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**Article**

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# Sustainable Development in Indonesia: A Study of Energy Consumption, $CO_2$ Emissions, FDI, and Gross Capital Formation

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**ABSTRACT**

The purpose of this study is to examine how the consumption of renewable and nonrenewable energy, $CO_2$ emissions, FDI, and gross capital formation affect the GDP per capita in the case of Indonesia. This study employs cointegration and ARDL to estimate the short and long-run coefficient which is preceded by ADF and PP unit root test using the annual time series data from 1960 to 2021. The result of the estimation shows that in the long run non-renewable energy consumption, $CO_2$ emission, and FDI impact the economic growth of Indonesia directly. Meanwhile, in the short run, the estimation result reveals that non-renewable energy and FDI are positive and statistically significantly affected the economic growth of Indonesia. Renewable energy hasn't yet been found to have a substantial impact on Indonesia's economic growth. This research offers novel perspectives on how nonrenewable and renewable energy consumption, $CO_2$ emissions, and FDI impact the economic growth. The findings provide valuable implications for Indonesia to develop long-term policies that can enhance the positive effects of energy consumption and $CO_2$ emissions on economic growth in the future. The involvement of FDI in the model also become the novelty of this study to examine the impact of FDI to economic growth.

**Keywords:** Economic Growth, Energy Consumption, $CO_2$ Emission, Foreign Direct Investment, Gross Capital Formation
**JEL Classifications:** K32, P18, P28, Q43, Q48

## 1. INTRODUCTION

Energy serves as the lifeblood of modern economies, underpinning the production of goods and services across various sectors. Within the realm of energy-related challenges, three critical topics consistently dominate discussions (Tarasawatpipat and Mekhum, 2020). To begin, fossil fuels, including coal, oil, and natural gas, are finite resources. While substantial reserves of these fuels still exist, their finite nature, coupled with growing demand, inevitably implies that their availability will eventually diminish. Thus, the quest for alternative energy sources becomes paramount (Anochiwa et al., 2020). Furthermore, energy security emerges as a significant concern for countries reliant on energy imports. Countries dependent on energy resources concentrated in specific global regions face vulnerabilities in terms of the reliability of their energy supplies. The energy crisis of 1970 served as a stark wake-up call, and recent upheavals of energy prices reiterate the risks associated with over-reliance on imported energy, highlighting its instability and potential political repercussions. Lastly, the utilization of nonrenewable energy sources, notably fossil fuels, remains a subject of debate, with some suggesting a link to climate change (Farabi et al., 2019).

A pivotal driver of climate change stems from the mounting concentration of greenhouse gases in the atmosphere, with an emphasis on carbon dioxide ($CO_2$) emissions originating from the combustion of fossil fuels. The combustion of fossil fuels has posed a significant threat to environmental well-being, as underscored by Ibhagui (2020). Without robust efforts to mitigate global warming, the world faces the grim prospect of grappling with catastrophic environmental events, as highlighted by Hayat and Tahir (2020). Consequently, numerous nations are initiating a shift away from their dependence on fossil fuels, gravitating toward the adoption of renewable energy sources. These sustainable alternatives encompass solar energy, wind power, hydropower, biomass, biofuels, geothermal energy, and other forms of renewable energy, such as tidal and wave energy. Elevating the proportion of renewable energy within the overall energy consumption matrix holds the potential to curtail carbon dioxide emissions, a point corroborated by Rahman (2020). Subsequently, nearly all nations are now striving to harness the potential of renewable energy to foster sustainable growth and reduce environmental pollution to zero.

Renewable and nuclear energies are widely regarded as carbon-neutral energy sources and are considered essential remedies for addressing the challenges posed by global warming and energy security (Salahuddin et al., 2018). Numerous nations have made substantial investments in renewable energy sources to bolster energy supply reliability and mitigate greenhouse gas emissions. However, the gradual shift from carbon-based to non-carbon energy sources is hindered by the relatively higher cost of most renewable options when compared to conventional energy sources, apart from hydroelectric and geothermal power (Rokhmawati, 2020). Additionally, the effectiveness of certain renewable energy sources in reducing $CO_2$ emissions remains a subject of scrutiny (Utomo et al., 2021).

