons of CO_2e. Currently, the energy and transportation sectors dominate emissions, with a proportion of 50.6% of the total emissions (Madyan, 2024).

Indonesia, as a developing country, has realized the impact of carbon emissions on the environment, so this country has promoted electricity generation from renewable energy sources such as solar, wind, hydropower, and bioenergy. Solar power plants (PLTS) convert solar energy into electricity using solar panels installed on the roofs of buildings and open land. Wind power plants (PLTB) use wind power to drive turbines and generate electricity. Meanwhile, hydroelectric power plants (PLTA) utilize the potential energy of falling water to drive turbines and generate electricity. These hydropower plants are generally built near rivers or dams. Meanwhile, biomass power generation uses organic waste, especially agricultural and plantation waste, to produce electricity.

According to the Environmental Kuznets Curve (EKC) theory, carbon emissions are associated with economic growth and environmental quality globally (Rizki & Anggaeni, 2022). Panayotou (1993) and Chirilus and Costea (2023) state that the rate of environmental degradation according to the Environmental Kuznets Curve (EKC) will increase as income increases. Dellink et al. (2017) in their research stated that, without additional mitigation policies, climate change is projected to reduce global GDP by 1–3.3% by 2060. This is due to declining agricultural productivity, rising sea levels, heat stress which affects workforce productivity, increasing health-related costs, and changes in energy and tourism demand. Among other sectors, the agricultural sector experienced the greatest loss with a decline in global added value of up to 9% by 2060, followed by the tourism sector. The largest economic losses are associated with a decline in capital and labor productivity due to heat stress.

Based on the problems described above, this study addresses the following research questions:

1. How do carbon emissions from waste affect economic growth in the long and short run?
2. How do carbon emissions from transportation affect economic growth in the long and short run?
3. How does electricity generation from renewable energy affect economic growth in the long and short run?
4. How do lending interest rates affect economic growth in the long and short run?

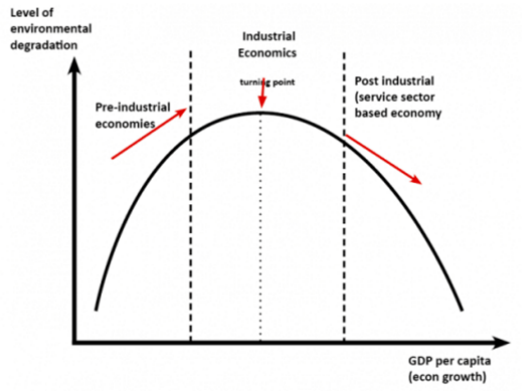

Figure 3. Environmental Kuznets Curve

5. How does portfolio investment affect economic growth in the long and short run?

This research is expected to contribute to the literature on green economy, green finance, environmental economics, and monetary economics. Its novelty lies in examining the effects of carbon emissions and monetary policy on economic growth in the short and long run using the Error Correction Model (ECM). Most Indonesian monetary studies focus primarily on price stability (inflation) and exchange rate stability. Relatively few studies have analyzed how Bank Indonesia can use monetary policy instruments, such as interest rate adjustments or macroprudential policies, to discourage high-emission activities (from transportation/waste) while incentivizing green financing. Besides, the waste sector has received little attention in macroeconomic and monetary studies, despite its significant contribution to emissions (around 8% of the total according to UGM) (Halizah & Furqon, 2024). Existing studies often focus solely on the energy sector or industry in general.

B. LITERATURE REVIEW

The theory underlying this research is the Environmental Kuznets Curve (EKC), which explains the relationship between economic growth and environmental degradation, including carbon emissions (Firmansyah, 2021). The Environmental Kuznets Curve is represented by an inverted U-shaped relationship, in which the Y axis is the environmental damage or carbon emissions generated, while the X axis is the per capita income. This inverted U-shape means that in the early stages of economic growth, carbon emissions will increase along with increased economic activity. However, once a certain point is reached, namely a higher level of per capita income, carbon emissions tend to decrease due to increased environmental awareness, the application of clean technology, and stricter policies related to the environment. The Environmental Kuznets Curve is presented in Figure 3.

