ECONOMIC TRANSFORMATION AND ENERGY CONSUMPTION TO REDUCE CARBON EMISSIONS TOWARDS INDONESIA'S SDGS

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Abstract

Indonesia's carbon dioxide emissions continue to rise despite its emission reduction commitments, highlighting a gap between policy and implementation. The country's reliance on fossil fuels, limited penetration of renewable energy, and the varied effects of foreign direct investment and industrialization highlight the importance of empirical analysis of the key drivers of emissions. This study strengthens the ARDL-based empirical evidence on the nexus among FDI, industrialization, energy consumption, and carbon emissions in Indonesia by incorporating the Environmental Kuznets Curve (EKC), the Pollution Haven Hypothesis, the Energy–Emissions Nexus Theory, and the Sustainable Development Theory. Using annual data from 1984 to 2023, the analysis evaluates the impacts of foreign direct investment, manufacturing value added, oil consumption, coal consumption, and low-carbon energy use on carbon dioxide emissions in both the short and long run. The results indicate that foreign direct investment initially increases emissions but has an insignificant adverse effect in the long run. Industrialization, oil, and coal consumption significantly raise emissions in both periods, while low-carbon energy consumption reduces emissions only in the long run. These findings suggest that Indonesia's clean energy transition requires more substantial policy commitment, greater green investment, and improved industrial efficiency to achieve sustainable decarbonization.

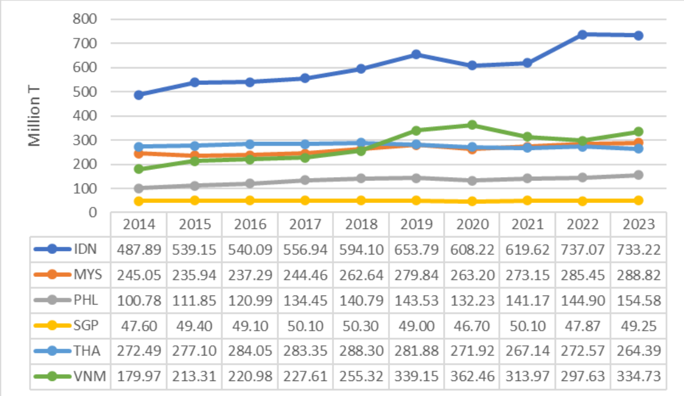
Keywords*: carbon dioxide emissions, FDI, fossil energy, industrialization, low-carbon energy*

INTRODUCTION

Climate change, as addressed in Sustainable Development Goal (SDG) 13, Climate Action, has become a crucial issue in global development. Climate change has serious negative implications for the environment and human life (Evitasari & Komarulzaman, 2023). This change is triggered by global warming, which causes a decline in environmental quality that many individuals feel (Putra, Purwaningsih, Hikam & Wau, 2024).

One of the main contributors to global warming is the release of greenhouse gases, especially carbon dioxide (CO_2). Increased carbon dioxide traps solar radiation in the atmosphere and triggers an increase in temperature (Maulidina & Maulana, 2022). The higher the temperature, the greater the risk of disasters in various parts of the world (Kurniarahma, Laut & Prasetyanto, 2020), which has an impact on health, food security, and human safety.

Indonesia is listed as one of the most significant contributors to carbon dioxide emissions in the ASEAN region, particularly from the energy and industrial sectors. Figure 1 describe CO_2 emissions in 6 ASEAN countries from 2014 to 2023. High dependence on fossil fuels is an important factor driving emissions growth in Indonesia compared to other ASEAN countries. Studies show that, despite commitments to reduce emissions, significant challenges mean that Indonesia's contribution to regional emissions remains dominant (Noviyanti et al., 2024; Triani, tambunan, Dewi & Ediansjah, 2023).



	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
IDN	487.89	539.15	540.09	556.94	594.10	653.79	608.22	619.62	737.07	733.22
MYS	245.05	235.94	237.29	244.46	262.64	279.84	263.20	273.15	285.45	288.82
PHL	100.78	111.85	120.99	134.45	140.79	143.53	132.23	141.17	144.90	154.58
SGP	47.60	49.40	49.10	50.10	50.30	49.00	46.70	50.10	47.87	49.25
THA	272.49	277.10	284.05	283.35	288.30	281.88	271.92	267.14	272.57	264.39
VNM	179.97	213.31	220.98	227.61	255.32	339.15	362.46	313.97	297.63	334.73

Figure 1. CO_2 Emissions in 6 ASEAN Countries from 2014 to 2023
Source: Our World in Data (2024)

Data from 2014 to 2023 indicate an upward trend in carbon dioxide emissions across six ASEAN countries, with Indonesia consistently being the primary contributor, rising from 487.89 million tons in 2014 to 733.22 million tons in 2023, and experiencing a sharp surge from 2021 to 2022. Vietnam has recorded a significant increase since 2014, ranking as the second-highest. Meanwhile, Malaysia, Thailand, and the Philippines have experienced relatively stable growth with moderate increases, while Singapore remains the lowest, with minimal fluctuations.

The trigger for the increase in carbon dioxide emissions is inextricably linked to economic activity in Indonesia. Foreign Direct Investment (FDI) is one economic activity that can affect carbon dioxide emissions. Figure 2 shows foreign direct investment in Indonesia. FDI directed toward the industrial and manufacturing sectors may raise emissions if not accompanied by the adoption of environmentally friendly technologies (Ihsan, 2019). FDI tends to flow into developing countries with weak environmental regulations, thereby increasing carbon emissions (Jinapor, Abor & Graham, 2024; Sarkodie, Adams & Leirvik, 2020).

