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Promoting a Low-carbon Indonesia: How Energy Consumption and Financial Development Shape its Path

Ahmad Farabi[1], Anggi Putri Kurniadi[1], Zamroni Salim[1], Turnad Lenggo Ginta[2]*, Lenggogeni[2], Muizuddin Azka[2], Hens Saputra[2], Setyo Margo Utomo[2], Ratna Nurmayni[3], Nur Islahudin[4]

[1]Research Center for Macroeconomy and Finance, National Research and Innovation Agency (BRIN), Jakarta, Indonesia, [2]Research Center for Process and Manufacturing Industry Technology, National Research and Innovation Agency, Kawasan Puspiptek Setu Serpong, Kota Tangerang Selatan, Banten, Indonesia, [3]Research Center for Transportation Technology, National Research and Innovation Agency (BRIN), Indonesia, [4]Industrial Engineering Department, Dian Nuswantoro University, Semarang, Indonesia. *Email: turn001@brin.go.id

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ABSTRACT

This study examines the impact of energy consumption (ENC) and financial development on environmental quality, measured by CO_2 emissions in Indonesia. Financial development is represented by domestic credit to the private sector (CRD), international trade (ITR), and foreign direct investment (FDI). The ARDL methodology was selected as the most suitable approach based on the characteristics of the data. The findings reveal that, in the long term, all independent variables show a significantly negative effect on CO_2 emissions, with CRD, ITR, and FDI contributing to emission reductions except ENC. However, ENC negatively affects CO_2 emissions in the short term, whereas ITR and FDI show positive effects highlighting the importance of prioritizing energy efficiency and environmental considerations. This study is novel in its use of the latest data and its inclusion of several financial development variables namely domestic credit, trade, and investment.

Keywords: CO_2 Emissions, Energy Consumption, Domestic Credit, International Trade, FDI, Indonesia
JEL Classifications: Q43, Q52, Q58

1. INTRODUCTION

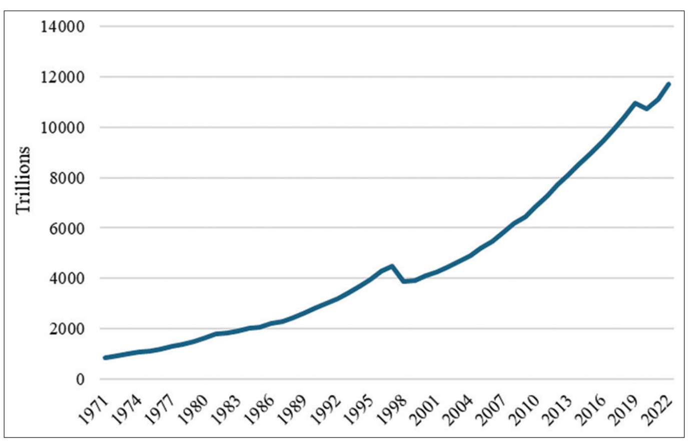
The growing severity of environmental damage has led to increased awareness among the public, environmental advocates, and government entities (Hassan et al., 2021). Addressing this issue is seen as urgent, given its direct impact on the survival of all life on Earth. In response, policymakers have implemented various strategies aimed at improving environmental conditions while supporting economic progress (Gani, 2021). In Indonesia, environmental protection is regulated under Law No. 32 of 2009, which prioritizes sustainable development to ensure the preservation and management of natural resources. Additionally, Indonesia demonstrated its commitment to global efforts in reducing greenhouse gas emissions by ratifying the Kyoto Protocol in 2004 through Law No. 17 of 2004 (Putra et al., 2021).

Even though various initiatives by the Indonesian government to enhance environmental quality, pollution levels continue to rise. Since the signing of the Kyoto Protocol, environmental degradation globally has only worsened (Farabi et al., 2024). Data from the World Bank's World Development Indicators reveals that Indonesia emitted 563,197 tons of CO_2 in 2020. This figure represents a significant surge compared to 1990, with emissions having grown by approximately 37% and continuing to climb. The primary drivers of this issue are the extensive use of fossil fuels, particularly gasoline for transportation and coal for industrial facilities and power generation (Chen et al., 2020).

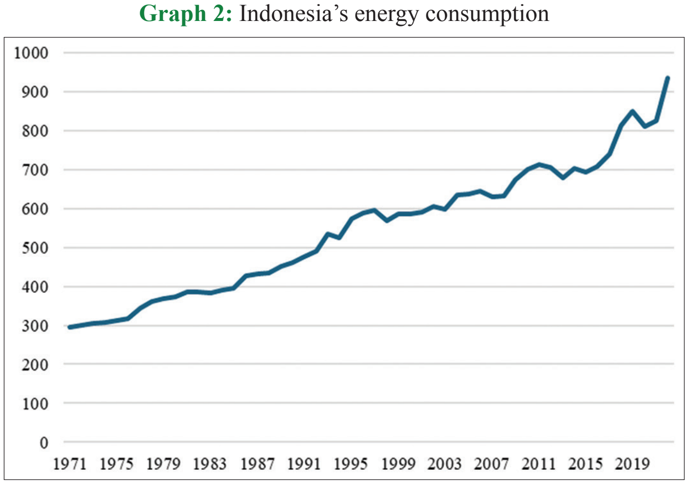
Indonesia's rapid economic expansion is closely linked to its growing reliance on fossil fuels and high energy usage (Farabi et al., 2019). Gross domestic product data highlights a steady and notable rise in the country's economic performance (Graph 1). Similar to trends observed globally, a nation's energy consumption plays a key role in shaping its economic development (Graph 2). However, this progress comes with a downside—rising carbon emissions, which are a major contributor to environmental degradation (Yu et al., 2018).

Numerous studies have explored the link between economic development and environmental quality. Many have found that rapid economic growth often correlates with higher pollution levels, driven by substantial energy consumption required for economic activities (Bastola and Sapkota, 2015). When fossil fuels, a primary energy source, are burned, CO_2 emissions increase, and higher energy demands result in greater environmental harm. Conversely, some research suggests that economic growth can coexist with improvements in environmental quality, proposing that a thriving economy can help preserve and enhance the environment. Additionally, other studies argue that there is no significant connection between economic growth and environmental degradation, treating them as independent factors. This perspective implies that changes in one do not necessarily influence the other. (Azwardi et al., 2021).