Several previous studies have analyzed the effects of green finance on economic growth from a macroeconomic perspective. Wen et al. (2025) examined the impact of the green economy on economic growth in 22 European Union (EU) member states. The results show that the green economy plays a crucial role in accelerating the transition to sustainable energy, reducing carbon emissions, and fostering economic growth, while investment in renewable energy drives GDP expansion, attracts foreign capital, and improves environmental quality. In addition, foreign direct investment (FDI) and trade liberalization emerge as key drivers of sustainability to integrate green finance policies with international economic strategies.

In addition, Qin et al. (2024) examined the relationship between China's mining regulations, resource utilization, and environmentally friendly policies and their overall impact on economic growth. The results show that China's economic growth has benefited significantly from mineral-intensive sectors and that eco-friendly measures are urgently needed to slow environmental degradation. The results of this study further highlight the important role of green projects in fostering economic growth.

Versal and Sholoiko (2022) examined the role of green finance in promoting macroeconomic growth in developing countries. This study shows that energy investment results in a less significant impact on economic performance at the national and regional levels. However, it plays an important role in creating employment opportunities and attracting foreign investment. Similarly, Wang et al. (2022) examined the macroeconomic impacts of the integration of green finance with renewable energy investment. The results of the study indicate that green finance can stimulate renewable energy investment, thereby fostering economic growth through job creation, energy security, and increased productivity.

The positive effect of green finance on economic growth is associated with the use of energy-efficient processes, thereby reducing long-term production costs and enhancing economic competitiveness. Green finance and economic growth are dynamic, with financial instruments serving as drivers of the transition to a more stable, low-carbon economy in the long run. Green finance policies such as tax incentives and clean energy subsidies may attract investment in environmentally friendly infrastructure and renewable energy projects. In addition, sustainable development can be achieved through the development of an environmentally friendly post-industrial society and horizontal economic relationships (Albekov et al., 2017).

Furthermore, monetary policy is an instrument for maintaining macroeconomic stability and stimulating economic growth. Most previous studies have shown that monetary policy has a positive effect on economic growth, especially in countries with financially advanced economies and relatively independent central banks. For example, Abille and Mpuure (2020) found that monetary policy has a positive and significant effect on economic growth in Ghana, thereby potentially generating sustainable growth. The government should

grant autonomy to the central bank to implement effective monetary policy to support sustainable economic development.

The effect of monetary policy on economic growth is formulated in Irving Fisher's Quantity Theory of Money, which lays the foundation for the relationship between monetary policy instruments and macroeconomic variables such as inflation and economic growth. Monetary policy is an important determinant of growth in both the short and long run, although the exact relationship remains ambiguous (Twinoburyo & Odhiambo, 2018). The relationship between monetary policy and economic growth is largely explained by the size and competition within the financial sector, the monetary policy regime, the exchange rate, and the degree of openness.

Economic growth has been one of the most important goals and a key priority for governments and policymakers for decades (Srithilat et al., 2022). The literature on the impact of monetary policy is divided into two schools of thought: the Keynesian school and the monetarist school. Monetarists believe that money supply can only influence real economic variables in the short run by increasing aggregate demand and employment. Meanwhile, Keynesians generally reject the monetarist view and argue that changes in the money supply influence interest rates and investment in the economy, driven by long-term changes in real output.

C. RESEARCH METHODS

This study used a quantitative approach with secondary data obtained from the World Bank and Statistics Indonesia (BPS). The secondary data consisted of time-series data of 30 years, from 1994 to 2023. The analysis method was the Error Correction Model (ECM) to examine the relationship between two or more variables by considering the correlation between variables and the possibility of measurement errors.

$$\Delta Y_t = \alpha_0 + \alpha_1 \Delta X_t + \lambda e_{t-1} + \epsilon_t \tag{1}$$

where ΔY_t denotes changes in the dependent variable (short run); ΔX_t denotes changes in the independent variable (long run); α_1 is the short-run coefficient; e_{t-1} is the error correction term; λ is the error correction coefficient ($0 < |\lambda| < 1$); and ϵ_t is the error term.