Among the significant themes previously discussed, global debate primarily centers on climate change. The looming menace of global warming and climate alteration has propelled the connection between economic advancement, environmental degradation, and energy usage—particularly the utilization of renewable energy—into the spotlight. While extensive research has explored the associations between economic growth and energy consumption, as well as between economic growth and environmental pollution, there remains a notable scarcity of empirical studies that investigate both aspects within a unified framework. Specifically, inquiries delving into renewable energy consumption, as opposed to total energy consumption, are even scarcer. Consequently, this study aims to bridge those research gaps, employing contemporary econometric methods to scrutinize how energy consumption and some macroeconomy variables affect the economic growth in Indonesia. The macroeconomic variables consist of energy consumption consisting of renewable and non-renewable energy, environmental degradation reflected by $CO_2$ emission, investment replicates by Foreign Direct Investment and the accumulation of capital reflected by gross capital formation.

The objective of this study is to assess the influence of nonrenewable energy consumption, renewable energy consumption, carbon dioxide emissions, foreign direct investment, and capital formation on the economic growth of Indonesia during the period of 1960-2021. Indonesia is a rapidly emerging Southeast Asian economy, marked by remarkable growth milestones over the years. With ambitious aspirations to evolve into a modern industrialized nation and secure a position among the high-middle income bracket of the global community, the country is poised for substantial economic expansion in the forthcoming years. Consequently, addressing the dual challenges of future energy demand fulfillment and environmental sustainability in the context of this growth trajectory represents a formidable task. Furthermore, the study's findings are anticipated to furnish empirical insights that can inform policymakers in shaping effective strategies for fostering economic growth and recovery post the COVID-19 pandemic. This includes a gradual reduction in dependence on traditional fossil fuels and the promotion of renewable energy sector development.

This study makes a noteworthy contribution in three distinct areas. Firstly, it fills a notable gap in the existing literature by uniquely exploring the impact of nonrenewable energy consumption, renewable energy consumption, carbon dioxide emissions, foreign direct investment and capital formation on the GDP per capita within the Indonesian context. To the best of the authors' knowledge, there is a dearth of research that delves into these factors and their impact on economic growth in Indonesia, making this study a pioneering endeavor in this regard. Secondly, unlike the conventional approach of combining non-renewable energy and renewable energy, this study separately dissects their individual effects on economic growth. While previous research has often examined the influence of energy consumption, particularly electricity consumption, on economic growth, there is a noticeable scarcity of literature addressing the distinct impact of renewable energy consumption on economic growth in the Indonesian context. Lastly, this study sheds light on the critical relationship between environmental degradation and economic growth in Indonesia. Previous research in the country has predominantly focused on the effect of economic growth on environmental quality, making this study's emphasis on the converse relationship, where environmental degradation impacts growth, a noteworthy departure from the prevailing literature.

The remaining sections of the paper are organized as follows. In chapter 2, this study provides an extensive review of the existing research literature concerning the effect of nonrenewable energy consumption, renewable energy consumption, environmental degradation, investment, and capital accumulation on economic growth. Chapter 3 offers a comprehensive description of the econometric methodology employed in this study consisting of unit root test, cointegration and ARDL along with an overview of the data sources utilized, unit of data, and variable definition. The experimental findings are analyzed and discussed in section 4, providing an in-depth assessment of the results of the research. Finally, section 5 serves as the conclusion, summarizing key insights drawn from the study, and offering recommendations based on the findings of the study.

## 2. LITERATURE REVIEWS

### 2.1. Theoretical Framework

Economic growth is the primary factor used as a benchmark for a country's economic development, it is also the primary macroeconomic indicator. Therefore, it is a crucial issue for economists to always discuss the factors that promote and affect economic growth. The Solow (1956) and Swan (1956) theories are the most widely accepted theories of economic growth. Based on production factors, technology, and capital accumulation, Solow established his model in 1956. The fact that this theory ignores the importance of innovation, knowledge, and various other endogenous variables has led to criticism of it. The effects of global commerce, economic openness, and foreign investment on economic growth were later integrated by Trevor Swan (1956), who further expanded Solow's thesis.