Figure 2. Foreign Direct Investment in Indonesia
Source: World Bank (2024)

Data from 2014 to 2023 shows that FDI in Indonesia has declined significantly from 2.82% to 1.57% (Figure 2). These fluctuations have the potential to affect carbon dioxide emissions, especially when foreign investment enters energy-intensive and fossil-based manufacturing sectors (Lesmana, Astuty & Jamil, 2024). Environmental regulations and the application of green technology are crucial to ensure that FDI drives economic growth without exacerbating environmental degradation (Rizki & Anggraeni, 2022).

Another factor affecting carbon dioxide emissions is industrialization, which is driven by the added value of the manufacturing sector. The added value of manufacturing in Indonesia can be seen in Figure 3. Fossil fuel-based industrial activities increase carbon dioxide emissions due to high energy consumption in production (Wicaksono et al., 2025). Early economic growth increases emissions, but after a certain income level is reached, clean technology and strict regulations can help reduce them. Jinapor et al. (2024) argue that early industrialization triggers an increase in emissions, but this can be mitigated through institutional improvements and environmental policies.

Figure 3. Manufacturing value added in Indonesia
Source: World Bank (2024)

Data from 2014 to 2023 shows that Indonesia's manufacturing value added rose from US$187.7 billion to US$256.0 billion, reflecting production expansion and downstreaming in the manufacturing sector. However, this increase was accompanied by a rise in carbon dioxide emissions, particularly from energy-intensive sectors (Swardanasuta, Sandy, Rohmah, Arindah & Kartiasih). *International Energy Agency* (IEA, 2023) also reports that Indonesia's industrial sector is a major contributor to carbon dioxide emissions resulting from the combustion of fossil fuels for electricity generation and industrial activities.

The use of fossil fuels is also a significant factor contributing to the rise in carbon dioxide levels. Dependence on fossil fuels poses a serious challenge to sustainability, despite increasing productivity (Ansari, Ahmad, Kumar, Yadav & Ritu, 2023). Oil consumption drives economic growth, but increases carbon dioxide emissions, which have a causal relationship with carbon dioxide (Aslam, Hu, Ali, AlGarni & Abdullah, 2022). Figure 4 shows oil consumption in Indonesia. The shift toward renewable energy sources is crucial for maintaining a balance between economic growth and environmental preservation.

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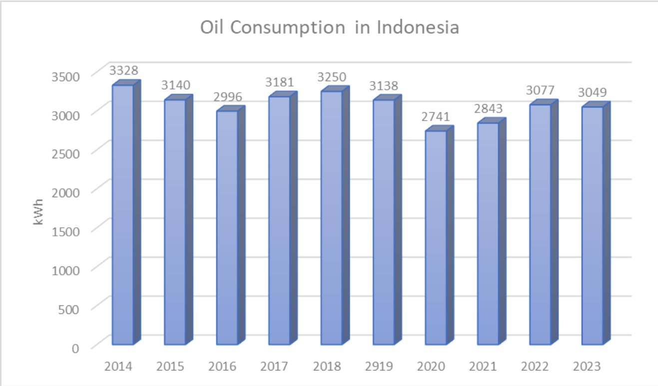

Figure 4. Oil Consumption in Indonesia
Source: Our World in Data (2024)

Data from 2014 to 2023 show a downward trend in oil consumption in Indonesia, from 3,356 kWh to 3,099 kWh, which has important implications for carbon dioxide emissions, as oil is the primary source of fossil energy. The higher the oil consumption, the greater the emissions from combustion (IEA, 2022), and global analysis confirms that fossil fuels, including oil, continue to drive emissions growth in major emitting countries (Zou, Zhang,Liu, Li & Wang, 2024). Although the decline is relatively small, this trend is a positive indication for long-term emissions control.

Coal consumption constitutes a substantial source of global carbon dioxide emissions, particularly in developing economies that rely heavily on fossil fuels. In Indonesia, coal consumption has increased in line with economic growth, resulting in environmental harm (Figure 5). Coal production, consumption, and exports significantly increase carbon emissions (Aimon, Kurniadi, Sentosa & Rahman, 2023), while combustion in industry and power plants generates significant emissions due to low energy efficiency (Zhu et al., 2020) and coal-based economic activities exacerbate global warming (Peng & Liu, 2023).

Figure 5. Coal Consumption in Indonesia
Source: Our World in Data (2024)

Data from 2014 to 2023 indicate that Indonesia's coal consumption increased from 469 TWh to 1,200 TWh, positioning it as a significant contributor to carbon dioxide emissions due to its continued reliance on fossil fuels in industrial activities and power generation. According to the Global Carbon Project, coal use in 2022 reached a record high, increasing greenhouse gas emissions by more than 20% (Jong, 2023). In addition to consumption volume, the quality of coal, which has a high carbon content, also increases the emissions produced (Damayanti & Khaerunissa, 2018).

Climate change, driven by carbon dioxide emissions originating from the energy sector, is accelerating the global shift toward low-carbon energy sources, including nuclear and renewable options. Low Carbon Energy Consumption Data in Indonesia can be seen in the Figure 6. Nuclear energy, which is stable and low in emissions, is effective in reducing long-term emissions (Xie et al., 2024). Renewable energy sources such as wind and solar contribute significantly, but are constrained by intermittency and weather (Paraschiv, 2023). The integration of nuclear-renewable hybrid systems is considered capable of increasing the efficiency and flexibility of carbon emission reduction (Suman, 2018).