Graph 1: GDP of Indonesia



Graph 2: Indonesia's energy consumption



The relationship between economic growth and environmental quality remains a subject of ongoing debate in academic literature. To better understand this complex interplay, researchers have incorporated additional variables into their analyses. Among these, energy consumption emerges as a critical intermediary, acting as a transmission mechanism that links economic growth to environmental outcomes (Rahman, 2017). Salahuddin and Gow (2019) provide evidence of a dynamic interconnection between economic growth, energy consumption, and environmental quality. Their findings are reinforced by studies such as those by Nasreen et al. (2020), Usman et al. (2022), and Khan et al. (2021), which examine these dynamics in diverse contexts, including 18 Asian nations, Arctic countries, and 10 Central European nations. These studies collectively underscore the pivotal role of energy consumption in shaping the intricate relationship between economic development and environmental sustainability.

In addition to other factors, numerous studies highlight the role of financial sector growth as a key variable influencing carbon emission. While the financial sector can drive economic and technological advancements through banking and investment, it can also contribute to higher carbon emissions, particularly through manufacturing activities and increased fuel consumption for private vehicles (Thangaiyarkarasi and Vanitha, 2021).

Building on this context, the present study seeks to explore how energy consumption and financial development impacts environmental quality in Indonesia. The financial development represents by domestic credit to private sector, international trade, and foreign direct investment. The scarcity of literature on this topic within the Indonesian context and the ongoing debate regarding the financial sector's role in environmental sustainability serve as the primary motivations for this research. This study aims to contribute to the academic discourse by providing fresh insights, while also offering evidence-based conclusions and actionable policy recommendations tailored to Indonesia's specific circumstances. These findings are intended to support the creation of effective and practical strategies for enhancing environmental quality.

This paper is structured into five sections. Section 1 introduces the background and objectives of the research. Section 2 presents the theoretical framework and a review of relevant literature. Section 3 focuses on defining the variables, the econometric models employed, and the estimation techniques used to analyse the data. The results and key findings are discussed in Section 4, while Section 5 concludes the paper, summarizing the key points and offering policy recommendations.

2. LITERATURE REVIEW

The influence of macroeconomic variables on CO_2 emissions has been extensively explored in previous studies, which have utilized various models and case studies. Many of these studies focus on energy consumption and economic growth as key factors driving CO_2 emissions. However, there is considerable disagreement regarding the specific ways in which these macroeconomic variables affect emissions. Nugraha and Osman (2019) argue that Indonesia's energy consumption contributes to increased CO_2 emissions. Similarly, countries like Turkey, which Yavuz (2014) suggests relying heavily on energy to fuel their economies, experience a similar dependence on fossil fuels, leading to higher emissions. In Pakistan, a study by Ali et al. (2015) found a direct link between energy consumption and CO_2 emissions. Furthermore, Hasan and Chongbo (2020) note that factors such as population growth and industrial activity significantly drive up CO_2 emissions in Bangladesh through energy usage.

According to data from Owusu (2018), Ethiopia's economic growth and increasing energy consumption are key contributors to both short- and long-term rises in CO_2 emissions. Supporting evidence from Wasti and Zaidi (2020) further suggests that energy consumption and carbon emissions both play a role in driving economic growth, implying that efforts to reduce emissions could hinder Kuwait's economic development. In India, one of the fastest-growing economies, primary energy consumption and GDP are significant factors contributing to the long-term increase in CO_2 emissions (Sikdar and Mukhopadhyay, 2018). Additional studies across various countries, including South Korea (Adebayo et al., 2021), Nigeria (Chindo et al., 2015), Thailand (Adebayo and Akinsola, 2021), Uganda (Otim et al., 2022), the United States (Susam and Hudaverdi Ucer, 2019), Pakistan (Raza, 2022), and India (Sikdar and Mukhopadhyay, 2018), consistently reinforce the idea that energy consumption and economic growth are primary drivers of CO_2 emissions. Some studies also compare multiple countries to better understand these dynamics.

Sah et al. (2023) employed the Artificial Neural Network (ANN) approach and found that energy consumption is the key factor driving the increase in CO_2 emissions across EU countries. Similarly, Alkasasbeh et al. (2023) confirmed this relationship in five Islamic countries, where economic growth, heavily dependent on fossil fuel usage, contributed to higher CO_2 emissions. Sarkar et al. (2018) also identified energy consumption as the primary cause behind a substantial rise in CO_2 emissions in four major Asian nations. In the MENA region, Arouri et al. (2012) emphasized that energy consumption plays a crucial role in the long-term increase in CO_2 emissions. Furthermore, Farhani and Rejeb (2012) found that growing energy consumption in MENA countries is directly linked to higher CO_2 emissions.

Additionally, the results of the causal link test revealed a significant relationship between income and energy consumption, suggesting that these two variables are interdependent. In the case of the GCC countries, Salahuddin and Gow (2014) found no direct correlation between income and CO_2 emissions. However, they identified a clear link between CO_2 emissions and energy consumption, indicating that both energy use and economic growth influence CO_2 emissions. Dritsaki and Dritsaki (2014) observed that energy consumption plays a role in driving economic growth in Greece, Spain, and Portugal, both in the short and long term. Given that fossil fuels remain the dominant energy source, this trend further contributes to the increase in CO_2 emissions.

Research on the relationship between energy consumption and economic growth has recently expanded to include additional variables, with financial development emerging as a key factor. Given the significant role the financial sector plays in shaping societal interactions, it has become increasingly relevant to this area of study. Bekhet et al. (2017) found a bidirectional correlation between financial development and carbon emissions in the GCC countries, suggesting that these nations need to prioritize environmental considerations in their financial development strategies. Jamel and Maktouf (2017) identified a feedback relationship between financial development and CO_2 emissions. In their study, Fatima et al. (2023) examined OECD countries and concluded that financial development exacerbates the effects of natural disasters, with technological innovation amplifying this impact. Additionally, Hung et al. (2022) uncovered a reciprocal causal relationship between financial development and CO_2 emissions in Vietnam.

The positive aspect of this research is that it suggests financial expansion could contribute to reducing CO_2 emissions. Shahzad et al. (2017) found that in Pakistan, financial development led to an increase in CO_2 emissions, with a unidirectional causality running from financial development to emissions. Ashraf et al. (2022) observed that the impact of financial expansion on CO_2 emissions varied across 124 countries, showing that energy consumption and income were the primary drivers of emissions. Additionally, Hussain et al. (2023) identified an N-shaped curve in the relationship between financial development and CO_2 emissions, based on case studies from 102 countries using the STIRPAT framework. The evidence supporting this pattern was stronger in developing nations and weaker in developed countries.