Even though it has been explained by previous theories, the factors influencing economic growth are not final and will continue to increase along with the times. Over the past few decades, energy consumption has emerged as the predominant topic of conversation due to its pivotal role in driving economic expansion. This prominence stems from not only the heavy reliance of economic activities on fossil energy consumption but also the consequential carbon emissions, which contribute to environmental deterioration and even pose threats to human well-being. Therefore, consumption of fossil energy and environmental quality are highly considered factors in analyzing economic growth. In addition, several factors that have been defined by previous theories are still involved to obtain a comprehensive analysis such as capital and investment.

## 2.2. Empirical Review

The empirical review of the variables that affect economic growth in this study, is generally grouped into four main streams. The first stream includes studies that argue that energy consumption is the variable that affects economic growth. Four types of energy sources become concerned by these studies namely oil, coal, gas, and renewable energy. As the main fuel for the transportation sector, oil consumption is the main factor supporting economic growth in almost all countries in the world. In the case of Korea, oil consumption is the main factor determining economic growth in the short term (Saboori et al., 2017). Meanwhile, in the case of Russia (Korkmaz, 2022) and Turkey (Sen and Uzunoz, 2017), oil consumption affects economic growth in the short and long term. In the case of Pakistan, besides driving the growth, the consumption of oil has also proven cause environmental degradation (Khan et al., 2019). Fluctuations in oil prices cause shocks to the economy, this is felt acutely by the United States (Ready, 2018) and especially Taiwan because most of its oil consumption comes from imports (Hong and Hsu, 2018). Contradicting results are shown by the study conducted by Bildirici (2017) in the case studies of Middle Eastern countries. The results of the study prove that several countries in the Middle East do not depend on oil consumption, including Afghanistan, Bahrain, Egypt, Kuwait, Morocco, Oman and Syria. Therefore, energy conservation policies can be implemented without worrying about disrupting economic growth. However, this does not take place in nations that are heavily reliant on oil consumption, such as Algeria, Israel, Jordan, Lebanon, Libya, Pakistan, Qatar, Saudi Arabia, Tunisia, the United Arab Emirates, and Yemen.

Many nations throughout the world use coal as a fuel source to produce electricity. As a result, coal also significantly contributes to economic growth. In the case of China, Bhattacharya et al. (2015), Chen et al. (2021)a, Chen et al. (2021)b, and Jia et al. (2022) confirmed that, coal has a significant contribution to China's economic growth which can hamper economic growth if the consumption is reduced. Similar findings were also confirmed by several studies on case studies in several different countries, such as Khan et al. (2019) for Pakistan, Adebayo et al., (2021) for the case of South Africa, and Ozturk and Ozturk (2018) with regard to Turkey. Different results are shown by studies conducted by Apergis and Payne (2010). They found that in the case of OECD countries, there is a feedback causality between coal consumption and economic growth in the long run. However, in the short term, coal consumption was found to inhibit economic growth. This shows that OECD countries are not too dependent on coal consumption because the use of clean energy is already at a significant level. A similar result was found by Apergis and Payne (2010) for the case of emerging countries. Even though gas is not the main fuel compared to oil and coal, studies have proven that gas consumption also makes a significant contribution to economic growth. Hasan and Raza (2022) confirmed that natural gas consumption together with population, contributes significant effect to the economy of Bangladesh. Meanwhile, the feedback hypothesis was also found between gas consumption and economic growth in Japan and Germany (Magazzino et al., 2021). Similar results were also found in various countries such as China (Wu et al., 2019), France (Farhani and Rahman, 2020), Turkey (Erdoğan et al., 2019), Nigeria (Galadima and Aminu, 2018), Poland (Lach, 2015), and Malaysia (Solarin and Shahbaz, 2015). In this condition, the supply of gas could be increased to replace coal and oil gradually. Studies with countries in the same group and using panel data also demonstrated that gas consumption has a significant impact on economic growth. The studies among others conducted by Moutinho and Madaleno (2022) in the case of OPEC countries, Aydin (2018) for the top 10 natural gas-consuming countries, and Destek (2016) for OECD countries. An interesting result was found by Solarin and Ozturk (2016) where they found different results between group and individual examination of OPEC countries. The regression of panel data reveals the feedback relationship between both variables. However, the result shows a neutral relationship for some countries such as Angola and Qatar which means that gas is not one of the primary fuels in both countries.