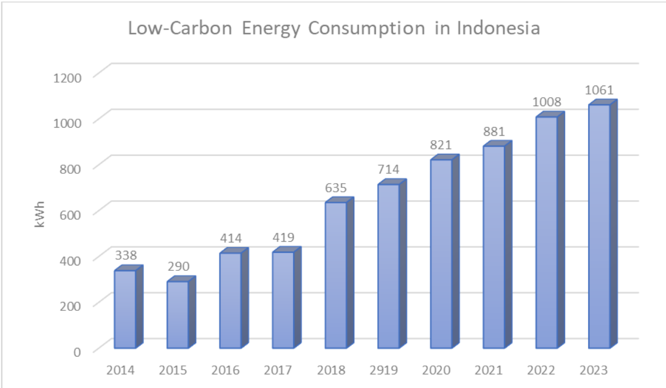

Figure 6. Low-Carbon Energy Consumption in Indonesia

Source: Our World in Data (2024)

Data from 2014 to 2023 show a significant increase in oil consumption in Indonesia, from 331 kWh to 1,057 kWh. This increase contributes to reduced carbon dioxide emissions because low-carbon energy sources produce lower emissions than fossil fuels (IEA, 2021). The shift to low-carbon energy can slow environmental degradation, in line with the findings of Dogan and Seker (2016), which show that renewable energy consistently reduces carbon dioxide emissions in developing countries.

Indonesia's carbon dioxide emissions continue to rise despite its reduction commitments, revealing a persistent gap between policy and implementation. The nation's reliance on fossil fuels, limited integration of low-carbon energy sources, and the multifaceted role of FDI and industrialisation highlight the need for empirical investigations into the primary drivers of emissions. The period 1984–2023 was selected as it captures four decades of Indonesia's and ASEAN's economic and environmental transformation from the onset of industrialisation and FDI liberalisation in the mid-1980s, through the Asian financial crisis (1997–1998), to the post-Paris Agreement era after 2015, allowing a comprehensive long-term analysis of structural shifts, industrial growth, and evolving energy policies.

Although prior research has explored the drivers of CO_2 emissions, only a small number of studies have investigated the combined effects of foreign direct investment, industrialisation, fossil fuel use, and low-carbon energy consumption in Indonesia. This study enhances the existing literature by examining the dynamic relationships among these factors from 1984 to 2023 using the Autoregressive Distributed Lag (ARDL) approach, providing evidence of both short-run and long-run impacts. Accordingly, the central research question is: How do foreign direct investment, industrialisation, fossil energy consumption, and low-carbon energy consumption shape CO_2 emissions in Indonesia over the 1984–2023 period?

LITERATURE REVIEW

Pollution Haven Hypothesis (PHH)

The Pollution Haven Hypothesis posits that multinational firms relocate polluting industries to developing countries that enforce less stringent environmental regulations. These firms move environmentally harmful activities to lower their production costs. Marques and Caetano (2020) demonstrated that the impact of FDI on emissions is more pronounced in middle-income countries compared to developed nations. Murshed (2023) likewise confirms that FDI can exacerbate pollution in host countries with weak environmental standards. Consistent with this, Pham, Nguyen, Nguyen and Tran (2025) reported that FDI inflows tend to raise carbon emissions across many developing economies.

Pollution Halo Hypothesis

In contrast to the PHH, the Pollution Halo Hypothesis emphasizes that foreign investment can contribute positively to the environment through the transfer of clean technology, improved production standards, and energy efficiency. Recent research shows that FDI can reduce pollution emissions, primarily when supported by strict environmental regulations (Liu, Cao, Wu, Xi & Zhang 2025), and encourage green technological innovation in urban areas (Fang, Zhang, Lei & Houadi, 2023).

Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve, depicts the relationship between economic growth and environmental degradation as an inverted U-shaped trajectory. Emissions typically increase during the initial stages of development and then decrease once income surpasses a certain threshold. Research by Ayık and Özer (2025) supports the EKC hypothesis in E7 countries, showing that carbon dioxide emissions decline as per capita income increases.

Structural Change Theory

Structural Change Theory posits that economic structural shifts from agriculture to industry lead to increased fossil fuel consumption and carbon dioxide emissions. Structural changes are closely related to export diversification and increased industrial sector productivity (Gabardo, Porcile & Perreima, 2018). Green innovation can moderate the negative environmental impacts of industrialization, making the shift to low-carbon technology sectors more sustainable.

Energy–Emissions Nexus Theory

The Energy–Emissions Nexus Theory emphasizes the strong connection between energy use and carbon emissions, with fossil-fuel energy being the most significant driver of environmental degradation. Existing studies indicate that improved energy access can enhance production efficiency and lower emissions (Ganda & Panicker, 2024). Nevertheless, unchecked growth in energy consumption may result in increased carbon emissions. Therefore, formulating energy policies that promote a transition to clean and efficient energy sources is essential.

Fossil Fuel Dependency Theory

The Fossil Fuel Dependency Theory asserts that a nation's reliance on fossil fuels is a major contributor to the growth of carbon dioxide emissions in the energy and industrial sectors. Predominant consumption of coal, oil, and natural gas hampers the shift toward clean energy, leading to substantial annual emission increases in countries with high dependency levels (IEA, 2025). This highlights the importance of reducing fossil fuel consumption to mitigate climate change.

Sustainable Development Theory

Sustainable Development Theory highlights the need to balance economic growth, environmental protection, and social equity (Sachs, 2013). Transitioning to low-carbon energy is an essential condition for achieving sustainable development. Consistent with this perspective, the use of low-carbon energy derived from renewable and nuclear sources plays a crucial role in lowering emissions relative to fossil fuels. Caglar, Daştan, Demirdağ and Avci, (2025) it has also been demonstrated that rising low-carbon energy consumption significantly contributes to reducing emissions in the long run.