The ECM model was introduced by Sargan and popularized by Engle and Granger. This ECM model has several uses, but the most important use in econometrics is to address non-stationary time-series data and the problem of spurious regression. The ECM aims to determine the long-run effects of the variables studied on the dependent variables (Iladini & Agustina, 2020).

ECM is used to correct short-run imbalances for the long run. The Ordinary Least Squares (OLS) multiple regression model analyzes the long-run relationship between independent variables and the dependent variable, while the ECM analyzes the short-run effect of independent variables on the dependent variable. Therefore, the models used in this study are as follows.
Multiple regression model:

$$\begin{aligned} GNI_t = {} & \alpha_0 + \alpha_1 EWA_t + \alpha_2 ETR_t \\ & + \alpha_3 EPR_t + \alpha_4 IPO_t \\ & + \alpha_5 LIR_t + \varepsilon_t \end{aligned} \tag{2}$$

Error Correction Model (ECM):

$$\begin{aligned} \Delta GNI_t = {} & \alpha_6 + \alpha_7 \Delta EWA_t + \alpha_8 \Delta ETR_t \\ & + \alpha_9 \Delta EPR_t + \alpha_{10} \Delta IPO_t \\ & + \alpha_{11} \Delta LIR_t + \varepsilon_t \end{aligned} \tag{3}$$

where GNI is economic growth, EWA is emissions from waste, ETR is emissions from transportation, EPR is electricity generation from renewable sources, IPO is portfolio investment, and LIR is lending interest rate. No logarithmic transformation was chosen because the estimated logarithmic transformation only changes the magnitude of the standard errors without affecting the significance of the effect of the independent variables on the dependent variable. The significance level used in this research is 5%.

The Error Correction Model includes the following steps:

1. Conducting a unit root test to determine whether the data is stationary using the Augmented Dickey–Fuller (ADF) method.
2. Conducting a cointegration test to determine the existence of a long-run relationship between variables.
3. Conducting diagnostic tests using the classical assumption test.
4. Estimating the long-run model to see the long-run effects of independent variables on dependent variables.
5. Estimating the short-run model to see the short-run effect of independent variables on dependent variables, including the effect of the error correction term.
6. Interpreting the results.

D. RESULTS AND DISCUSSION

This study used three variables to represent carbon emissions: carbon emissions from waste, namely methane (CH_4), which is denoted as EWA (Emissions from Waste); carbon emissions from transportation, namely nitrous oxide (N_2O), which is denoted as ETR (Emissions from Transport); and electricity generation from renewable energy sources such as hydroelectric, which is denoted as EPR (Electricity Generation from Renewable Sources). Meanwhile, the monetary policy instruments used the variables of lending interest rates denoted as LIR (Lending Interest Rates) and portfolio investments such as bonds, which are denoted as IPO (Investment Portfolio). These variables are assumed

to be the independent variables. Meanwhile, the dependent variable is economic growth, which uses GNI growth data (%) and is denoted as GNI (Gross National Income). The GNI variable was selected based on its ability to reflect the real prosperity of a country's population, rather than just the value of production in that region.

The ECM analysis method was used to analyze the effects of carbon emissions from waste, emissions from transportation, electricity generation from renewable energy sources, lending interest rates, portfolio investments, and other factors on economic growth in the long and short run and how the two interact with each other.

The first step in the Error Correction Model (ECM) analysis is the stationarity test (unit root test) to determine whether the variables used are stationary. A variable is considered stationary if the mean, variance, and autocovariance are constant over time. According to David Dickey and Wayne Fuller, if a variable is not stationary at the level form, then stationarity can be achieved through the next order, until the required (n) order is obtained. Based on the results of the stationarity test, the GNI variable is stationary at level while EWA, ETR, EPR, IPO, and LIR are stationary at the first differencing. Overall, all variables are stationary because the p-value is less than 0.05. The results of the stationarity test are presented in Table 1.

Table 1. Stationarity Test

Variable	p-value (Level 0)	p-value (First Diff.)	Result
GNI	0.0022	0.0000	Stationary
EWA	0.7926	0.0000	Stationary
ETR	0.9031	0.0012	Stationary
EPR	0.1717	0.0000	Stationary
IPO	0.0503	0.0000	Stationary
LIR	0.6338	0.0001	Stationary

Source: STATA data processing results, 2025.

