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## Exploring the Interrelationship Between Economic Growth, Investment, and CO<sub>2</sub> Emissions in Indonesia: A Time-Series Approach

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### **ABSTRACT**

This study aims to analyze the influence of economic growth, investment, industrial added value, trade value, and oil consumption on CO<sub>2</sub> emissions in Indonesia in the period 1987-2019, before the COVID-19 pandemic. In addition, this study also considers the role of government policies in regulating carbon emissions and mitigating negative impacts on the environment. The method used in this study is the ECM (Error Correction Model) regression approach. The results show that in the long term, economic growth, industrial value-added, and oil consumption have a positive effect on increasing CO<sub>2</sub> emissions in Indonesia, while investment (GFCF) and trade value have a negative effect on CO<sub>2</sub> emissions. In the short term, industrial value added, and trade value have no significant effect on CO<sub>2</sub> emissions, while economic growth and oil consumption encourage an increase in CO<sub>2</sub> emissions. Investment (GFCF) contribute to the reduction of CO<sub>2</sub> emissions. Indonesian government policies that focus on reducing carbon emissions through regulations that support renewable energy and energy efficiency, as well as controlling oil consumption, are expected to accelerate the transition to a low-carbon economy. The implication of these findings is that more assertive and integrated policies between the economic and environmental sectors are needed to effectively reduce CO<sub>2</sub> emissions, while supporting economic growth and industrialization.

**Keywords:** CO<sub>2</sub> emissions, ecm model, economic growth, oil consumption

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## 1. INTRODUCTION

Indonesia, as one of the developing countries with the largest economy in Southeast Asia, faces significant challenges in maintaining a balance between economic growth and environmental sustainability. Increasing carbon emissions, especially from the energy and industrial sectors, have become a major issue in global climate change mitigation efforts

([Liu, et al., 2016](#)). Over the past few decades, Indonesia's rapid economic growth has been accompanied by an increase in energy consumption, especially oil, which has contributed to increased CO<sub>2</sub> emissions ([Alam, et al., 2016](#)). In addition, Indonesia's industrial sector has undergone significant transformations that have the potential to worsen environmental impacts if not managed properly.

The Indonesian government has taken various policies to address these environmental problems, including plans to reduce greenhouse gas emissions through increased use of renewable energy, energy efficiency, and reduced dependence on fossil fuels ([Indonesia Ministry of Environment and Forestry, 2018](#)). However, despite these existing policies, there is still little research that addresses the influence of economic factors and oil consumption on CO<sub>2</sub> emissions in the Indonesian context, especially before the COVID-19 pandemic.

Research by [Aye & Edoja \(2017\)](#) and [Dauda, et al \(2019\)](#) shows that economic growth has a positive effect on increasing CO<sub>2</sub> emissions in the long and short term. This suggests that rapid economic growth is often accompanied by increased energy consumption, which in turn increases CO<sub>2</sub> emissions. While many studies have shown a positive link between economic growth and CO<sub>2</sub> emissions, more in-depth research on how the application of green technologies can reduce the negative impact of economic growth on the environment is limited. Research on green economic transition in developing countries such as Indonesia is still lacking ([Endriana, et al., 2016](#)).

Research by [Tian, et al. \(2022\)](#) and [Fankhauser & Jotzo \(2018\)](#) shows that investments in the renewable energy and green technology sectors can accelerate the transition to a low-carbon economy. While many studies have shown the positive impact of investment on reducing emissions, there is a lack of research exploring which types of investments are most effective in the context of developing countries, particularly Indonesia. The application of green investment in the industrial and transportation sectors in Indonesia still requires further research ([Ramadhan, et al., 2024](#)).

[Hao \(2022\)](#) shows that industrial activities often increase energy consumption, which contributes to carbon emissions. However, in the short term, the impact is not significant, suggesting that other factors are more dominant in influencing CO<sub>2</sub> emissions in a short period. Many studies have shown that the industrial sector contributes significantly to emissions, but there has not been much research exploring the influence of low-carbon technologies in the industrial sector on long-term emissions. Research by [Avenyo & Tregenna \(2022\)](#) shows that green industries in developing countries can reduce emissions.