Zhao and Yang (2020) found that the impact of financial development on CO_2 emissions differs across Chinese provinces and regions. In contrast to studies that focus on countries, Gallego-Álvarez et al. (2015) conducted a case study of 89 companies and examined the relationship between financial development and CO_2 emissions. Their findings revealed that better financial performance is linked to lower emissions. Meanwhile, Safi et al. (2021) conducted a study in E7 countries and concluded that financial instability can significantly reduce consumption-based CO_2 emissions.

In addition to financial development, trade plays a significant role in contributing to the economy, which is why export-import variables are often considered in studies of carbon emissions. Salman et al. (2019) found that exports contribute to higher carbon emissions in seven ASEAN countries. Al-Mulali and Sheau-Ting (2014) examined 189 countries and their panel regression results revealed that, except for Eastern Europe, all regions display a long-term proportional relationship, where increases in trade significantly boost GDP and vice versa. Mpeqa et al. (2023) noted that trade activities, particularly imports and exports, negatively impact carbon emissions in China. However, they also found that implementing green initiatives plays a crucial role in reducing CO_2 emissions. Li et al. (2014) further revealed that export and import operations contribute differently to CO_2 emissions, with exports generally generating higher emissions than imports.

Wang and Li's (2024) research suggests that imports can help reduce carbon emissions in China, while exports have the opposite effect.

Lu et al. (2023) confirmed that import and export regulations in 19 developed countries can lower CO_2 emissions. Boamah et al. (2017) argue that China should modify its trade practices to facilitate CO_2 emission reductions, as their study demonstrates that both export and import activities can lead to higher emissions. Further studies by Hassan et al. (2022), Wang and Watson (2008), Mahmood et al. (2020), Pié et al. (2018), and Kozul-Wright and Fortunato (2012) show that imports and/or exports can contribute to increased CO_2 emissions. On the other hand, research by Hu et al. (2020), Lu et al. (2023), Arce et al. (2016), Jijian et al. (2021), Najibullah et al. (2021), and Khan et al. (2020) provides evidence that exports and/or imports can help reduce CO_2 emissions.

The trade sector is closely linked to investment, particularly in developing countries where foreign investment plays a crucial role in driving technological advancements from developed nations. However, several studies suggest that foreign investment can contribute to increased CO_2 emissions. As a result, many studies examining the impact of foreign direct investment (FDI) on CO_2 emissions include investment as a key variable. Some research has found that FDI negatively affects the environment by increasing CO_2 emissions. Abid et al. (2022) identified a long-term negative relationship between FDI and CO_2 emissions in G8 countries. Fauzel (2017) argued that FDI in the industrial sector could be harmful to the environment. Additionally, Pao and Tsai (2011) observed a bidirectional causality between FDI and CO_2 emissions, supporting the pollution haven theory.

Essandoh et al. (2020) found that an increase in FDI inflows leads to higher CO_2 emissions in low-income countries over the long term. Additional studies by Ali et al. (2021), Ullah et al. (2022), Boamah et al. (2023), Jafri et al. (2022), Bukhari et al. (2014), Lee et al. (2021), and Balli et al. (2021) also indicate that FDI contributes to higher CO_2 emissions. However, other research suggests that FDI could have a mitigating effect, potentially limiting or even reducing CO_2 emissions. Notably, Pazienza (2019) observed that FDI helps decrease CO_2 emissions from forest fires by promoting growth in the manufacturing sector, as FDI facilitates the transfer of clean technologies. Similarly, Zhang and Zhou (2016) found that FDI supports China's efforts to reduce CO_2 emissions, while Asongu et al. (2021) highlighted its positive impact on the development of the green economy. Other studies, including those by Sung et al. (2018), Hao and Liu (2015), Mukhtarov et al. (2021), Ren et al. (2024), and Boateng et al. (2024), reached similar conclusions. In contrast, Blanco et al. (2013) found insufficient evidence to support the claim that FDI increases CO_2 emissions, particularly in sectors like highly polluted industries, based on a study of 18 Latin American countries.

Following research on the relationship between CO_2 emissions and economic growth, the question of the Environmental Kuznets Curve (EKC) emerged. The EKC hypothesis suggests that it is possible to achieve both environmental improvements and high economic growth. In their study of eleven European countries, Destek et al. (2016) confirmed the presence of the EKC, showing that while CO_2 emissions initially rise with energy consumption, they begin to decline after reaching a turning point. In the case of Thailand, Bunnag (2023) found that economic growth contributes to environmental degradation through higher CO_2 emissions, but also confirmed the existence of the EKC as a key factor. Arouri et al. (2012) identified the presence of the EKC in twelve MENA countries, although they noted significant variations in its characteristics, with some countries exhibiting very low turning points, raising questions about the robustness of the theory. Meanwhile, Shahbaz et al. (2019) concluded that foreign direct investment (FDI) does not significantly contribute to CO_2 emissions in Turkey. A similar conclusion was drawn by Shaari et al. (2014) in their study of 15 developing countries.

In Indonesia, Bashir et al. (2021) found that energy consumption leads to an increase in CO_2 emissions in the short term. Their study also confirmed a long-term relationship between economic growth, energy consumption, urbanization, and CO_2 emissions. However, the positive news is that the study identified the Environmental Kuznets Curve (EKC) hypothesis between economic growth and CO_2 emissions, suggesting that Indonesia has the potential to achieve both high economic growth and improved environmental quality in the future. Farabi and Abdullah (2020) also identified foreign direct investment (FDI) as a key factor driving CO_2 emissions in Indonesia. Furthermore, Cahyo et al. (2023) highlighted that exports and the growing number of motor vehicles significantly contribute to CO_2 emissions in the country. Literature across various countries and methodologies consistently points to the unique characteristics of each nation. As a result, generalizing the relationship between variables impacting CO_2 emissions is not feasible, even within similar case studies. Therefore, continuous assessments and the adoption of updated methodologies are essential for understanding these dynamics effectively.