The existence of non-stationary variables leads to the possibility of long-run relationships among the variables. Such a relationship is called cointegration. The cointegration test aims to determine whether a long-run relationship between an independent variable and a dependent variable exists. As a continuation of the stationarity test, its main purpose is to determine whether the residuals are stationary, to indicate if cointegration exists. If the variables are cointegrated, there is a stable relationship in the long run. On the other hand, no cointegration between variables implies no relationship in the long run. The term cointegration is also known as the term error because deviation from the long-run equilibrium is gradually corrected through a partial series of short-run adjustments.

Table 2. Cointegration Test

t-statistic value	p-value
−5.737	0.0000

Source: STATA data processing results, 2025.

Based on the results in Table 2, the p-value is 0.0000, which is below 0.05, indicating cointegration. This means that the residuals in the long-run equation are stationary.

Before estimating the long-run ECM, it is necessary to carry out classical assumption tests, consisting of normality, multicollinearity, heteroscedasticity, and autocorrelation tests, as follows.

Table 3. Normality Test (Shapiro–Wilk W Test for Normal Data)

Obs	W	V	Z	Prob > z
28	0.89905	3.049	2.295	0.1087

Source: STATA data processing results, 2026.

Based on the result above, the probability value is 0.1087, which is greater than 0.05, indicating the presence of normal distribution.

Table 4. Multicollinearity Test

Variable	VIF	1/VIF
EWA	84.33	0.011859
EPR	58.31	0.017150
ETR	10.74	0.093117
LIR	3.93	0.254624
IPO	2.24	0.447399
Mean	31.91	

Source: STATA data processing results, 2026.

Based on the result above, the mean VIF is 31.91, which is greater than 4, indicating the presence of multicollinearity in the long-run model. High VIF is a well-known issue in long-run macroeconomic time-series analysis where variables share common trends over extended periods. This is not uncommon in Environmental Kuznets Curve and energy–growth literature (O'Brien, 2007).

Table 5. Heteroscedasticity Test (Cameron & Trivedi's Decomposition of IM-Test)

Source	Chi^2	df	p
Heteroscedasticity	26.29	20	0.1564
Skewness	12.42	5	0.0295
Kurtosis	6.75	1	0.0094
Total	45.46	26	0.0105

Source: STATA data processing results, 2026.

Based on the result above, the probability value is 0.1564, which is greater than 0.05, indicating the absence of heteroscedasticity.

Table 6. Autocorrelation Test

Statistic	Value
Durbin–Watson d-statistic (6, 28)	2.181781

Source: STATA data processing results, 2026.

Based on the result above, the DW-statistic is 2.181781, which is around 2, indicating the absence of autocorrelation.

Table 7. Long-Run ECM Estimation

Variable	Coefficient	Std. Error	Prob.
_Cons	43.7293	5.8001	0.000
EWA	−0.6544	0.1941	0.003
ETR	3.8498	3.3715	0.265
EPR	−5.24e–11	9.40e–11	0.583
IPO	4.32e–11	5.47e–11	0.438
LIR	−1.1942	0.1379	0.000
F-statistic	16.79	R-squared	0.7776
Prob (F)	0.0000	Adj. R-squared	0.7313

Source: STATA data processing results, 2025.

The long-run ECM estimation results show that carbon emissions from waste (EWA) and lending interest rates (LIR) had a negative and significant effect on economic growth (GNI). This indicates that higher carbon emissions from waste will reduce economic growth in the long run. Carbon emissions from waste are primarily generated from the decomposition of organic waste in landfills, which releases methane (CH_4), and from waste incineration, which produces carbon dioxide (CO_2). These carbon emissions from waste contribute to global warming and climate change, which lead to changes in rainfall patterns, increased temperatures, and extreme weather that will affect the agricultural sector, an important component of Indonesia's economy, thereby in the long run threatening food production and food security. Reduced food production challenges access to food for all levels of society, thereby lowering public welfare and constraining economic growth in the long run. Furthermore, the lending interest rate had a negative effect. This means that the lower the lending interest rate, the better the economic growth. This implies that lower lending interest rates will foster economic growth by encouraging people to borrow money for productive investment, thereby increasing the production of goods and services.