The value of trade has a negative effect on CO<sub>2</sub> emissions in the long run, suggesting that international trade can bring clean technologies that reduce emissions. However, in the short term, the effect is not significant, which suggests that other factors (such as energy policy) are more dominant in a short period of time ([Spampatti, et al., 2022](#)). The research of [Wu, et al., \(2021\)](#) explores the influence of international trade on CO<sub>2</sub> emissions in more detail, especially in the context of developing countries that have a high dependence on trade in fossil energy-based goods.

Research by [Alkhathlan & Javid \(2015\)](#) and [Mahmood \(2022\)](#) shows that oil consumption has a positive effect on increasing CO<sub>2</sub> emissions in the long and short term. Research shows that the use of fossil energy, including oil, is a major contributor to CO<sub>2</sub> emissions. Research by [Covert, et al \(2016\)](#) shows that oil consumption reduction policies, especially in the context of developing countries that rely heavily on fossil fuels, are very effective in reducing oil consumption.

This study aims to analyse the influence of economic factors, such as economic growth, investment, industrial added value, trade value, and oil consumption on CO<sub>2</sub>

emissions in Indonesia in the period 1987-2019, before the impact of the COVID-19 pandemic. In addition, this study also aims to evaluate the extent to which government policies related to reducing carbon emissions play a role in mitigating the environmental impact of rapid economic growth and industrialization. The results of this study are expected to provide further insight into the policies that need to be taken to support sustainable development in Indonesia, with a focus on reducing carbon emissions.

This study offers a more complete perspective by combining the influence of five main factors of economic growth, investment, industrial added value, trade value, and oil consumption on CO2 emissions in Indonesia. Using data for the period 1997-2019, this study bridges the gap between economics and environmental policies in developing countries, particularly Indonesia, which face major challenges in managing economic growth and environmental sustainability.

This study uses the ECM (Error Correction Model) regression approach, which allows the separation of influences in the long and short term ([Basuki & Prawoto, 2019](#)). This is new because many previous studies have only focused on one aspect (long-term or short-term) without distinguishing the effects of the two time periods. Thus, the results of this study provide a more comprehensive picture of the dynamics between the economy and CO2 emissions in two different time periods.

## 2. RESEARCH METHOD

The Error Correction (ECM) model is one of the models that is often used to analyse the long-term and short-term relationships between economic variables. ECM combines two main concepts: long-run equilibrium and short-run dynamics.

Before building an ECM model, the first step is to ensure that the data used does not contain root units, which can lead to misleading analysis results. Root units can be tested using the Augmented Dickey-Fuller (ADF) or Phillips-Perron (PP) test. The data must be stationary, meaning it has a constant mean and variance all the time ([Enders & Li, 2015](#)).

After stationary or differentiation data is performed, the next step is to check if there is a long-term relationship between the variables being analysed. The cointegration test is usually carried out with the Johansen Cointegration Test ([Johansen, 2014](#)) or the Engle-Granger Test ([Granger, 2004](#)).

After confirming the cointegration, the next stage is to estimate the ECM model. The ECM model essentially combines two parts: the long-term part that describes equilibrium relationships and the short-term part that describes the dynamics of adjustment.

ECM models can be written in the form of:

$$\Delta Y_t = \alpha + \sum_{i=1}^p \beta_i \Delta X_t + \lambda ECT_{t-1} + \epsilon_t$$

Where:

$\Delta Y_t$	is the change of the dependent variable,
$\Delta X_t$	is an independent variable change,
$ECT_{t-1}$	is the term for error correction of cointegration,
$\alpha$	is a constant,
$\lambda$	is the error correction coefficient,
$\epsilon_t$	is an error term.

To analyse the influence of economic growth (GDP), investment (INV), industrial value added (IVA), trade value (TRADE), and oil consumption (OIL) on CO<sub>2</sub> (CO<sub>2</sub>) emissions, the proposed model can be written as follows:

Long-Term Model:

$$CO_{2t} = \alpha_0 + \alpha_1 GDP_t + \alpha_2 GFCF_t + \alpha_3 IVA_t + \alpha_4 TRADE_t + \alpha_5 OIL_t + \epsilon_t$$

Where:

CO <sub>2t</sub>	: CO <sub>2</sub> emissions at time t
GDP <sub>t</sub>	: Economic growth at time t (usually measured in real GDP)
GFCF <sub>t</sub>	: Investment in time t
IVA <sub>t</sub>	: Added value of the industry at the time t
TRADE <sub>t</sub>	: The value of international trade in time t
OIL <sub>t</sub>	: Oil consumption at the time t
ε <sub>t</sub>	: Term errors or random interference

This model states that CO<sub>2</sub> emissions are influenced by economic factors such as economic growth, investment, industrial value-added, trade value, and oil consumption in the long run. The coefficients α<sub>1</sub>, α<sub>2</sub>, α<sub>3</sub>, α<sub>4</sub>, α<sub>5</sub> show the influence of each variable on CO<sub>2</sub> emissions.

### Short-Term Model (ECM):

Once the long-term model is established, the next step is to analyse the short-term dynamics using the Error Correction Model. The ECM model corrects for the imbalance between the variables that exist in the short term, based on the deviation from the long-term equilibrium. The ECM equation can be written as follows:

$$\Delta CO_{2t} = \gamma_0 + \gamma_1 \Delta GDP_t + \gamma_2 \Delta GFCF_t + \gamma_3 \Delta IVA_t + \gamma_4 \Delta TRADE_t + \gamma_5 \Delta OIL_t + \lambda EC_{t-1} + \epsilon_t$$

Where:

Δ	indicates the first change or change of the existing variable
EC <sub>t-1</sub>	is the Error Correction Term (ECT), which indicates the deviation from the long-term equilibrium in the previous period (usually measured by the difference between the actual value and the long-term equilibrium value of the first model)
λ	is the long-term adjustment coefficient, which indicates how quickly the economy will adjust to the imbalance
γ <sub>1</sub> , γ <sub>2</sub> , γ <sub>3</sub> , γ <sub>4</sub> , γ <sub>5</sub>	The coefficient shows the direct impact of changes in economic factors (economic growth, investment, industrial value-added, trade value, and oil consumption) on changes in CO <sub>2</sub> emissions in the short term

EC<sub>t-1</sub> (Error Correction Term) serves to measure the extent to which the imbalance in the previous period corrects itself in the current period. And a significant and negative λ indicates that the imbalance in a long-term relationship will return to equilibrium quickly. The greater the value of λ, the faster the economy will adjust to the long-term equilibrium.

### 3. RESULTS AND ANALYSIS

The stages of conducting an ECM model start from conducting a statistical test for all variables, both independent and dependent. Stationarity tests such as Augmented Dickey-Fuller (ADF) or Phillips-Perron can be used to check if a variable in the model has a unit root, which means it is not stationary.

Table 1. Stationary Test

Series: ECO <sub>2</sub> , GDP, GFCF, IVA, TRADE, OIL						
Method	Data Level		First Difference		Obs	
	Statistic	Prob.*	Statistic	Prob.**		
Null: Unit root (assumes common unit root process)						
Levin, Lin & Chu t*	-0.06649	0.4735	-10.7964	0.0000	192	
Null: Unit root (assumes individual unit root process)						
Im, Pesaran and Shin W-stat	0.65121	0.7425	-11.7819	0.0000	192	
ADF - Fisher Chi-square	15.582	0.2111	119.297	0.0000	192	
PP - Fisher Chi-square	14.7963	0.2528	145.08	0.0000	192	

Source: Data processed, 2023

Based on Table 1, the probability value for data level is above 0.05. This indicates that the variable is not stationary at the data level. Furthermore, the stationary test was upgraded to a stationary test on the first difference data, and it was seen that the probability value was below the value of 0.05, this shows that all data is stationary on the first difference data.

Furthermore, a long-term test was carried out by regressing the influence of economic growth, investment, industrial added value, trade value and oil consumption on CO<sub>2</sub> emissions in Indonesia. This study uses data from 1987-2019 before the occurrence of covid 19. The results of the study show that before the occurrence of covid 19 in the long term, economic growth, industrial added value, and oil consumption had a positive influence in increasing Co<sub>2</sub> emissions in Indonesia, while investment (GFCF) and trade value had a negative influence on Co<sub>2</sub> emissions in Indonesia.