3. METHODS OF ECONOMETRIC MODELLING AND ESTIMATION TECHNIQUES

The primary objective of this study is to evaluate the impact of energy consumption and financial development consisting of domestic credit, international trade, and foreign direct investment on CO_2 emissions in Indonesia. To achieve this, the study critically reviews the methodologies used in previous research that has examined similar topics in different countries. Mukhopadhyay and Chakraborty (2002) employed input-output structural decomposition analysis (SDA) to analyse changes in fossil energy consumption and economic growth in India. Paul and Bhattacharya (2004) applied a decomposition method, while Liu (2005) used a simultaneous equation system where GDP and CO_2 emissions were mutually determined. Ramanathan (2005) adopted data envelopment analysis (DEA), and Shahbaz and Lean (2012) used a single equation model. Al-Mulali et al. (2013) applied dynamic OLS, Antonakakis et al. (2017) utilized panel vector autoregression (PVAR), Cai et al. (2018) and Adedoyin and Zakari (2020) implemented a newly developed bootstrap ARDL bounds test with structural breaks, and Haldar and Sethi (2021) employed GMM and FMOLS. Building on these methodologies, this study develops a multivariate model inspired by the work of Shahbaz et al. (2013), as Indonesia and Malaysia share similar economic characteristics, geographical locations, and cultural contexts. The study includes energy consumption, domestic credit, and international trade as key variables influencing CO_2 emissions in Indonesia.

$$CO_{2t} = f(ENC_t, CRD_t, ITR_t) \quad (1)$$

All variables are converted into their natural logarithmic form to reduce heteroscedasticity, narrow the differences between variables, and make the data more closely align with a normal distribution. The resulting model for the estimable equation, after applying the natural logarithm, is expressed as follows:

$$\ln CO_{2t} = \alpha_0 + \alpha_{ENC} \ln ENC_t + \alpha_{CRD} \ln CRD_t + \alpha_{ITR} \ln ITR_t + \varepsilon_t \quad (2)$$

In addition to the existing variables, this study incorporates foreign direct investment (FDI) as a key factor to assess its impact on CO_2 emissions. Given Indonesia's vast land, abundant labor supply, and stable macroeconomic environment, the country presents an attractive opportunity for foreign investment. The influx of advanced technology and knowledge from developed nations is anticipated to make FDI a crucial contributor to reducing CO_2 emissions, particularly within Indonesia's industrial sector (Muhammad and Khan, 2019). With the inclusion of FDI as an additional variable, Equation 2 is revised as follows:

$$\ln CO_{2t} = \beta_0 + \beta_{ENC} \ln ENC_t + \beta_{CRD} \ln CRD_t + \beta_{ITR} \ln ITR_t + \beta_{FDI} \ln FDI_t + \varepsilon_t \quad (3)$$

This study incorporates the squared terms of the financial development variables—CRD^2, ITR^2, and FDI^2—to investigate the potential presence of an inverted U-shaped relationship between CO_2 emissions and these financial development indicators, as suggested by the Environmental Kuznets Curve (EKC). The hypothesis posits that, in the initial stages, an increase in financial development leads to higher CO_2 emissions. However, once a specific threshold is surpassed, further financial development is expected to drive a decline in emissions by channelling financial transactions into environmentally friendly. The empirical equation for this model is formulated as follows:

$$\begin{aligned} \ln CO_{2t} &= \delta_0 + \delta_{ENC} \ln ENC_t + \delta_{CRD} \ln CRD_t + \delta_{CRD^2} \ln CRD_t^2 \\ &+ \delta_{ITR} \ln ITR_t + \delta_{ITR^2} \ln ITR_t^2 + \delta_{FDI} \ln FDI_t + \delta_{FDI^2} \ln FDI_t^2 + \varepsilon_t \end{aligned} \quad (4)$$

This study defines the variables as follows: CO_2 represents carbon emissions per capita, ENC_t denotes total energy consumption per capita, CRD_t indicates domestic credit to the private sector, TRD_t measures trade as the sum of exports and imports per capita, and FDI_t represents foreign direct investment. The squared terms of CRD, TRD, and FDI are included to explore potential non-linear relationships and assess the existence of the Environmental Kuznets Curve (EKC). The findings are anticipated to show that financial development variables can contribute to reducing carbon emissions in Indonesia through green finance mechanisms. These mechanisms may include initiatives such as green financing, which emphasizes bank financing in environmentally sustainable sectors, or financial instruments like green bonds. This process is expected to simultaneously foster economic growth and improve environmental quality. Achieving this outcome depends on the coefficients of the financial development variables being positive, while the coefficients of their squared terms are negative, confirming the EKC hypothesis. Positive coefficients for the ENC variable suggest that economic activities in Indonesia heavily rely on energy consumption, which drives CO_2 emissions. Consequently, the study expects a negative coefficient for ENC to reflect a potential reduction in emissions. In contrast, a negative coefficient for financial development indicates that increased financial activities promote environmentally friendly transactions, thereby enhancing environmental quality. The squared financial development variables further validate the presence of the EKC, suggesting that after reaching a certain threshold, financial development can contribute to both economic growth and environmental sustainability.

The long-term relationship between the variables is analyzed using the ARDL bounds testing approach, as introduced by Pesaran et al. (2001). This method was chosen due to its distinct advantages over other techniques. One key benefit of ARDL is its flexibility, as it does not require all variables to be integrated at the same level for the model to be effective. Additionally, the short-term dynamics are identified through the Error Correction Model (ECM), which is derived from the ARDL framework via a straightforward linear transformation. The ARDL model is mathematically represented by the following equation:

$$\begin{aligned} \Delta \ln CO_{2t} &= \theta_0 + \theta_{DUM} DUM + \theta_T T + \sum_{i=1}^{p} \vartheta_i \Delta \ln ENC_{t-i} \\ &+ \sum_{i=1}^{p} \rho_i \Delta \ln CRD_{t-i} + \sum_{i=1}^{p} \sigma_t \Delta \ln ITR_{t-i} + \sum_{i=1}^{p} \eta_i \Delta \ln FDI_{t-i} \\ &+ \phi_{CO2t} \ln CO_{2t-1} + \phi_{ENC} \ln ENC_{t-1} + \phi_{CRD} \ln CRD_{t-1} \\ &+ \phi_{ITR} \ln ITR_{t-1} + \phi_{FDI} \ln FDI_{t-1} + \varepsilon_t \end{aligned} \quad (5)$$

where ϑ, ρ, σ, η reflects the short run parameter while $\phi_{CO2}, \phi_{ENC}, \phi_{CRD}, \phi_{ITR}, \phi_{FDI}$ are the long-run parameter. The null hypothesis of no cointegration denotes with H_0: $\phi_{CO2} = \phi_{ENC} = \phi_{CRD} = \phi_{ITR} = \phi_{FDI} = 0$. The rejection of the null hypothesis confirms the presence of cointegration. This is assessed by comparing the calculated F-statistic with the upper critical bound (UCB) and lower critical bound (LCB) values. Cointegration is established if the F-statistic exceeds the UCB. Conversely, if the F-statistic falls below the LCB, cointegration is not present. However, if the F-statistic lies between the UCB and LCB, the results are inconclusive, requiring further analysis through an error correction mechanism to determine the existence of a long-term relationship.