Various empirical studies conducted in recent years have provided diverse insights into the impact that the use of renewable energy has on economic growth in various countries and regions. Almost all studies conducted in various countries conclude that renewable energy consumption can increase economic growth and reduce pollution, especially in the long term. Only the study conducted by Wei et al. (2022) for a case study in China states that renewable energy consumption has a negative impact on China's economic growth, so China must formulate a more proactive strategy to increase renewable energy consumption so that it can continue to support economic growth. Fakher et al. (2023) highlight that OPEC countries tend to face environmental challenges due to the use of non-renewable energy, while renewable energy is emerging as an option that has proven to have more potential for creating a sustainable economy and environment. In South Africa, Saba (2023) found that renewable energy consumption can have a positive and significant impact on economic growth in the long term, although the effect becomes insignificant and even negative in the short term while Gyimah et al. (2022) report that Ghana has had a significant positive impact from renewable energy consumption.

Namahoro et al. (2021) shows that in various countries in Africa, renewable energy contributes greatly to reducing emissions within 10 years and is the largest factor in economic growth and $CO_2$ reduction, mainly due to its low variability. Radmehr et al. (2021) study on European Union countries highlights that renewable energy consumption has a significant contribution to increasing GDP, but it should be noted that an increase in non-renewable energy use by 1% has a greater positive impact on GDP than an increase in renewable energy. In addition, the results of Ivanovski et al. (2021) study show that in non-OECD countries, there is encouragement for economic growth from both renewable and non-renewable energy, despite obstacles in technical progress. Dogan et al. (2020) study highlights the differences between high-income OECD countries and low to lower-middle-income countries in the impact of renewable energy consumption on economic growth, where renewable energy consumption has an impact on high economic growth in lower-middle-income countries to low. Meanwhile, Ito (2017) emphasized the positive contribution of renewable energy in the long term in developing countries. These findings illustrate the complexity of the relationship between renewable energy, economic growth, and environmental impacts, and highlight the importance of formulating appropriate policies to address these challenges at global and national levels.

The second stream contains studies that focus on how carbon emission ($CO_2$) affects economic growth. In the case of Pakistan, studies conducted by Raza (2022), Abbasi et al. (2021), Khan et al. (2020), Khan et al. (2019), Satti et al. (2014), and Mirza and Kanwal (2017) concluded that there is an interplay relationship between economic growth and $CO_2$ through fossil energy consumption. Several studies in the case of various countries also found the mutually influencing relationships between $CO_2$ emission and economic growth such as by Bouznit and Bouznit (2016) and Chekouri et al. (2021) in the case of Algeria, Hasan et al. (2022) and Usman et al. (2021) for the case of Bangladesh, Shahbaz et al. (2022), Xiong and Xu (2021), Wang et al. (2015) in the case of China, Ohlan (2015) and Sehrawat et al. (2015) for the case of India, Wasti and Zaidi (2020) and Salahuddin et al. (2018) in the case of Kuwait, and Farabi et al. (2019), Shahbaz et al. (2013) in the case of Indonesia. A tight relationship between $CO_2$ emission and GDP through energy consumption reflects that the economy of the countries has a dependency on fossil energy consumption. Therefore, policies are needed to reduce Pakistan's dependence on fossil energy and increase the positive effects of several other variables to improve environmental quality such as investment and trade openness.

The third stream includes research on the impact of foreign investment on economic growth. Studies in this area reveal contradictory conclusions even for the same case study. Joo et al. (2022) argued that FDI has no impact on BRICS country's growth. However, FDI has a significant effect on growth when it interacts with several other variables such as trade openness, human resources, and financial development. Iqbal et al. (2023) and Abdouli et al. (2018) confirmed that FDI increased not only economic growth but also $CO_2$ in the BRICS countries. Therefore, the BRICS countries could improve the amount of foreign investment to spur economic growth, but it will ruin the environment. The study performed by Bildirici and Çoban Kayıkçı (2023), Luo et al. (2022), Wei et al. (2022), and Udemba et al. (2020) conclude that FDI increases economic growth in China even though the level of contribution is based on the economic condition.