Meanwhile, carbon emissions from transportation (ETR) did not have an effect on economic growth (GNI) in the long run. This is likely because of the Indonesian government's transition toward fully electric vehicles through hybrid cars. These cars are more fuel-efficient than conventional vehicles and are expected to significantly reduce carbon emissions from transportation. This is consistent with the Environmental Kuznets Curve theory, which shows that in the long run, the curve reaches a peak or shifts to the right. This means that as per capita income increases over the long run, society and the government begin to shift their focus to environmental sustainability. This leads to regulatory reforms that reduce emissions in the long run (Fardin et al., 2022).

In the long run, electricity generation from renewable energy (EPR) did not have a significant effect on economic growth (GNI). This is likely because the renewable energy development in Indonesia is still in the investment and planning stage, including mapping the needs of human resources and stakeholders who provide employment, thereby bringing no direct positive impact on economic growth. Similarly, portfolio investment (IPO) did not have a significant effect on economic growth (GNI). This is likely because long-term bond investments (10 to 20 years) involve a relatively high risk considering the fact that it is difficult to predict future corporate performance and macroeconomic conditions, so this variable cannot be considered a monetary instrument that can foster economic growth (Sihombing & Rahmawati, 2015). The overall goodness of fit of the model is indicated by the R^2 value of 0.7776, indicating valid cointegration despite multicollinearity.

Classical assumption tests, which include normality, multicollinearity, heteroscedasticity, and autocorrelation tests, were also conducted prior to estimating the short-run ECM, as follows.

Table 8. Normality Test (Shapiro–Wilk W Test for Normal Data)

Obs	W	V	z	Prob > z
27	0.96882	0.917	−0.179	0.57103

Source: STATA data processing results, 2026.

Based on the result above, the probability value is 0.57103, which is greater than 0.05, indicating the presence of normal distribution.

Table 9. Multicollinearity Test

Variable	VIF	1/VIF
EWA	2.55	0.391757
EPR	2.08	0.481035
ETR	1.27	0.788300
LIR	2.16	0.464011
IPO	1.05	0.952363
Mean	1.76	

Source: STATA data processing results, 2026.

Based on the result above, the mean VIF is 1.76, which is below 4, indicating the absence of multicollinearity in the short run.

Table 10. Heteroscedasticity Test (Cameron & Trivedi's Decomposition of IM-Test)

Source	Chi^2	df	p
Heteroscedasticity	27.00	26	0.4093
Skewness	17.84	6	0.0066
Kurtosis	0.24	1	0.6269
Total	45.08	33	0.0783

Source: STATA data processing results, 2026.

Based on the result above, the probability value is

0.4093, which is greater than 0.05, indicating the absence of heteroscedasticity.

Table 11. Autocorrelation Test

Statistic	Value
Durbin–Watson d-statistic (7, 27)	2.087902

Source: STATA data processing results, 2026.

Based on the result above, the DW-statistic is 2.087902, which is around 2, indicating the absence of autocorrelation.

A robustness test is conducted to verify the consistency of previous estimates. This test can be performed using alternative proxies for variables, periods, and sectors, although they might not be identical to those used previously. In this study, the test used multiple regression analysis, except that the GNI proxy was used for the dependent variable, while the robustness test used GDP.

Table 12. Robustness Test Results for Long-Run ECM Estimation

Dependent Variable	Estimation Results of GNI	Estimation Results of GDP	Result
EWA	Significant negative	Insignificant	Not robust
ETR	Insignificant	Insignificant	Robust
EPR	Insignificant	Insignificant	Robust
IPO	Insignificant	Insignificant	Robust
LIR	Significant negative	Significant negative	Robust

Source: STATA data processing results, 2026.

Based on the robustness test above, the EWA variable is not robust in the long run because the multiple regression analysis results between the GNI and GDP proxies differ. This is because the long-run effect of carbon emissions from waste on economic growth is sensitive to model specification. In addition, this non-robustness is also caused by the presence of high multicollinearity between EWA and EPR (VIF of 84.33 and 58.31, respectively). Therefore, the government should carefully design and implement long-term waste emission reduction policies. Meanwhile, the robustness test confirms the consistency of the other variables.