This study employs a methodology to explore causal relationships between variables using the approach developed by Engle and Granger (1987). The Granger causality method, integrated within the Vector Error Correction Model (VECM) framework, is utilized to identify causal links among the variables. Cointegration between the series typically indicates the existence of at least one causal relationship. Engle and Granger (1987) cautioned that applying the Granger causality test to first differences within a VAR model could lead to misleading conclusions in the presence of cointegration. To address this, an error-correction term is incorporated into the

Granger causality test, allowing long-term associations to be captured. The representation of the error-correction term in the causality test is as follows:

$$\begin{bmatrix} \text{Ä}\ln CO_{2t} \\ \text{Ä}\ln ENC \\ \text{Ä}\ln CRD_t \\ \text{Ä}\ln ITR_t \\ \text{Ä}\ln FDI_t \end{bmatrix} = \begin{bmatrix} k_1 \\ k_2 \\ k_3 \\ k_4 \\ k_5 \end{bmatrix} + \sum_{i=1}^{p} \begin{bmatrix} d_{11}(L) & d_{12}(L) & d_{13}(L) & d_{14}(L) & d_{15}(L) \\ d_{21}(L) & d_{22}(L) & d_{23}(L) & d_{24}(L) & d_{25}(L) \\ d_{31}[L] & d_{32}(L) & d_{33}(L) & d_{34}(L) & d_{35}(L) \\ d_{41}(L) & d_{42}(L) & d_{43}(L) & d_{44}(L) & d_{45}(L) \\ d_{51}(L) & d_{52}(L) & d_{53}(L) & d_{54}(L) & d_{55}(L) \end{bmatrix} \begin{bmatrix} \text{Ä}\ln CO2_t \\ \text{Ä}\ln ENC_t \\ \text{Ä}\ln CRD_t \\ \text{Ä}\ln ITR_t \\ \text{Ä}\ln FDI_t \end{bmatrix} + \begin{bmatrix} \tau_1 ECM_{t-1} \\ \tau_2 ECM_{t-1} \\ \tau_3 ECM_{t-1} \\ \tau_4 ECM_{t-1} \\ \tau_5 ECM_{t-1} \end{bmatrix} + \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{bmatrix} + \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \end{bmatrix} \quad (6)$$

The symbol Δ represents the difference operator, while ECM denotes the error-correction term derived from the ARDL method's long-run cointegrating equation. Constants are represented by C_1 through C_5 and μ_1-μ_5 are the error terms that satisfy classical assumptions. The Vector Error Correction Model (VECM) determines the direction of Granger causality. Short-run causality is identified using the F-statistic or Wald test, whereas long-run causality is assessed by evaluating the significance of the lagged ECMs through a t-test.

4. DATA AND EXPERIMENTAL FINDING

The dataset for this study encompasses several key variables. CO_2 emissions (CO_2) represent the total primary energy consumption. Energy consumption (ENC) refers to the total energy utilized within the country. Domestic credit (CRD) is measured by real domestic credit extended to the private sector. International trade (ITR) captures the combined value of exports and imports. Lastly, foreign direct investment (FDI) reflects the total volume of investments originating from overseas. All data used in this study are secondary and sourced from the World Development Indicators (WDI) provided by the World Bank. The dataset spans annually from 1970 to 2020. Indonesia's economic growth during this period exhibits a trend of rapid expansion, resembling an exponential trajectory. Notable disruptions occurred during the economic crisis and restructuring around 1998, while the global crisis in 2020 caused a smaller shock. Despite these challenges, Indonesia's economic growth is projected to recover and gain momentum through 2023.

4.1. Descriptive Statistics

Descriptive statistical analysis is a vital step in research as it establishes the context and foundational understanding necessary for more advanced or inferential analysis. It provides preliminary insights, facilitates subsequent investigations, and supports effective data-driven communication and decision-making. By summarizing complex datasets into an easily interpretable format, descriptive statistics reveal key measures such as mean, standard deviation, and skewness. Table 1 offers a detailed summary of the descriptive statistical findings from this study, enhancing clarity and comprehension.

Table 1 reveals that the average CO_2 emissions in Indonesia during the study period was 12.36 kilotons, providing valuable insight into the pollution levels and environmental impact of industrial activities and other sources. The analysis also found an average energy consumption (ENC) of 11.04 terajoules, a crucial metric for the nation's energy planning and assessment. The financial sector had a significant impact on the economy, with the domestic credit to the private sector (CRD) averaging 101.95%, indicating that it contributed more than the total GDP. Meanwhile, the average international trade ratio (ITR) stood at 83.20%, emphasizing its critical role in economic activity. Foreign direct investment

Table 1: Descriptive statistics of research variables

Deskripsi data	Variable				
	CO_2	ENC	CRD	ITR	FDI
Mean	12.36	11.04	101.95	83.20	2.67
Std. Dev	0.60	0.73	61.95	86.83	2.11
Skewness	−0.37	−0.58	0.07	0.19	0.35

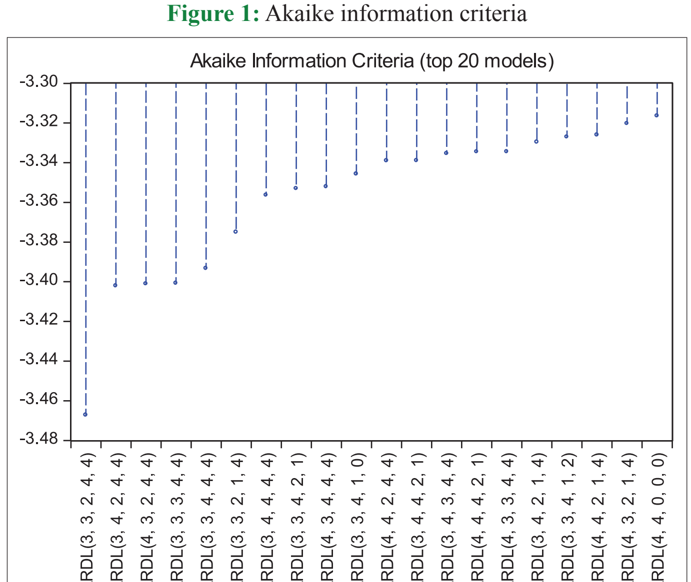
CO_2 in kilo ton; ENC in terajoule; CRD, ITR, and FDI in in persentase to GDP

Table 2: Results of the variable stationarity test

Variable	ADF		PP	
	I (0)	I (1)	I (0)	I (1)
CO_2	0.1138	0.0000***	0.4675	0.0000***
ENC	0.1288	0.0001***	0.4282	0.0001***
CRD	0.2863	0.0022***	0.4062	0.0021***
ITR	0.2577	0.0002***	0.2386	0.0002***
FDI	0.0022***	-	0.0027***	-

Significant at: ***1%

Figure 1: Akaike information criteria



(FDI) accounted for an average of 2.67% of GDP, underscoring its importance and impact on the Indonesian economy. Additional data from Table 1 shows variability across the variables, with CRD and ITR exhibiting wider dispersions compared to CO_2 and ENC, as indicated by their standard deviations. The skewness analysis suggests asymmetry in the data distribution: CO_2 and ENC are left-skewed, CRD is nearly symmetric, while ITR and FDI distributions are right-skewed.