The influence of capital formation on economic growth is a significant topic discussed in the fourth section. Research examining the role of capital formation in driving economic growth consistently highlights its substantial impact, particularly in developing countries like Malaysia (Etokakpan et al., 2020) and Pakistan (Rahman and Ahmad, 2019). Additionally, it has been observed that an increase in capital formation leads to a rise the energy consumption demand (Rafindadi and Mika'Ilu, 2019). Nevertheless, it's essential to note that the relationship between increased capital formation and economic growth isn't without its complexities. Rahman and Ahmad (2019) contend that capital formation, when coupled with fossil energy consumption, contributes to higher levels of carbon emissions in Pakistan. Furthermore, capital formation funded through foreign debt has faced widespread criticism. Consequently, it's advisable for governments not to rely solely on foreign debt-financed capital formation. In the context of mitigating environmental damage, it may be more prudent to allocate investment to the agricultural sector rather than the manufacturing industry, as agriculture tends to have a lesser adverse environmental impact than manufacturing (Abouelfarag and Abed, 2020).

## 3. DATA AND METHODOLOGY

### 3.1. Data

The present study makes use of Indonesia's annual time series data spanning from 1990 to 2022. The period of which is dictated by data availability. This study focuses on Indonesia as a case study due to its significant contribution to global $CO_2$ emissions. The data used in this study includes the per capita economic growth, which is determined by the gross domestic product (GDP) and gross capital formation (CAP) in constant 2015 US$. Additionally, the data also incorporates foreign direct investment (FDI) in the current USD 2015, the consumption of renewable energy (RE) and non-renewable energy (NRE), which is defined as the sum of oil, coal, and gas consumption, and $CO_2$ emissions ($CO_2$) from solid, liquid, and gas consumption.

The GDP, FDI, and CAP data were retrieved from the World Development Indicator (WDI), World Bank 2023. Meanwhile, the rest of the data are sourced from the British Petroleum (BP) Statistical Review 2022. All data in this study transforms into the natural logarithm (ln) to achieve constant variance in the data series. A detailed description of variables, variable definitions, and sources is presented in Table 1. GDP per capita is the dependent variable, while the remaining variables are independent.

### 3.2. Methodology

This study employs econometrics techniques, namely the ARDL bound testing approach proposed by Pesaran et al. (2001), to

**Table 1: Data and variables definition**

| Variables | Definition | Data sources |
|---|---|---|
| LnGDP | Natural logarithm of GDP per capita (constant 2015 US$) | WDI World Bank |
| LnCAP | Natural logarithm of gross capital formation (constant 2015 US$) | |
| LnFDI | FDI, net inflows (current USD 2015) | |
| LnNRE | Natural logarithm of the sum of oil, coal, and gas consumption (exajoules) | BP statistical review |
| LnRE | Natural logarithm of renewable energy consumption (exajoules) | |
| $LnCO_2$ | Natural logarithm of $CO_2$ emission | |

BP: British petroleum, GDP: Gross domestic product, WDI: World development indicator, FDI: Foreign direct investment, LnNRE: Logarithm non-renewable energy, LnGDP: Logarithm GDP, LnFDI: Logarithm FDI, LnRE: Logarithm renewable energy

analyze the long-run and short-run impact of renewable and non-renewable energy consumption, capital formation, $CO_2$ emission, and FDI on GDP per capita. This approach captures the data-generating process from a general to a specific modeling framework by taking a sufficient number of lags. In order to obtain the optimum lag for each variable, ARDL estimates require $(p + 1)k$ regressions. Where $k$ is the number of variables and p is the number of lags to be used. Initially, the analysis begins by presenting the descriptive statistics of the raw data. Then, the unit root test is performed through ADF and PP tests to determine whether the data series is stationary at level I(0) or first difference (I(1); ignoring this process will result in spurious regression. The final step involves identifying cointegration using ARDL to detect the existence of the long-run and short-run relationships with an error correction mechanism model (ECM).

### *3.2.1. Unit root test*

In accordance with established procedures, the assessment of the causal connection between the variables follows a three-stage process. Initially, an examination is conducted to determine the level of integration in all the variables. In other words, this evaluation aims to check for the presence of unit roots, specifically whether the series exhibit stability or variability in their fundamental form. A time series is considered stable when its statistical characteristics (such as mean and variance) remain consistent over time, whereas non-stationary time series exhibit fluctuations over time.