Conceptual Framework

Referring to the previous theoretical and research descriptions, the conceptual framework of this study is structured as follows (Figure 7):

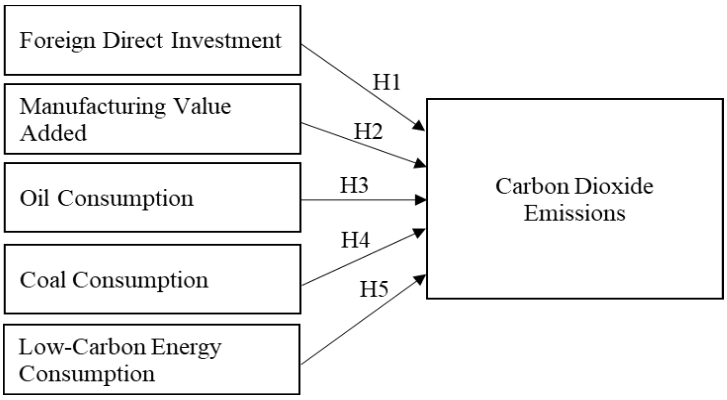

Figure 7. Conceptual Framework

RESEARCH METHOD

This study adopts a quantitative method using time series data consisting of 40 observations covering the period from 1984 to 2023. It relies on secondary data obtained from the World Bank and Our World in Data. The dependent variable in this research is carbon dioxide emissions, while the independent variables include FDI, manufacturing value added, oil consumption, coal, and low-carbon energy. Research variable indicators can be seen in Table 1.

The Auto-Regressive Distributed Lag (ARDL) method was employed in this study as an analytical technique to examine the effects of the independent variables on the dependent variables in both the short run and the long run. This modelling approach is considered valid when cointegration exists among the lagged variables, with the main requirement being that the coefficient is negative and statistically significant at the 5% level in the short run (Buana & Riyanto, 2019).

Table 1. Research Variable Indicators

Variable	Description	Unit	Source
Carbon Dioxide Emissions	The amount of carbon dioxide emissions per year generated by the country	Ton	Our World in Data
Foreign Direct Investment	The percentage of foreign investment entering a country compared to that country's GDP	%	World Development Indicators − World Bank
Manufacturing Value Added	Manufacturing value added shows industrial output after deducting input costs.	Current US$	World Development Indicators − World Bank
Oil Consumption	Average fuel consumption per person in a country	Kilowatt-hour (kWh)	Our World in Data
Coal Consumption	Total annual coal consumption by country	Terawatt-hour (TWh)	Our World in Data
Low-carbon Energy Consumption	Total per capita low-carbon energy consumption, including nuclear and renewable energy	Kilowatt-hour (kWh)	Our World in Data

The ARDL approach is appropriate for time series data because it can accommodate variables integrated at orders I(0) and I(1), although it cannot be applied when any variable is integrated at order I(2) (Kripfganz & Schneider, 2023; Ghouse, Khan & Rehman, 2018). The general equation form in this study is presented as follows:

$$LNCO2_t = \beta_0 + \beta_1 FDI_t + \beta_2 LNMVA_t + \beta_3 LNOC_t + \beta_4 LNCC_t + \beta_5 LNLCE_t + \varepsilon \quad (1)$$

Based on Equation (1), it can be derived into Equation (2), which represents the ARDL estimation model that includes the estimation of long-term and short-term relationships as follows:

$$\Delta LNCO2_t = \alpha_0 + \sum_{i=0}^{k} \alpha_{1i}\ \Delta LNCO2_{t-1} + \sum_{i=0}^{k} \alpha_{2i}\ \Delta FDI_{t-1} + \sum_{i=0}^{k} \alpha_{3i}\ \Delta LNMVA_{t-1} + \sum_{i=0}^{k} \alpha_{4i}\ \Delta LNOC2_{t-1} + \sum_{i=0}^{k} \alpha_{5i}\ \Delta LNCC2_{t-1} + \sum_{i=0}^{k} \alpha_{6i}\ \Delta LNLCE2_{t-1} + \theta_1 \Delta FDI_t + \theta_2 \Delta LNMVA_t + \theta_3 \Delta LNOC_t + \theta_4 \Delta LNCC_t + \theta_5 \Delta LNLCE_t + \varepsilon_t \quad (2)$$

Explanation:

Δ	: Lag
$\alpha_1 - \alpha_6$	: Short-term coefficient
$\alpha_1 - \alpha_6$	: Long-term coefficient
LNCO2	: Carbon dioxide emissions

FDI	: Foreign direct investment
LNMVA	: Manufacturing value added
LNOC	: Oil consumption
LNCC	: Coal consumption
LNLCE	: Low-carbon energy
ε_t	: Error term

From the previously formed model equation, the Error Correction Model (ECM) form of the ARDL model can be derived as follows:

$$\Delta LNCO2_{\mathrm{t}} = \alpha_0 + \sum_{i=0}^{k} \alpha_{1i}\ \Delta LNCO2_{t-1} + \sum_{i=0}^{k} \alpha_{2i}\ \Delta FDI_{t-1} + \sum_{i=0}^{k} \alpha_{3i}\ \Delta LNMVA_{t-1} + \sum_{i=0}^{k} \alpha_{4i}\ \Delta LNOC2_{t-1} + \sum_{i=0}^{k} \alpha_{5i}\ \Delta LNCC2_{t-1} + \sum_{i=0}^{k} \alpha_{6i}\ \Delta LNLCE2_{t-1} + \gamma ECT_t + \varepsilon_t \quad (3)$$

Keterangan:
γECT_t : Error correction

RESULTS AND DISCUSSION

Before estimating the ARDL model, various diagnostic tests were carried out to confirm that the model complied with the basic econometric assumptions (Ridha & Mutia, 2021). The stationarity test using the Augmented Dickey-Fuller (ADF) approach was applied to identify the integration order of the variables and to ensure the absence of any I(2) variables. Stationarity test results can be seen in Table 2. Subsequently, the Bound Test for cointegration was carried out to examine the existence of long-run relationships among the variables. Lastly, classical assumption testing was employed to assess autocorrelation, heteroscedasticity, multicollinearity, and the normality of residuals.