4.2. Stationarity Results and Optimum Lag

Stationarity is a critical requirement for the validity of the ARDL model, as the model performs more effectively and accurately when applied to stationary data. To check for stationarity, the ADF and PP test methods will be used, as outlined in Table 2. If the data is found to be non-stationary, differencing or other transformations will be applied to stabilize it. Additionally, determining the optimal lag length is essential for accurately specifying the ARDL model (Figure 1). Identifying the correct lag length ensures that the model can more accurately capture both short- and long-term relationships between the variables. In summary, the stationarity test ensures that the data meets the necessary conditions for reliable analysis, while determining the optimal lag structure enables the construction of an effective model that yields more accurate results and predictions.

The data in Table 2 clearly show that the variables are not stationary at the same level when tested using the ADF and PP methods. Except for FDI, the variables CO_2, ENC, CRD, and ITR are not stationary at I(0). However, when the stationarity test is extended to I(1), all variables meet the stationarity condition. Therefore, the stationarity requirement is satisfied, allowing for the continuation of the analysis using the ARDL approach. The next step is to determine the optimal lag length based on the AIC criteria, which will be used to estimate the ARDL bound test. As illustrated in Figure 1, the optimal lag structure selected for this study is ARDL (3, 3, 2, 4, 4).

4.3. Cointegration and Bound Test Results

The cointegration test is used to determine whether a long-term relationship exists between the variables under investigation. The purpose of the bound test, on the other hand, is to assess whether the variables in the ARDL model exhibit a cointegrating relationship. Cointegration reflects the long-term movement of variables in tandem and their stable relationship over time, even if the variables are not stationary individually. Therefore, the bound test is an essential tool in ARDL analysis, helping to understand the long-term dynamics between variables and ensuring the model's suitability for the intended analysis. According to the interpretation of the bound test results, cointegration is confirmed when the F-statistic exceeds the critical value at each significance level. The cointegration and bound test results, based on this interpretation, are presented in Tables 3 and 4, respectively.

Table 3: Cointegration result

Hypothesized No. of CE (s)	Eigenvalue	trace Statistic	0.05 Critical value	Prob.**
None*	0.623	86.394	69.818	0.001
At most 1*	0.571	55.121	47.856	0.008
At most 2	0.393	27.998	29.797	0.079
At most 3	0.179	12.022	15.494	0.155
At most 4*	0.162	5.6825	3.841	0.017

Table 4: Bound test result

K	Test Statistic (F-Statistic)	Critical Value Bound							
		10%		5%		2.5%		1%	
		I (0)	I (1)	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
4	5.096	1.45	1.52	1.86	2.01	1.25	2.49	1.74	3.06

Table 5: ARDL estimation result

Variable	Coefficient	Std. error	t-statistic	Prob.*
ln CO_2(−1)	1.356	0.271	4.998	0.0007***
ln CO_2(−2)	–1.089	0.421	–2.593	0.0290**
ln CO_2(−3)	1.147	0.307	3.734	0.0047***
lnENC	0.190	0.066	2.883	0.0181**
lnENC(−1)	0.032	0.048	0.675	0.5163
lnENC(−2)	0.290	0.099	2.908	0.0174**
lnENC(−3)	0.227	0.105	2.151	0.0599*
CRD	0.097	0.161	0.606	0.5590
CRD(−1)	1.359	0.471	2.889	0.0179**
CRD(−2)	–0.532	0.347	–1.535	0.1591
ITR	0.036	0.014	2.473	0.0353**
ITR(−1)	0.081	0.025	3.231	0.0103**
ITR(−2)	0.004	0.018	0.259	0.8008
ITR(−3)	–0.003	0.011	–0.311	0.7636
ITR(−4)	0.021	0.013	1.587	0.1468
FDI	0.035	0.009	3.696	0.0049***
FDI(−1)	0.033	0.014	2.334	0.0444**
FDI(−2)	–0.009	0.014	–0.666	0.5220
FDI(−3)	0.005	0.005	0.970	0.3572
FDI(−4)	0.012	0.004	2.241	0.0517*
C	–7.821	2.791	–2.803	0.0206**

*,**, *** denote significant at 1%, 5% and 10% respectively

Table 6: Long-term estimation results

Variable	Coefficient	Std. error	t-statistic	Prob.
lnENC	0.228	0.131	1.741	0.115
lnCRD	–2.229	0.203	–10.935	0.000***
lnITR	–0.342	0.035	–9.581	0.000***
lnFDI	–0.179	0.031	–5.874	0.001***
C	18.885	1.637	11.534	0.000***

*** denotes significant at 1% level of significant

Table 7: Short-run estimation results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D (ln CO_2(−1))	–0.058	0.254	–0.228	0.824
D (ln CO_2(−2))	–1.147	0.307	–3.734	0.004**
D (lnENC)	–0.191	0.066	–2.883	0.018**
D (lnENC(−1))	–0.291	0.099	–2.908	0.017**
D (lnENC(−2))	0.227	0.105	2.151	0.059*
D (CRD)	0.097	0.160	0.606	0.559
D (CRD(−1))	0.532	0.347	1.535	0.159
D (ITR)	0.036	0.014	2.473	0.035**
D (ITR(−1))	–0.004	0.018	–0.259	0.801
D (ITR(−2))	0.003	0.011	0.311	0.763
D (ITR(−3))	–0.021	0.013	–1.587	0.146
D (FDI)	0.035	0.009	3.696	0.004***
D (FDI(−1))	0.009	0.014	0.666	0.522
D (FDI(−2))	–0.005	0.005	–0.970	0.357
D (FDI(−3))	–0.011	0.004	–2.241	0.051*
CointEq(−1)	–0.414	0.149	–2.762	0.022**