Table 2. Long-term regression outcomes

Dependent Variable: LOG(ECO<sub>2</sub>)

Variable	Coefficient t	Std. Error	t-Statistic	Prob.
LOG(GDP)	1.1369	0.1570	7.2438	0.0000
LOG(GFCF)	-0.4443	0.0818	-5.4284	0.0000
LOG(IVA)	0.3301	0.1143	2.8879	0.0075
LOG(TRADE)	-0.3883	0.1289	-3.0126	0.0056
LOG(OIL)	0.7315	0.1203	6.0814	0.0000
C	-21.0876	1.0870	-19.4000	0.0000
R-squared	0.996792			
Adjusted R-squared	0.996198			

Source: Data processed, 2023

Next, a Cointegration Test was carried out. The cointegration test was carried out by taking the residuals in the Long-Term equation ([Gregoriou & Kontonikas, 2010](#)), then named the ECT variable and stasione tested at the data level. Based on Table 2, the probability value of ECT is below 0.05, this indicates that there has been cointegration in the Long-Term equation.

Table 3. Cointegration Test

Null Hypothesis: ECT has a unit root		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.39759	0.0015
Test critical values:	1% level	-3.65373	
	5% level	-2.95711	

Source: Data processed, 2023

Furthermore, after the ECT passed the stationary test at the data level, a short-term analysis (ECM Model was carried out). Table 4 shows that in the short term, industrial added value and trade value have no influence on CO2 emissions, while economic growth and oil consumption have an influence in driving an increase in CO2 emissions. investment (GFCF) has an influence in reducing CO2 emissions.

Table 4. Short-Term Test Results

Dependent Variable: D(LOG(ECO2))				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOG(GDP))	1.1447	0.3149	3.6347	0.0013
D(LOG(GFCF))	-0.4051	0.1285	-3.1536	0.0042
D(LOG(IVA))	0.1997	0.1367	1.4604	0.1566
D(LOG(TRADE))	-0.2084	0.1445	-1.4420	0.1617
D(LOG(OCT))	0.6890	0.1240	5.5568	0.0000
ECT (-1)	-0.7281	0.1977	-3.6822	0.0011
C	-0.0025	0.0114	-0.2154	0.8312
R-squared	0.680272			
Adjusted R-squared	0.603538			

Source: Data processed, 2023

An ECT value of -0.7281 indicates that in the following period, the system will correct about 72.81% of the errors or deviations from the long-term equilibrium that occurred in the previous period. Specifically, this negative ECT value signifies that the system is moving toward equilibrium, but the adjustment occurs in a way that reduces the value of the variable in question to return to equilibrium. An ECT of -0.7281 indicates that the model corrects the imbalance that occurred in the past at a high speed. Intuitively, this means that deviations from the long-term equilibrium will be corrected more quickly in the next one period. A negative ECT value (-0.7281) indicates that changes in the variables involved tend to correct towards a lower or reduced equilibrium. This suggests that there is a negative relationship between errors (e.g., long-term imbalances) and variables in the model.

Based on this large and negative ECT, policies that encourage faster adjustments can be designed to correct imbalances in the management of CO2 emissions, such as policies that reduce oil consumption, improve energy efficiency, or introduce environmentally friendly technologies. Policies that reduce oil consumption will play a role in lowering CO2 emissions, and if there is an imbalance caused by excessive consumption of fossil energy, the system will correct the error quickly (72.81% in a single period). Investments in green sectors that support the use of environmentally friendly technologies and renewable energy can accelerate the reduction of CO2 emissions, suggesting that this model can quickly respond to policies that promote structural changes in the economy.

High and negative ECT values, such as -0.7281, also indicate that the right policies can be highly influential in restoring the balance between economic growth and CO2 emission reductions in a short period of time. Effective policies can ensure that Indonesia achieves a balance between sustainable economic growth and the reduction of negative impacts on the environment, including CO2 emissions. Overall, the ECT value of -0.7281 indicates that the model used has a high speed of adjustment in correcting short-term imbalances. This gives an idea that the right economic policies can immediately correct deviations to the long-term balance and play an important role in reducing CO2 emissions in Indonesia, over time.