Table 2. Stationarity Test Results

Variable	Level	*1st Different*	Conclusion
LNCO	0.6956	0.0000	Stasionary I(1)
FDI	0.1361	0.0000	
LNMVA	0.7006	0.0000	
LNOC	0.2704	0.0001	
LNCC	0.5585	0.0463	
LNLCE	0.8446	0.0000	

All variables are non-stationary at the levels (p-value > 0.05). However, after first differentiation, all variables become stationary (p-value < 0.05), which permits the implementation of the cointegration test in the ARDL model to examine the long-term relationships among the variables. Table 3 shows cointegration bounds test results.

Table 3. Cointegration Bounds Test Results

Test Statistic	Value	k	Critical Value Bounds		
			Significance	**I(0)**	**I(1)**
F-statistic	19.3329	5	10%	2.08	3
			5%	2.39	3.38
			2.50%	2.7	3.73
			1%	3.06	4.15

A cointegration test was performed to examine the long-term relationship between the variables. The F-statistic value of 19.3329, exceeding the 5% critical bounds of I(0) and I(1), confirms the existence of a correlation among the variables in both the short and long term.

The number of lags was determined through an optimal lag test to improve the accuracy of the cointegration analysis and model estimation (Figure 8). This test ensures that the model accurately reflects the relationship between components. The lag selection was determined using the Akaike Information Criterion (AIC), with the model exhibiting the lowest AIC value deemed the most optimal.

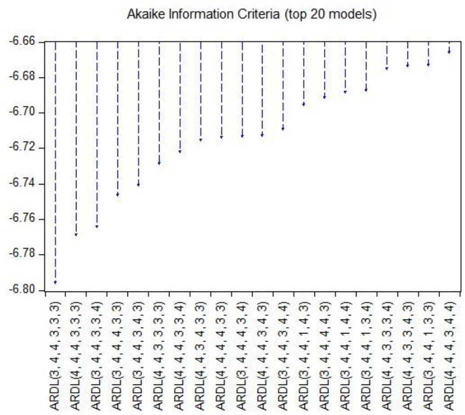

Figure 8. Determination of Optimal Lag

The ARDL model was selected based on the Akaike Information Criterion (AIC). The findings show that the ARDL (3, 4, 4, 3, 3, 3) specification is the most appropriate, incorporating four lags for each variable to ensure more reliable and stable estimates in both the short and long run. Table 4 shows results of classical assumption tests.

Table 4. Results of Classical Assumption Tests

	Autocorrelation Test		Heteroscedasticity Test		Normality Test	
	Short Term	Long Term	Short Term	Long Term	Short Term	Long Term
Obs*R-squared	3.3111	4.3000	15.2154	2.8261	0.2962	0.6623
Prob. Chi-Square	0.1910	0.1165	0.9362	0.7268	0.8624	0.7181

The autocorrelation test is employed to determine whether residuals in the regression model are correlated across time periods. The Breusch–Godfrey results report probabilities of 0.1910 for the short run and 0.1165 for the long run, both exceeding the 0.05 threshold, indicating that the regression model is free from autocorrelation issues.

The heteroscedasticity test is performed to verify the consistency of residual variance within the regression model. According to the Breusch–Pagan–Godfrey test, the probability values of 0.9362 in the short run and 0.7268 in the long run are above 0.05, suggesting that the model does not exhibit heteroscedasticity.

A normality test is conducted to confirm the residuals' distribution in the regression model. Based on the Jarque–Bera test, the probability values of 0.8624 in the short run and 0.7181 in the long run, both greater than 0.05, indicate that the residuals follow a normal distribution. The results of the multicollinearity data can be seen in the Table 5.

Table 5. Multicollinearity Test Results

Long-Term	
Variable	***Centered* VIF**
D(FDI)	1.2756
D(LNMVA)	1.4811
D(LNOC)	1.3231
D(LNCC)	1.1202
D(LNLCE)	1.1770

Short-Term						
Lag	**D(LNCO2)**	**D(FDI)**	**D(LNMVA)**	**D(LNOC)**	**D(LNCC)**	**D(LNLCE)**
0		4.4520	2.6641	2.7635	2.4021	2.4988
1	9.0072	3.1975	5.9688	3.5745	3.2743	2.9745
2	4.6120	3.2606	5.0401	4.7744	1.9311	3.0252
3	3.8184	3.4271	4.9908	3.8065	2.6006	3.9258
4		3.9345	3.3677			

A multicollinearity test was conducted to ensure that there was no high correlation between the independent variables in the model. The results show that all Centered VIF values in both the short and long term are below 10, indicating that the model is free from multicollinearity problems. Table 6 shows long-term ARDL model regression results.

Table 6. Long-Term ARDL Model Regression Results

Variabel	Koefisien	Probabilitas
D(FDI)	-0.005467	0.0830
D(LNMVA)	0.093849	0.0312
D(LNOC)	0.766813	0.0000
D(LNCC)	-0.1711	0.0005
D(LNLCE)	0.127547	0.0007

The results of the long-term coefficient test estimation indicate that the variables of industrialization, oil consumption, coal consumption, and low-carbon energy consumption have a long-term impact on carbon dioxide emissions. This is demonstrated by the probability values of each variable being below the 5% significance threshold, except for the FDI variable, which is not significant. Therefore, it can be inferred that most of the independent variables in the model have a substantial long-term influence on the dependent variable. The results short-term ARDL model regression can be seen in Table 7.