*,**,*** denote significant at 1%, 5%, and 10% level of significant respectively

Figure 2: Stability test result

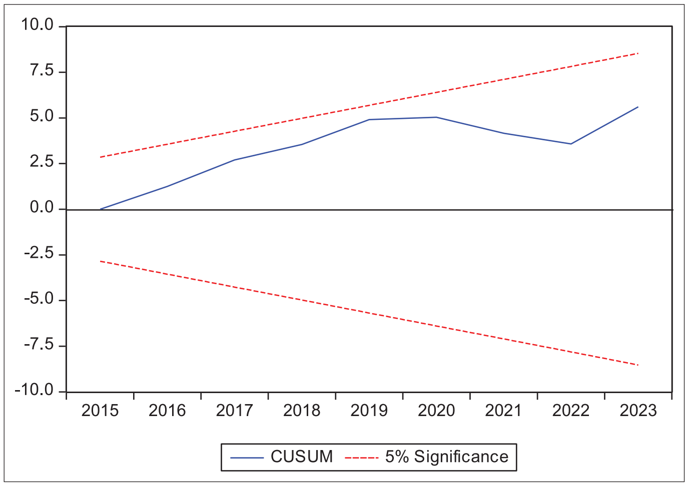


Table 8: EKC estimation results

Variable	Coefficient	Std. error	t-statistic	Prob.*
LnCRD	1.013	0.061	–4.513	0.0043
lnCRD2	–5.074	0.093	–2.817	0.0082
lnITR	2.251	0.024	3.726	0.0283
lnITR2	–4.759	0.247	–2.781	0.0004
lnFDI	7.736	0.885	5.768	0.0021
lnFDI2	5.165	0.066	8.115	0.0236

Dependent variable: ln CO_2

It is determined that there is no cointegration based on the cointegration analysis results in Table 3, which show a $P > 0.05$, that is at most 2 and 3 are 0.079 and 0.1559, respectively. This outcome demonstrates that the model satisfies the requirements, specifically that the Johansen Test indicates no cointegration.

As shown in Table 4, the model demonstrates cointegration, indicating that all variables are consistently related over the long term, despite any potential short-term fluctuations. This conclusion is supported by the F-statistic value exceeding the critical value at each significance level.

4.4. Estimation Result

This section groups the interpretation of the estimation results into multiple categories namely ARDL estimation results (3, 3, 2, 4, 4) displayed in Table 5, long-term test results (Table 6), short-term test results (Table 7), and stability test results using the CUSUM approach (Figure 2). This study also considers the outcomes of the EKC analysis between CO_2 and financial development variables (Table 8), which will also be interpreted in this part, in accordance with the previously stated explanation.

Based on the findings presented in Table 5, CO_2 levels are significantly influenced by all the current variables and their lagged counterparts, including CO_2's own lagged values. Notably, the ARDL (3, 3, 2, 4, 4) estimation highlights a compelling relationship where increases in CO_2 appear to follow changes in ENC. Moreover, both the current ENC and its lagged values consistently exhibit a positive impact on CO_2 levels. These results underscore the importance of prioritizing efforts to manage ENC consumption and transition toward greener, more energy-efficient sources to mitigate CO_2 emissions effectively. Specifically, the observed positive correlation between lagged ENC and CO_2 indicates that past ENC usage has a prolonged impact on present CO_2 levels, demonstrating how historical increases in ENC can drive current rises in CO_2 emissions.

The long-run coefficients of the ARDL model are presented in Table 6. Notably, all independent variables in the research model exhibit negative coefficients with a significant impact on CO_2 emissions, except for ENC, which shows a small but positive effect. Firstly, promoting CRD growth can play a pivotal role in achieving environmental objectives, as CRD significantly contributes to reducing CO_2 emissions. The negative relationship between CRD and CO_2 suggests that expanding CRD provides the private sector with greater access to genuine domestic financing, thereby supporting CO_2 reduction efforts. This highlights CRD as an effective tool in advancing environmental goals.

Secondly, increased ITR activities and policies that support ITR are associated with sustained reductions in carbon dioxide emissions. ITR activities can aid in diversifying energy sources and adopting cleaner technologies. In Indonesia, ITR participants are actively seeking environmentally friendly energy sources and CO_2 reduction technologies. The findings further suggest that ITR's influence on CO_2 reductions becomes more pronounced over time, emphasizing its growing significance in environmental sustainability.

Third, foreign direct investment (FDI) often brings advanced, environmentally friendly technologies and more efficient management practices to the host country. Foreign companies investing in a nation may adopt and implement technologies that help lower CO_2 emissions. The findings suggest that over time, FDI has a more significant impact on reducing CO_2 emissions. This long-term effect can be enhanced by implementing stricter environmental regulations, adopting clean technologies, and improving operational efficiency.

Fourth, a closer analysis of ENC shows that while it contributes to CO_2 emissions by promoting fossil fuel combustion and other industrial activities, no clear long-term relationship between ENC and CO_2 is evident. Although rising ENC often aligns with increasing CO_2 emissions, this link may be influenced by factors such as the enforcement of emission control regulations, advancements in environmentally friendly energy technologies, or shifts in economic structures that alter the dynamics between ENC and CO_2 emissions.

The short-term coefficient estimation outcomes utilizing the ARDL technique are displayed in Table 7. An intriguing discovery is that all the independent variables' directional coefficients in the short-term estimate findings are different from the long-term circumstances. First, while the impact of CO_2 during the preceding period (lag 1) might not be felt right away, over the longer term (lag 2), it becomes more noticeable and important. This shows that the influence of CO_2 over an extended duration could have a greater and more noteworthy impact on CO_2 levels today. This result might point to a delay or carryover effect in the way that previous CO_2

epochs influence the CO_2 levels today. The substantial negative impact of CO_2 lag 2 suggests that it might take longer for CO_2 trends or changes to become noticeable.

Second, energy consumption significantly and negatively affects CO_2. This finding indicates that a rise in energy consumption is not always correlated with an increase in CO_2 during a brief period. This can reveal whether, at least during the time period taken into consideration, energy saving initiatives, or the usage of clean energy have been successful in lowering the CO_2 impact of energy consumption. The decrease in present carbon emissions is therefore caused by the increase in energy consumption in the preceding era, as shown by the negative and significant effect of lag 1 of energy consumption. This could mean that although energy consumption rises, CO_2 has been successfully reduced by the efficiency or technology employed in the preceding time. Furthermore, the positive and significant effect of lag 2 of energy consumption suggests a relationship between the current increase in CO_2 and the rise in energy consumption during the preceding two periods. This could reflect the lag or cumulative effects of energy consumption pattern modifications.