As emphasized by Engle and Granger (1987), it is crucial to confirm that the variables of interest do not demonstrate unit root to ensure the proper application of classical econometric methods. Analyzing non-stationary data can yield misleading outcomes. Consequently, it becomes imperative to assess the stationarity of the series by employing a unit root test. This study utilizes the Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1981) and Phillips-Perron (PP) (Phillip and Perron, 1988) unit root tests for this purpose. The decision to use the PP test in conjunction with the ADF test stems from the recognition that the ADF test may have limited power in rejecting the presence of a unit root, whereas the PP tests address issues related to serial correlation in unit root testing. By combining these two tests, the assessment of the level of integration for all series becomes robust. The unit root test uses the ADF estimation approach with the following specifications:

$$\Delta X_t = \gamma_1 + \gamma_2 t + \delta X_{t-1} + \sum_{i=1}^{q} a_i \Delta X_{t-i} + \varepsilon_t$$

Where $\Delta X_t = X_t - X_{t-1}$. The null hypothesis of the ADF unit root test can be written as below:

$H_0$: $\delta = 0$ (the unit root found at the series and the time series $X_t$ is non-stationary);

$H_0$: $\delta < 0$ (the unit root is not found at the series, and the time series $X_t$ is stationary).

In addition, the Phillips-Perron (PP) unit root test will also be conducted for robustness check. This method is a development of the ADF method. If the ADF method assumes that there are homogeneous and independent errors, the PP method accommodates the existence of dependent and heterogeneously distributed errors. The specification of the PP unit root test is as follows:

$$\Delta y_t = \beta' D_t + \pi y_{t-1} + \mu_t$$

Where $\mu_t$ is $I(0)$ and may be heteroskedasticity.

### *3.2.2. Cointegration test and ARDL*

Cointegration is a statistical method employed to examine the enduring connection between two or more time series variables that are not stationary. This technique is based on the concept that even if these variables exhibit non-stationary trends, they may still possess a long-term relationship. By exploring the cointegration among these variables, the study can determine whether changes in one variable will eventually influence the other variables and to what extent. If the variables are stationary at the same level, either at level 0 or level I, the Johansen and Juselius (JJ) cointegration test can be utilized. Conversely, if the variables do not share the same order of stationarity, the cointegration assessment should be carried out using the autoregressive distributed lag (ARDL) method. Additionally, the ARDL approach is suitable when there is substantial evidence of a cointegration link among the data series. The ARDL model employed to analyze the impact of non-renewable and renewable energy consumption, $CO_2$ emissions, and foreign direct investment (FDI) on economic growth in Indonesia is formulated as follows:

$$\begin{aligned}
\Delta LnGDP_t &= \beta_0 + \sum_{i=1}^{p} \beta_{0i} \Delta LnGDP_{t-i} + \sum_{i=0}^{q_1} \beta_{1i} \Delta LnCAP_{t-i} \\
&+ \sum_{i=0}^{q_2} \beta_{2i} \Delta LnNRE_{t-i} + \sum_{i=0}^{q_3} \beta_{3i} \Delta LnRE_{t-i} + \\
&\sum_{i=0}^{q_4} \beta_{4i} \Delta LnCO2_{t-i} + \sum_{i=0}^{q_4} \beta_{4i} \Delta LnFDI_{t-i} + \\
&\theta_0 LnGDP_{t-1} + \theta_1 LnCAP_{t-1} + \theta_2 LnNRE_{t-1} + \\
&\theta_4 LnRE_{t-1} + \theta_5 + LnCO2_{t-1} + LnFDI_{t-1} + \mu_t
\end{aligned}$$

Where GDP is per capita gross domestic product, CAP is Gross capital formation, NRE represents non-renewable energy which is sum of oil, coal, and gas consumption, RE is renewable energy consumption, $CO_2$ is carbon dioxide emissions, and FDI is foreign direct investment. $\theta_i, \overline{(k=1,2)}, \beta_0$ and $\beta_{kj}\overline{(k=1,2)}$ are parameters; $\Delta$ symbolizes the difference operator; $\beta_0$ is the constant term; and $\mu_t$ is an error term.