### Classic Assumption Test

The purpose of the classical assumption test in regression equations is to ensure that the regression model used is valid and reliable in producing accurate estimates and providing appropriate conclusions ([Wooldridge \(2016\)](#), [Pollock \(2008\)](#) and [Damodar \(2021\)](#)). In econometrics, classical assumption tests aim to verify whether the data meets some of the basic assumptions required for the validity of regression results (Gujarati & Porter (2019) and Basuki & Prawoto (2019)).

Linearity: The relationship between independent (X) and dependent (Y) variables should be linear. That is, the change of the independent variable is expected to change the dependent variable proportionally in a relationship that can be described with a straight line. Table 5 of the results of the linearity test with the Ramsey Reset method shows that the regression results meet the assumption of linearity, this is shown by the probability value of t statistic above 0.05.

Table 5. Linearity Test Results

Ramsey RESET Test			
Specification: D(LOG(ECO2)) D(LOG(GDP)) D(LOG(GFCF)) D(LOG(IVA)) D(LOG(TRADE)) D(LOG(OCT)) ECT (-1) C			
Keterangan	Value	df	Prob.
t-statistic	0.444246	24	0.6608
F-statistic	0.197354	(1, 24)	0.6608
Likelihood ratio	0.262063	1	0.6087

Source: Data processed, 2023

Homoskedasticity: The variance of the residual must be constant for each predictor value. In other words, the spread of error in the regression model should not depend on the level of value of the independent variable. If there is heteroscedasticity (changing residual variance), the estimation of the coefficient can be inefficient and can lead to false hypothesis testing. Based on table 6, the probability value of Obs\*R-squared is above 0.05, this shows that the above model does not contain heteroscedasticity.

Table 6. Heteroscedasticity Test Results

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	0.678479	Prob. F (6,25)	0.6683
Obs*R-squared	4.481046	Prob. Chi-Square (6)	0.6119
Scaled explained SS	9.082477	Prob. Chi-Square (6)	0.1690

Source: Data processed, 2023

Error Independence (No Autocorrelation): Errors or residual ( $\epsilon$ ) must be independent of each other. This means that there is no predictable pattern in the residual from one observation to another. If there is autocorrelation, the model may not be able to describe the data well. Table 7 shows that the Obs\*R-squared probability value in the Breusch-Godfrey Serial Correlation LM Test autocorrelation test is above 0.05, indicating that the model avoids autocorrelation.

Table 7 Autocorrelation Test Results

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	1.158968	Prob. F (2,23)	0.3315
Obs*R-squared	2.929699	Prob. Chi-Square (2)	0.2311

Sumber: Data diolah, 2023

The results of the study in Table 4 found that economic growth has a positive influence on increasing CO<sub>2</sub> emissions in Indonesia in the long term. This means that the higher the rate of economic growth, the more likely it is that there will be an increase in CO<sub>2</sub> emissions. This phenomenon often occurs because rapid economic growth tends to increase energy consumption, especially fossil energy, which contributes greatly to carbon emissions.

In the period studied (1997 to before COVID-19), Indonesia experienced significant economic growth, mainly driven by the growing industrial and manufacturing sectors. The growth of this industrial sector directly increases energy consumption, which comes mostly from fossil fuels such as oil, coal, and gas. The burning of fossil fuels produces carbon dioxide (CO<sub>2</sub>) emissions. Rapidly growing industries, especially the manufacturing and mining industries, require a great deal of energy. Most of this energy comes from the burning of fossil fuels, which contribute significantly to increased CO<sub>2</sub> emissions. Research by [Lamb, et al \(2021\)](#) shows that fast-growing industrial sectors typically lead to increased energy use, which in turn impacts higher greenhouse gas (GHG) emissions.

The results of this study are in accordance with research by [Fankhauser & Jotzo \(2018\)](#) showing that rapid economic growth in developing countries is often accompanied by increased consumption of fossil energy, which then leads to an increase in CO<sub>2</sub> emissions. [Vo, et al \(2019\)](#) also found a positive relationship between economic growth and CO<sub>2</sub> emissions in several Asian countries, including Indonesia. [Saidi & Hammami \(2015\)](#) in their research also stated that economic growth has a significant impact on increasing CO<sub>2</sub> emissions in countries with industrial structures that are heavily dependent on fossil fuels.