Third, the positive correlation between domestic credit and CO_2 indicates that higher levels of domestic credit are often associated with increased CO_2 emissions. This suggests that domestic credit-driven investments and economic activities may contribute to rising CO_2 levels. However, the potential relationship between past CRD (lag 1) and current CO_2 increases appears weak and inconsistent, lacking statistical significance. This could be due to the delayed impact of domestic credit on CO_2, where its effects take longer to manifest, or the influence of additional factors not accounted for in the model.

Fourth, the scale effect—driven by the large volume of goods produced and transported—creates a strong link between increased trade activity and higher CO_2 emissions in the current period. However, the influence of trade from two prior periods (lag 2) may not yet be fully evident in current CO_2 levels, potentially due to mitigating factors that dampen trade's impact on emissions. Additionally, while trade shows a negative effect on CO_2 at certain points (lags 1 and 3), this effect is neither statistically significant nor impactful in the short term.

Fifth, there is a significant positive correlation between FDI and increased CO_2 emissions, underscoring the importance of implementing regulations to mitigate the environmental impact of FDI and closely monitoring its effects on the environment. This finding also highlights the significant and beneficial role of FDI. However, the impact of FDI on CO_2 emissions takes time to manifest, as the effects from the previous period (lag 1) are not immediately evident. While the conditions for FDI in the two preceding periods show no significant influence, those from three periods earlier reveal a substantial impact, indicating that FDI's effect on CO_2 emissions becomes pronounced only after several periods.

Sixth, the cointeq(−1) variable represents the deviation of CO_2 from its long-run equilibrium, as determined by the cointegration relationship among the model's variables. The negative coefficient of −0.414 indicates that CO_2 decreases by 0.414 units for every unit increase in its deviation from the long-run equilibrium. This suggests that when CO_2 levels exceed the long-run equilibrium (i.e., are too high), the system adjusts by reducing CO_2 as part of the process to restore equilibrium. In other words, an excessive CO_2 level relative to the long-run equilibrium triggers a natural corrective mechanism to lower it. The negative coefficient reflects the system's inherent tendency to bring CO_2 back to its equilibrium trajectory.Figure 2 illustrates the results of the parameter stability test using the cumulative sum (CUSUM) method based on recursive residuals, with a 5% confidence interval. The model is considered stable if the cumulative residual line (blue line) remains within the critical boundaries (red dashed lines) on the CUSUM graph. If the blue line stays within these limits, the CUSUM test confirms the stability of the model. This implies that the ARDL model employed is stable, the estimated parameters remain valid throughout the observation period, and there are no significant changes in the model parameters over time.

In the final step, this study checks for the presence of the Environmental Kuznets Curve (EKC) by using nonlinear regression and adding a quadratic term to the existing model. The EKC hypothesis requires a nonlinear relationship between YY and its influencing variables. Specifically, the EKC is supported if the coefficient a β_1 is positive and significant, while the coefficient β_2 associated with the quadratic term, is negative. Furthermore, the related variables must also exhibit statistical significance. Based on the results of the nonlinear regression analysis presented in Table 8, the study confirms the existence of the EKC hypothesis for the domestic credit and trade variables. However, the hypothesis does not hold for the foreign investment variable. These findings suggest that policies aimed at enhancing domestic credit availability and promoting export-import activities can contribute to improved environmental quality over time while simultaneously supporting increased financial transactions through domestic credit and international trade.

5. CONCLUSION AND POLICY IMPLICATIONS

This study aims to evaluate how energy consumption and financial development—measured through domestic credit, exports, imports, and foreign investment—affect Indonesia's environmental quality. CO_2 emissions are chosen as the dependent variable to represent environmental degradation. Key factors influencing CO_2 emissions include energy consumption, financial development, trade, and investment. The analysis utilizes annual time series data from 1990 to 2023, obtained from the World Bank's World Development Indicators.

To achieve the study's objectives, the ARDL methodology is employed, considering certain restrictions and constraints. The long-run ARDL model reveals that all independent variables, except energy consumption, have a significant negative effect on CO_2 emissions. Domestic credit reduces CO_2 emissions by improving access to credit, while international trade and

FDI support energy diversification and the adoption of clean technologies, yielding positive long-term environmental benefits. Although energy consumption shows a positive correlation with CO_2 emissions, no conclusive evidence of a long-term relationship has been found. This could be attributed to the implementation of emission control policies and the adoption of environmentally friendly technologies.

The short-term ARDL model reveals notable variations in its findings. Energy consumption shows a negative impact on CO_2 emissions, indicating the effectiveness of energy efficiency measures. Although financial development has been linked to increased CO_2 emissions, these effects take time to fully materialize. A positive correlation between CO_2 emissions and international trade activities is evident, likely driven by the scale of production. Conversely, foreign direct investment (FDI) significantly and positively influences CO_2 emissions, emphasizing the need to account for environmental impacts in policy considerations.

The cointegration (−1) coefficient further highlights the system's tendency to reduce CO_2 emissions to restore equilibrium. Additionally, the Environmental Kuznets Curve (EKC) hypothesis is evident in the relationship between financial development and CO_2 emissions. In the early stages of financial development, CO_2 emissions tend to rise. However, as financial development progresses, emissions begin to decline. Ultimately, this leads to a state of advanced financial development paired with improved environmental quality, characterized by lower CO_2 emissions.

This study offers several key policy recommendations to reduce CO_2 emissions in Indonesia, based on the analyzed data. These include establishing green finance schemes, enforcing stricter renewable energy regulations, and implementing a carbon trading system. By providing incentives for renewable energy adoption and promoting investment in green technologies, governments can drive innovation and support sustainable economic growth. Public awareness can also be enhanced through educational initiatives that emphasize the importance of reducing emissions.

The implications of these policies are profound. They not only have the potential to improve air quality and public health but also to accelerate Indonesia's transition to sustainable energy. Developing sustainable finance initiatives would enhance financial stability, while participation in carbon trading could elevate Indonesia's role in global climate change cooperation. Collectively, this integrated approach could form the foundation of a more sustainable and environmentally friendly development strategy for the future. This study has certain limitations, primarily its focus on Indonesia as the sole case study. To gain a more comprehensive understanding and develop tailored strategies, future research should explore case studies in other countries. This would provide insights into the specific conditions of each nation and allow for the formulation of more appropriate models based on actual findings.

Future studies could replicate this research framework in other contexts, either by using the same model or incorporating additional variables to address the unique economic characteristics and needs of different nations. Moreover, alternative methodologies could be employed to account for the distinct features of data across various countries, further enriching the analysis and its applicability.

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