Table 7. Short-Term ARDL Model Regression Results

Lag	D(LNCO2)	D(FDI)	D(LNMVA)	D(LNOC)	D(LNCC)	D(LNLCE)
0		-0.0065	0.2030	0.7264	0.0254	-0.0308
		(0.0021)	(0.0000)	(0.0000)	(0.2623)	(0.1351)
1	0.6819	-0.0012	-0.1160	-0.1608	0.2379	-0.2905
	(0.0001)	(0.5473)	(0.0009)	(0.1032)	(0.0000)	(0.0000)
2	0.5377	0.0032	-0.0769	-0.1734	0.0574	-0.0473
	(0.0000)	(0.0904)	(0.0138)	(0.0430)	(0.0292)	(0.0852)
3		0.0060	0.0580			
		(0.0023)	(0.0067)			
4						
CointEq(-1)		-2.268953			0.0000	

In the short-run estimation of the integrated ARDL model, the Error Correction Term (ECT) reflects the speed of adjustment toward the long-run equilibrium. The estimation produces an ECT coefficient of –1.7239 with a significance level of 0.0000, demonstrating that the model can correct the previous period's disequilibrium by 172.39% within a single period. The validity requirements for ECT, namely a negative coefficient and significance at the 5% level, have been met. Therefore, the short-term ARDL model can be declared suitable for analyzing the dynamics of the relationship between variables while maintaining long-term interdependence. F test and R-squared can be seen in Table 8.

Table 8. F Test & R-squared Results

Output			
F-statistic	25.43196	R-squared	0.986042
Prob(F-statistic)	0.000011		

Testing in both the short and long run offers a thorough understanding of the relationships among the variables. The F-test produces a value of 25.43196 with a probability of 0.000011, which is below 0.05, demonstrating that all independent variables exert a statistically significant influence on the dependent variable. The R^2 value of 0.986042 shows that the model accounts for 98.60% of the variation in carbon dioxide emissions, while the remaining 1.40% is explained by external factors.

This study uses the CUSUM and CUSUM of Squares tests to assess the stability of regression model parameters over time (Figure 9). These tests are essential in time series models, such as ARDL, because parameter stability determines the reliability of the estimates. In the graph, the blue line shows the cumulative deviation of the residuals, while the dotted red line marks the 5% significance limit. The model is considered stable if the blue line is within that limit.

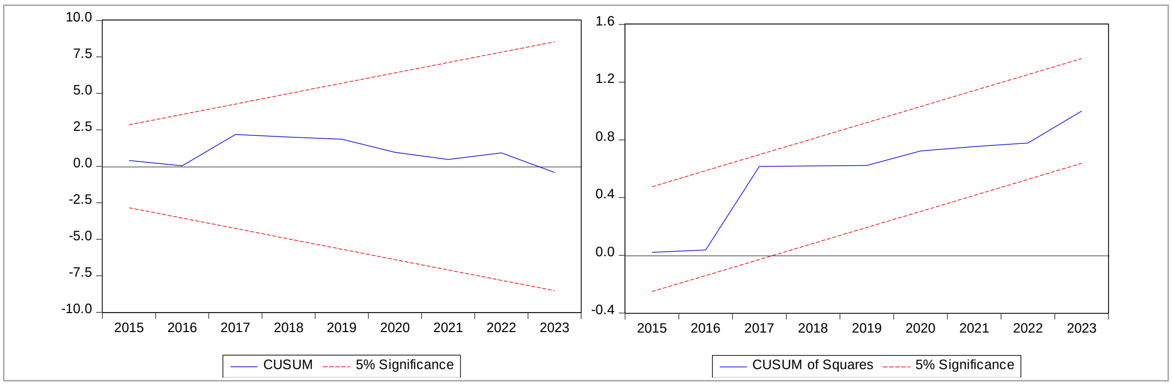

Figure 9. CUSUM & CUSUMQ Test Results
Source: EViews 10 (data processed, 2025)

The test results show that the CUSUM and CUSUM of Squares curves remain within the 5% critical limit from 2015 to 2023, indicating that the model parameters are stable and have not undergone significant structural changes, making the ARDL model valid and reliable for analysis and prediction.

This study employs the Granger causality test to examine the direction of causality between variables in a time series model. This test aims to determine whether changes in one variable in the past can be used to predict changes in other variables in the present or future. In the context of the ARDL model, the Granger test serves to understand the dynamics of the correlation between variables, such as whether the correlation is unidirectional, bidirectional, or has no causal correlation at all. The test results are usually based on probability values (p-values), where values below 0.05 indicate a significant causal correlation between the variables being tested. Table 9 shows granger causality tests.

Table 9. Granger Causality Tests

Hyphothesis	Optimal Lag	Prob	Decision
FDI → LNCO2	4	0.4278	No causal correlation
LNCO2 → FDI	4	0.7244	No causal correlation
LNMVA → LNCO2	4	0.7074	No causal correlation
LNCO2 → LNMVA	4	0.4160	No causal correlation
LNOC → LNCO2	4	0.6078	No causal correlation
LNCO2 → LNOC	4	0.6550	No causal correlation
LNCC → LNCO2	4	0.0342	Causal correlation
LNCO2 → LNCC	4	0.0622	No causal correlation
LNLCE → LNCO2	4	0.1917	No causal correlation
LNCO2 → LNLCE	4	0.9567	No causal correlation

The results of the Granger causality test indicate that an increase in coal consumption significantly contributes to an increase in CO_2 emissions. At the same time, other variables, such as FDI, manufacturing value added, oil consumption, and low-carbon energy, have no significant causal effect. These findings confirm that Indonesia's dependence on coal remains a major factor in carbon emissions, and that energy transition efforts need to focus on diversifying energy sources towards cleaner energy.