The added value of the industry in Table 4 shows a positive influence on CO<sub>2</sub> emissions in the long term. The increase in industrial added value indicates that the manufacturing and industrial sectors in Indonesia are growing rapidly, which in turn increases energy consumption and carbon emissions. The more the industrial sector develops, the greater the use of energy for production, which leads to an increase in CO<sub>2</sub> emissions. Industrial added value is one of the important indicators in measuring the contribution of the industrial sector to a country's economy. In the context of Indonesia between 1997 and before the COVID-19 pandemic, industrial added value had a positive influence on CO<sub>2</sub> emissions. This is due to several main reasons related to industrial structure, energy consumption patterns, and policies implemented during that period.

The industrial sector in Indonesia, especially in the period studied, is heavily dependent on fossil energy such as coal, oil, and natural gas. Despite the development of the renewable energy sector, the contribution of renewable energy to total energy

consumption is still limited, so CO<sub>2</sub> emissions from the industrial sector increase along with the increase in industrial value. Rapidly growing industries, such as manufacturing, mineral processing, and other heavy industries, require large amounts of energy for the production process, which in turn leads to increased CO<sub>2</sub> emissions.

The production process in these industries often involves burning fossil fuels, which produce carbon dioxide (CO<sub>2</sub>) as a byproduct. Research by [Huang, et al \(2023\)](#) shows that the increase in industrial value-added in developing countries tends to increase the demand for fossil energy, which in turn encourages an increase in CO<sub>2</sub> emissions. Indonesia has an industrial structure dominated by sectors that are very energy-intensive, such as the mining, manufacturing, and energy industries. In the period from 1997 to before COVID-19, many industries continued to grow in this sector, so that the added value of the industry increased rapidly. However, these sectors still use energy derived from fossil fuels, which increases CO<sub>2</sub> emissions.

The processing and manufacturing industries, for example, operate with high energy consumption to process raw materials into semi-finished products or finished goods. With the increase in added value of industry, larger production volumes require more energy consumption, which tends to produce more CO<sub>2</sub> emissions. Research by [Fais, et al \(2016\)](#) shows that larger industrial sectors tend to have higher emissions, especially if they rely on fossil energy.

The results of this study are in accordance with the results of [Yao, et al \(2021\)](#) research that in developing countries, industrial added value is often accompanied by greater energy use, which contributes to increased CO<sub>2</sub> emissions. Likewise, research by [Uzair Ali, et al \(2022\)](#) shows that industrialization in developing countries tends to increase CO<sub>2</sub> emissions due to dependence on fossil energy. [Cassar \(2015\)](#) notes that although industrial value-added can increase employment and income, the industrial sector that relies on conventional energy remains a major contributor to carbon pollution.

Oil consumption in Table 4 has a positive influence on the increase in CO<sub>2</sub> emissions in Indonesia in the long term (1997 to before COVID-19) due to several factors related to economic structure, energy policy, and the country's dependence on fossil fuels. The following explanation outlines the main factors that lead to this positive relationship. Indonesia, during the period from 1997 until before the COVID-19 pandemic, relied heavily on fossil fuels to meet its energy needs, and one of the main components of these fossil fuels is oil. Despite efforts to diversify energy sources using renewable energy, oil consumption remains high, both for the transportation, industry, and power generation sectors. The burning of oil as an energy source produces significant carbon dioxide (CO<sub>2</sub>) emissions. Oil is one of the main fuels used in the transportation and industrial sectors in Indonesia. For example, cars, motorcycles, and public transportation based on internal combustion engines use fuel oil (BBM). Much of this oil consumption relies on imports, which exacerbates Indonesia's dependence on fossil energy. Research by [Paraschiv & Paraschiv \(2020\)](#) shows that countries that depend on fossil energy, including oil, tend to experience increased CO<sub>2</sub> emissions as energy consumption increases.

The results of this study are in line with the results of research by [Saboori, et al \(2017\)](#) and [Shaari, et al \(2020\)](#) that oil consumption contributes significantly to CO<sub>2</sub> emissions, especially in developing countries that rely on oil as the main energy source. These studies support the finding that Indonesia, as a country that is still heavily dependent on fossil energy, will continue to face challenges in reducing CO<sub>2</sub> emissions without a transition to renewable energy. [Huisinsh, et al \(2015\)](#) also note that countries with high oil

consumption typically have larger carbon footprints, especially when there are no effective emission reduction policies.