Table 13. Robustness Test Results for Short-Run ECM Estimation

Dependent Variable	Estimation Results of GNI	Estimation Results of GDP	Finding
EWA	Insignificant	Insignificant	Robust
ETR	Insignificant	Insignificant	Robust
EPR	Insignificant	Insignificant	Robust
IPO	Significant positive	Significant negative	Not robust
LIR	Significant negative	Significant negative	Robust
ECT	Significant negative	Significant negative	Robust

Source: STATA data processing results, 2026.

Based on the robustness test above, the IPO variable is not robust in the short run because the multiple regression analysis results between the GNI and GDP proxies differ. Meanwhile, the test confirmed the consistency of the other variables.

Table 14. Short-Run ECM Estimation

Variable	Coefficient	Std. Error	Prob.
_Cons	−0.2974	0.5930	0.621
EWA	−0.4786	0.4708	0.320
ETR	6.3835	3.5576	0.087
EPR	−6.16e–11	5.19e–11	0.248
IPO	1.03e–10	4.82e–11	0.044
LIR	−1.4528	0.1456	0.000
ECT	−1.2105	0.2072	0.000
F-statistic	29.93	R-squared	0.8909
Prob (F)	0.0000	Adj. R-squared	0.8611

Source: STATA data processing results, 2025.

The coefficient of the Error Correction Term (ECT) reflects the speed of adjustment back to the long-run equilibrium in one year. The ECT coefficient is an absolute value to explain how quickly the economy returns to an equilibrium after a shock. In addition, the ECT coefficient measures the regression response of each period that deviates from equilibrium. Table 14 shows that the ECT value is −1.2105 with a probability of 0.0000, indicating that it is negative and significant, so the short-run ECM model is valid. The ECT measures how quickly short-run disequilibrium is corrected to return to its long-run equilibrium. An ECT coefficient that is negative and significant indicates a short-run correction following economic shocks in the previous period, such as stock market volatility and fluctuations in the Japanese yen exchange rate, which directly affected the external debt burden of Asian countries, including Indonesia. These deviations are corrected back to the long-run equilibrium.

The results of the short-run ECM estimation show that portfolio investment (IPO) had a positive and significant effect on economic growth (GNI), indicating that the higher the portfolio or bond investment, the higher the economic growth. Portfolio investment increases financial market liquidity, raises asset prices,

and improves financing conditions for economic actors, thus boosting economic activity and growth. An increase in portfolio investment also strengthens investor confidence and the exchange rate, thereby lowering the cost of importing capital goods and stimulating production activities, ultimately contributing positively to economic growth (Twinoburyo & Odhiambo, 2018). Furthermore, short-term bond investments have shorter maturities, so corporate risk conditions can be predicted more accurately and conservatively, thereby minimizing the risk of losses for investors and encouraging greater investments, which result in increased production of goods and services in the economy (Khakim, 2022).

The lending interest rate (LIR) also had a negative and significant effect on economic growth in the short run, indicating that the lower the lending rate, the higher the economic growth. Higher lending interest rates increase business costs, thereby reducing investment and production expansion, thus directly slowing down economic growth. High interest rates can also reduce household consumption, particularly credit-based consumption. Unfortunately, the lower the consumption, the lower the aggregate demand, and the lower the economic growth in the short run (Drobyshevsky et al., 2017).

Short-run lending interest rates are usually lower than long-run lending interest rates, thereby providing higher returns for investors or business capital borrowers. Therefore, lower short-run lending interest rates tend to encourage investment and foster economic growth (Luthfiana et al., 2022).

On the other hand, carbon emissions from waste (EWA) did not have a significant effect on economic growth (GNI) in the short run because the adverse impacts of climate change are generally realized over a longer period and there is a compensation mechanism between economic growth and carbon emissions from waste in accordance with the Environmental Kuznets Curve theory. This mechanism occurs because of the relationship between economic growth and increased carbon emissions in the early stages of development. However, along with the development of technology and environmental awareness, developed countries gradually separate economic growth from increased carbon emissions through the adoption of green technology (Gonzalez Alvarez & Montanes, 2023).