The Effect of Foreign Direct Investment on Carbon Dioxide Emissions in Indonesia

Short-Term Result:

In the short run, FDI does not influence carbon emissions in the current year. At lag 1, it shows a negative yet insignificant effect, whereas at lags 2 and 3, it exhibits a positive and significant effect at the 5% level. These results suggest that FDI typically contributes to higher carbon emissions in the short term, although it may lead to emission reductions over a longer time horizon. This implies that foreign investment inflows tend to increase carbon emissions in the short term, aligning with the Pollution Haven Hypothesis, which posits that foreign investors may exploit weak environmental regulations in host countries.

Long-Term Result:

In the long run, the direction of FDI's impact on carbon emissions changes to negative, towards an increase in carbon dioxide emissions. However, this effect is not yet significant, meaning it is not strong enough to be considered stable. These findings support the potential of FDI as a channel for environmentally friendly technology transfer, as suggested by the Pollution Halo Hypothesis, but this potential has not been fully realized. Pham et al. (2025) add that without the implementation of green screening, FDI can actually worsen emissions through the effects of production scale.

The correlation between foreign direct investment and carbon emissions in Indonesia does not reveal a causal correlation, either in one direction or both. This suggests that fluctuations in foreign investment levels do not directly impact CO_2 emissions, and shifts in carbon emissions do not directly influence foreign investment inflows. Consequently, the influence of foreign investment on carbon emissions in Indonesia is likely indirect, operating through channels such as changes in industrial structure, production efficiency, or the adoption of environmentally sustainable technologies.

The rise in extreme weather events in Indonesia, including coastal flooding and heatwaves, highlights the urgent need to channel FDI into environmentally responsible sectors. The KLHK (2024) the report also shows that emissions from the industrial and energy sectors increase in line with investment in heavy manufacturing areas, indicating that without firm policies, FDI actually exacerbates environmental degradation and hinders the transition to clean energy. These results describe who note that FDI in Indonesia remains concentrated in sectors that are not environmentally sustainable. Pujiati et al. (2023) also, confirm that most foreign investment is still focused on fossil fuel-based sectors.

The Effect of Manufacturing Value Added on Carbon Dioxide Emissions in Indonesia

Short-Term Result:

In the short run, manufacturing has a fluctuating effect on carbon emissions. An increase in output in the current year drives an increase in emissions, while in lags 1 and 2, there is a significant decrease, reflecting energy efficiency or policy responses. However, lag 3 shows a positive effect, confirming the dynamic relationship between manufacturing and emissions (Raihan, 2023; Raza & Hasan, 2022). These findings align with Structural Change Theory, which emphasizes the role of changes in the composition of economic sectors on environmental impacts.

Long-Term Result:

In the long run, manufacturing has a significant positive effect on emissions, in line with the Environmental Kuznets Curve (EKC), which places Indonesia in an increasing phase, where industrialization still relies on fossil fuels (Leal & Marques, 2022; Zhang, Chen, Wu, Shuai & Shen, 2019). To reach the declining phase of the EKC, transformation is needed through environmentally friendly technology, low-carbon energy, and increased human resource capacity (Bekun, Gyamfi, Olasehinde-Williams & Yadav, 2024).

The correlation between manufacturing sector value added and carbon emissions shows no direct causal correlation between the two. This suggests that changes in manufacturing output do not directly cause changes in carbon emission levels. However, both tend to move in the same direction in the long term, with a general upward trend. Thus, the influence between the two is more structural than directly causal.

Several new industrial areas in the downstream program are still not connected to clean energy, with around 67% of them still relying on coal-fired power plants (Setiawan, 2024). Air quality indices in Cilegon and Karawang show a worsening trend, with PM2.5 reaching 42.5 µg/m³ and Cilegon's index rising to 63.91 in 2023 (IQAir, 2025; Selatsunda, 2024), reflecting increased emissions in line with industrial expansion. This condition underscores the importance of striking a balance between manufacturing growth and decarbonization strategies through effective emission regulations, renewable energy incentives, and clean production technologies.

The Impact of Oil Consumption on Carbon Dioxide Emissions in Indonesia

Short-Term Result:

In the short run, energy consumption exerts a positive and significant influence on carbon emissions in the current year, but exhibits a negative effect in lags 2 and 3, although not consistently. This outcome is consistent with the Energy–Emissions Nexus Theory, which highlights the strong linkage between fossil fuel use and carbon emissions (Dissanayake et al., 2023). The positive impact can be attributed to the dependence on fossil fuels, while the delayed negative impact may be due to improvements in energy efficiency or partial substitution with cleaner energy sources (Guevara-Segarra, Guevara-Segarra, Quinde-Pineda & Guerrero-Vásquez, 2025).

Long-Term Result:

In the long run, energy consumption has a significantly positive impact on carbon emissions, suggesting that a structural dependence on fossil fuels remains the primary driver of increasing emissions. This aligns with the Fossil Fuel Dependency Theory, which posits that the dominance of oil, coal, and natural gas hinders the transition to clean energy (IEA, 2025). Therefore, decarbonization strategies that reduce fossil fuel consumption and accelerate the adoption of renewable energy are crucial for reducing long-term emissions (Shaari et al., 2024).

The correlation between oil consumption and carbon emissions is not causal, meaning that although increased oil consumption contributes to higher emissions in the long term, the change does not occur immediately. This finding reflects structural trends in Indonesia's fossil fuel use patterns, where dependence on petroleum remains part of the national energy dynamic that is difficult to change quickly.