Investment (GFCF) in Table 4 has a negative effect on CO<sub>2</sub> emissions in Indonesia in the long term. This suggests that investments, especially in greener and more energy-efficient sectors, can help reduce carbon emissions. The research provides hope that green investment and clean technology can accelerate the transition to a low-carbon economy.

Significant investment in the industrial and infrastructure sectors can encourage more efficient use of technology in terms of energy consumption. Energy-efficient technologies, such as more energy-efficient production machines, more environmentally friendly transportation systems, and green building infrastructure, can reduce the energy requirements derived from burning fossil fuels, which in turn reduces CO<sub>2</sub> emissions. During the period 1997 to 2019, Indonesia began to adopt some more efficient technologies in the industrial sector, especially in the manufacturing and processing sectors. For example, investment in the renewable energy sector, although still limited, is also starting to play a role in reducing dependence on fossil energy. Research by [Dissanayake, et al \(2020\)](#) shows that investment in energy-efficient technologies contributes to the reduction of CO<sub>2</sub> emissions in developing countries, including Indonesia.

These results are in line with the research of [Xu, et al \(2023\)](#) and [Hussain, et al \(2022\)](#) that investments in renewable energy and green technologies can reduce CO<sub>2</sub> emissions. This suggests that the right investments can serve as instruments for climate change mitigation. [Tariq, et al \(2022\)](#) also emphasized the importance of investing in green technologies to reduce dependence on fossil energy and reduce carbon footprints. [Akram, et al \(2022\)](#) show that countries that focus investment on the renewable energy sector or energy efficiency experience a decrease in CO<sub>2</sub> emissions even though their growth remains positive.

Table 4 of this study shows that the added value of industry does not have a significant influence on CO<sub>2</sub> emissions in the short term. This suggests that in a shorter period, the industrial sector may not have fully experienced an increase in energy consumption significant enough to cause a spike in CO<sub>2</sub> emissions, although the industrial sector contributes significantly to the long run. This can be due to several factors, such as better energy efficiency in the industrial sector or increased use of renewable energy in the period. In the short term, Indonesia's industrial sector, although growing well, remains heavily dependent on fossil energy, especially coal and oil. Although the added value of the industry increases, this does not necessarily lead to an increase in energy efficiency or a reduction in CO<sub>2</sub> emissions. In the short term, most of Indonesia's industrial sectors, such as manufacturing and processing of natural resources, tend to use lower technologies in terms of energy efficiency and are still dependent on fossil energy that produces CO<sub>2</sub> emissions. Therefore, despite the increase in industrial added value, its effect on CO<sub>2</sub> emissions is not so large in a relatively short period. [Shahzad, et al \(2022\)](#) research shows that increased production in industrial sectors that are not supported by green technologies or energy transitions can exacerbate pollution in the short term, even though industrial added value increases.

The results of this study are in accordance with research conducted by [Yang & Khan \(2022\)](#) that industrial added value influences CO<sub>2</sub> emissions in the long term, but in the short term the effect can be limited by the influence of technological efficiency and emission reduction policies implemented by the government. [López-Manuel, et al \(2023\)](#) also found that the industrial sector does need time to show a significant impact on CO<sub>2</sub> emissions, especially in developing countries that still rely on conventional technologies.

The trade value in Table 4 also does not show a significant effect on CO2 emissions in Indonesia in the short term. Although international trade has the potential to affect energy use and emissions, its impact in the short term may not be large enough. One reason could include limited trade influence on a particular sector or reliance on efficient technology within that time frame. This study is in line with research conducted by [Jiang & Guan \(2017\)](#) that international trade is associated with an increase in CO2 emissions in the long term, but the effect in the short term is not always immediately felt. [Kozul-Wright & Fortunato \(2012\)](#) also show that although trade has a long-term impact on emissions, in a shorter period other factor, such as domestic policies and technology adoption, can mitigate such negative influences.