In the short run, this transition has not been fully realized in developing countries such as Indonesia. Furthermore, carbon emissions from transportation (ETR) did not have a significant effect on economic growth (GNI) in the short run. Environmental pollution from transportation, despite its high emissions, takes a long time to impact economic productivity. Although transportation, particularly motorized vehicles, is the largest contributor to emissions, it remains a key driver of mobility which supports economic activities. In addition, although air pollution has adverse health impacts, these impacts are generally not severe enough to trigger a significant decrease in either productivity or overall economic growth within a short period of time (Nahar et al., 2016). For example, an increase in asthma cases among children may not directly decrease labor productivity or overall economic growth. This is consistent with the Environmental Kuznets Curve (EKC) theory, which suggests that, in the short run, the inverted U curve is on the left side, indicating that high transportation activities are prioritized to support economic growth, without considering exhaust emissions (Peng et al., 2025).

Finally, electricity generation from renewable energy (EPR) did not have a significant effect on economic growth (GNI) in the short run because the development of renewable energy infrastructure such as solar, wind, or geothermal power plants requires large initial investment, possibly hindering economic growth in the near future. Infrastructure development involves research, land acquisition, exploration, and construction before electricity can be generated and supplied to the grid. During the infrastructure development phase, electricity generation from renewable energy is not yet commercially available. As a result, these capital inputs have not yet been converted into productive outputs capable of driving industry and macroeconomic GNI immediately (Pongtuluran & Setyari, 2026).

In addition, renewable energy sources, such as solar and wind power, are highly dependent on weather conditions, possibly causing instability in electricity supply, which in turn can hinder economic growth that requires a stable and reliable energy supply (Safitri, 2024).

E. CONCLUSION

The results of the long-run estimation reveal that carbon emissions from waste and lending interest rates had a negative and significant effect on economic growth, while carbon emissions from transportation, electricity generation from renewable energy sources, and portfolio investments did not have an effect on economic growth. If the government aims to promote economic growth, they should reduce carbon emissions from waste and lending interest rates. Reducing carbon emissions from waste can improve the quality of human health and productivity, ultimately contributing to stronger economic growth.

In the short run, portfolio investments had a positive and significant effect on economic growth, while lending interest rates had a negative and significant effect on economic growth. On the other hand, carbon emissions from waste, carbon emissions from transportation and electricity generation from renewable energy did not have an effect on economic growth. An increase in carbon emissions from transportation indicates an increase in the economic activities of people in developing countries such as Indonesia, thereby promoting economic growth. The fluctuations in Indonesia's eco-

nomic growth during 2019–2023 may be influenced by other factors, such as pandemic shocks, global commodity price dynamics, and changes in domestic consumption patterns. Increased portfolio investment will increase corporate capital, eventually increasing profits and promoting economic growth. Lower lending interest rates in the short run may encourage people to borrow for consumption or production activities, thereby contributing to stronger economic growth.

Future researchers could examine the reverse relationship, namely the effect of economic growth on carbon emissions. These two variables may influence each other simultaneously. Furthermore, future researchers could also include the unemployment rate as an explanatory variable to examine its effect on carbon emissions, as high unemployment rates will lead to reduced economic activity, resulting in lower carbon emissions. Finally, future research may use alternative estimation techniques to address the non-robustness of the EWA variable in the long run.

DECLARATIONS

Author contributions. A.F.: conceptualization, methodology, data curation, formal analysis, software, visualization, and writing — original draft. I.P.A.: conceptualization, validation, writing — review and editing, and supervision. Both authors have read and approved the published version of the manuscript.

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Use of artificial intelligence. The authors declare that generative artificial intelligence tools were not used to generate the substantive content, analysis, or conclusions of this manuscript. Where AI-assisted language tools were used, they were limited to grammar and readability checking, and the authors reviewed and take full responsibility for the entire content of the published article.

Data availability. All data analysed in this study are secondary time-series data for 1994–2023, obtained from publicly accessible databases of the World Bank and Statistics Indonesia (BPS). The compiled dataset and the STATA do-files used for the Error Correction Model estimation are available from the corresponding author on reasonable request.

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