The phenomenon of increasing air pollution in major cities, such as Jakarta, Surabaya, and Medan, highlights the intensity of oil combustion. PM2.5 concentrations in Indonesia rose by 20% from the previous year, mainly from transportation and oil-based industries (CREA, 2024). Energy subsidies of more than IDR 300 trillion in 2024 are slowing the transition to clean energy (Rahayu & Arief, 2025), highlighting structural and policy challenges that reinforce oil dependency.

The Impact of Coal Consumption on Carbon Dioxide Emissions in Indonesia
Short-Term Result:

In the short run, energy consumption exhibits a positive yet insignificant effect in the current year, whereas at lags 1 and 2 it demonstrates a significant positive influence on carbon emissions. This aligns with the Energy–Emissions Nexus Theory, which emphasizes the close relationship between energy consumption, particularly from fossil fuels, and increased carbon emissions (Ganda & Panicker, 2024). Meanwhile, the weaker effect at lag two may be attributed to improvements in energy efficiency or a partial shift toward cleaner energy sources.

Long-Term Result:

In the long run, energy consumption has a negative and significant impact on carbon emissions, indicating that the adoption of more efficient or low-carbon energy sources is contributing to reduced emissions. These results correspond with Sustainable Development Theory, which underscores the need to balance economic expansion, environmental preservation, and social equity, as well as the critical contribution of low-carbon energy to advancing sustainable development (Caglar, Daştan, Ahmed, Mert & Avci, 2024).

The correlation between coal consumption and carbon emissions is reinforced by the results of the Granger test, which shows a one-way causal correlation from coal consumption to carbon dioxide emissions. This means that changes in coal consumption significantly affect carbon emission levels, but not vice versa. These findings align with the results of the ARDL model estimation, which indicate that coal consumption is a significant factor driving emissions growth in Indonesia.

Data from the Sinaga (2024) indicate that more than 60% of the country's electricity is generated from coal-fired power plants. Indonesia also remains one of the world's largest coal exporters. This situation creates a dilemma between short-term economic interests and the urgency of decarbonization. Global pressures, such as the European Union's Carbon Border Adjustment Mechanism (CBAM), are driving strategies for a clean energy transition, increased energy efficiency, reduced coal use, and increased investment in renewable energy, all aimed at mitigating long-term emissions.

The Impact of Low-Carbon Energy Consumption on Carbon Dioxide Emissions in Indonesia

Short-Term Result:

In the short run, low-carbon energy consumption in the current year and lag 2 have a negative influence on carbon emissions, with lag 1 being significant, indicating that the early adoption of clean energy begins to directly reduce CO_2 emissions. This positive effect reflects the role of low-carbon energy in reducing dependence on fossil fuels, while variations in the effect in the current year and lag two can be attributed to infrastructure limitations or uneven technology implementation (IEA, 2022; Sarkodie et al., 2020).

Long-Term Result:

In the long run, low-carbon energy consumption has a positive and significant impact on mitigating carbon emissions. These outcomes suggest that the consistent adoption of clean technologies can significantly reduce CO_2 emissions and facilitate the transition toward a more sustainable energy framework in Indonesia.

The correlation between low-carbon energy consumption and carbon emissions shows that there is no direct causal correlation from year to year. This indicates that although low-carbon energy use has been proven to reduce emissions in the long term, its impact is not immediate; instead, it occurs through cumulative effects and long-term policies that encourage a gradual transition to clean energy.

This is consistent with the Indonesian government's plan to expand renewable energy capacity by 75 GW over the next 15 years as part of its pathway toward achieving net-zero emissions (Reuters, 2024). This achievement is also crucial, considering that the BMKG (2025) the report shows a trend of an increase in the national average temperature of 0.23°C per decade, which indicates the urgency of accelerating and strengthening greenhouse gas reduction efforts. Consequently, scaling up investments, regulations, and policies that stimulate low-carbon energy adoption constitutes a crucial strategy for decreasing long-term carbon emissions (Osman, 2024).

This aligns with Sustainable Development Theory, which emphasizes the importance of integrating economic growth, sustainable development, and environmental protection. This theory posits that the transition to clean energy and the adoption of low-carbon technologies not only reduce emissions but also foster inclusive and environmentally friendly economic growth.

CONCLUSION AND SUGGESTION

The study's results indicate that a combination of factors, including foreign investment, the manufacturing sector, and energy consumption patterns, influences carbon emission reductions in Indonesia. FDI has the potential to introduce low-carbon technologies, but its implementation has not been consistent. In the short term, FDI contributes to increased emissions, consistent with the Pollution Haven Hypothesis. In the long term, however, it may reduce emissions, aligning with the Pollution Halo Hypothesis. The manufacturing sector remains the primary driver of emissions due to its reliance on fossil fuels, supporting the Environmental Kuznets Curve (EKC), which suggests that Indonesia is still in the upward phase. Oil and coal consumption also significantly influence long-term emissions increases, supporting the Energy–Emissions Nexus Theory. Conversely, low-carbon energy effectively reduces emissions when applied consistently and supported by appropriate energy transition policies, consistent with the principles of Sustainable Development Theory.

The government and stakeholders need to strengthen regulations and incentives that encourage the use of low-carbon energy and investment in the green sector. Additionally, energy efficiency and the adoption of clean technology in the manufacturing sector must be expanded to reduce dependence on fossil fuels. Support in the form of policies, funding, and human resource capacity is also crucial for ensuring the effective and sustainable transition to a low-carbon economy.

Further research could focus on the role of environmental policy in moderating factors such as green finance, carbon regulations, energy efficiency indices, and indicators of green technological innovation and green fiscal policy, to provide a more comprehensive understanding of the mechanisms underlying the transition to a low-carbon economy. In addition, a dynamic cross-country ASEAN panel approach or spatial analysis between domestic industrial regions can be used to identify temporal and geographical variations in the relationship between economic development and carbon emissions.

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