Economic growth has a positive influence on increasing CO2 emissions in the short term. This reflects that during periods of rapid economic growth, energy consumption increases, often through increased consumption of fossil fuels, which contributes to high carbon emissions. While economic growth can bring prosperity, in developing countries like Indonesia, this is often accompanied by increased carbon pollution. This research is in line with research conducted by [Barreto \(2018\)](#) that economic growth in the short term is generally driven by industries that depend on fossil fuels, which leads to an increase in CO2 emissions. Research by [Fankhauser & Jotzo \(2018\)](#) also indicates that developing countries often experience sharp increases in emissions in line with the acceleration of economic growth, especially if their energy infrastructure has not been fully diversified.

Table 4 also shows that oil consumption has a positive influence on increasing CO2 emissions in the short term. This study shows that during periods of economic growth, Indonesia tends to increase the consumption of fossil energy, especially oil, which has a direct impact on CO2 emissions. The increase in oil consumption, although in the short term, remains a major contributor to carbon emissions in Indonesia. This study is in line with research conducted by [Alam & Paramati \(2015\)](#) found that in the short term, oil consumption in developing countries is associated with an increase in CO2 emissions. [Akhmad & Amir \(2018\)](#) also noted that oil consumption, as the main energy source in the Indonesian economy, contributes directly to the increase in CO2 emissions. [Bildirci & Bakirtas \(2016\)](#) also showed a strong relationship between oil consumption and CO2 emissions, especially in countries that have a high dependence on fossil fuels.

#### **4. CONCLUSION**

In the long term, economic growth has a positive effect on increasing CO2 emissions in Indonesia. This suggests that the higher the rate of economic growth, the greater the impact on increased CO2 emissions. However, in the short term, economic growth also drives increased CO2 emissions, indicating that rapid economic growth can lead to increased energy consumption and greater use of resources, which in turn increases emissions.

**Industrial Added Value:** In the long run, industrial added value has a positive effect on increasing CO2 emissions. This means that the growing industrial sector will contribute more to CO2 emissions, along with the increase in energy use and environmentally friendly industrial processes. However, in the short term, industrial value added does not show a significant impact on CO2 emissions, which may be due to other factors that offset the direct impact of the industrial sector on emissions.

**Oil Consumption:** Oil consumption has a positive effect on increasing CO2 emissions, both in the long and short term. This indicates that Indonesia's dependence on

fossil fuels, especially oil, is leading to an increase in CO2 emissions. Policies that reduce oil consumption or switch to cleaner energy sources will be crucial to reduce negative impacts on the environment.

Investment (GFCF): Investments (Gross Fixed Capital Formation / GFCF) have a negative influence on CO2 emissions. This suggests that increased investment in certain sectors, such as green infrastructure or environmentally friendly technology, can reduce CO2 emissions. In the long run, investments that focus on sustainability and energy efficiency have the potential to reduce negative impacts on the environment.

Trade Value: Trade value has a negative effect on CO2 emissions in the long term, but in the short term, it has no significant effect on CO2 emissions. Increased trade may be related to increased efficiency or a shift to greener technologies, but this impact has not been fully seen in the short term.

Here are some recommendations that can be taken to reduce CO2 emissions in Indonesia, in line with sustainable economic growth and industrial development:

Given that oil consumption contributes significantly to increased CO2 emissions, governments and the private sector need to accelerate the transition to renewable energy sources such as solar, wind, and bioenergy. Policies that support the development of renewable energy, such as subsidies for green power generation or incentives for the use of electric vehicles, can help reduce dependence on fossil fuels.

Investment (GFCF) has a negative impact on CO2 emissions, which means that investments focused on green infrastructure and low-carbon technologies can lower CO2 emissions. Therefore, policies that encourage efficient technological innovation in energy use, such as clean technology and sustainable industries, should be prioritized. The government needs to provide incentives for the private sector to invest in green infrastructure development.

Although the value of trade has a positive effect on the reduction of CO2 emissions in the long term, the role of trade in emission reduction can be further maximized. Governments should encourage trade that supports the use of environmentally friendly technologies and introduce carbon taxes or environmental tariffs on goods that do not meet environmental sustainability standards. In addition, international cooperation in trade in environmentally friendly goods can also provide opportunities to support emission reduction efforts.

High economic growth can increase CO2 emissions if it is not followed by policies that support sustainability. Therefore, the government needs to integrate sustainability goals into economic development plans, such as the implementation of green growth strategies that prioritize improving energy efficiency and reducing carbon emissions in key economic sectors.

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