The ARDL Bound test for cointegration is used to examine the short-term and long-term relationships among the series. The test statistics are developed to test the null hypothesis ($H_0$: $\varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = 0$) of no long-term relationship (cointegration) among the series against the alternative hypothesis of the existence of log-run relationship ($H_a$: $\varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq 0$). The decision to accept or reject $H_0$ is determined based on the F value. Nevertheless, the F-statistic asymptotic distribution generated by this model is non-standard, irrespective of whether the variable is I(0) or I(1). Narayan (2005) has compiled a collection of suitable critical values. Should the F-statistic exceed the upper threshold, it signifies the rejection of the null hypothesis, signifying the presence of a long-term relationship among the variables. Conversely, if the F-statistic falls below the lower threshold, the null hypothesis cannot be refuted. The outcome remains inconclusive when the F-statistic falls within the range between the lower and upper boundaries (Kasim, 2013). This study employs Akaike Information Criterion (AIC) to determine the optimum leg lengths for the variables. This study presumes that the proper lags for the series are ($p$, $q_1$, $q_2$, $q_3$, $q_4$, $q_5$), where "$p$" signifies the lag-length of the LnGDP series and "$q_1$," "$q_2$," "$q_3$," "$q_4$," "$q_5$" reveals the to lag length of series GDP, CAP, NRE, RE, $CO_2$, and FDI respectively.

If co-integration exists, the process then estimates the long-run and short-run coefficients of the ARDL model. The short-run analysis will be conducted through an error correction model (ECM) in ARDL based on the following equation:

$$\Delta LnGDP_t = \beta_0 + \sum_{i=1}^{p}\beta_{0i}\Delta LnGDP_{t-i} \boxplus \sum_{i=1}^{q_1}\beta_{1i}\Delta LnCAP_{t-i}$$
$$+\sum_{i=1}^{q_2}\beta_{2i}\Delta LnNRE_{t-i} + \sum_{i=1}^{q_3}\beta_{3i}\Delta LnRE_{t-i} + \sum_{i=1}^{q_4}\beta_{4i}\Delta LnCO2_{t-i}$$
$$+\sum_{i=1}^{q_3}\beta_{5i}\Delta LnFDI_{t-i} + \mu ECT_{t-1} + v_t$$

Where $\beta_{kj}\left(k=\overline{1,2}\right)$ are coefficients, ECT is the error correction term, and $\mu$ is the speed of adjustment that is expected to have a value between −1 and 0 and is statistically significant. At the end of the step, the structural stability test to ascertain the goodness of fit of the selected model by using the Breusch-Godfrey Lagrange Multiplier test for autocorrelation proposed by Breusch and Godfrey (1981), the Cumulative Sum (CUSUM) methods proposed by Chow (1960) and Cumulative Sum of Squares (CUSUMSQ) designed by Brown et al. (1975).

## 4. EMPIRICAL RESULTS AND DISCUSSION

This section presents and discusses the ARDL cointegration test procedure results on how economic growth is affected by capital formation, renewable and non-renewable energy consumption, FDI, and $CO_2$ emissions in Indonesia. The results include unit root tests, cointegration, regression, and VECM analysis.

### 4.1. Descriptive Statistics and Unit Root Test Results

The summary statistics of the variables are presented in Table 2. All values are in natural logarithms. The natural logarithm of per capita GDP ranges from 7.302 to 8.266. Gross capital formation ranges from 31.789 to 36.215. Non-renewable energy consumption ranges from 0.732 to 2.086. Renewable energy consumption ranges from −4.533 to −0.461. With regards to $CO_2$ emission, the range is from 5.211 to 6.628. Finally, the foreign direct investment ranges from 0.000 to 23.946.

The integration level of the data should be ensured before performing the ARDL test procedure. In order to detect the presence of a unit root in the variable, this study conducted an ADF and PP unit root test. If a unit root is present, it indicates that the variable is not stationary and vice versa. The results of both tests are presented in Table 3.

Based on Table 3, it is observed that the series of LnGDP, LnFDI, LnNRE, LnRE, and $LnCO_2$ are not stationary at the level and stationer at their first difference I(1) with exceptions to LnCAP that is stationary at the level I(0). Therefore, the variables in the model are not stationary at the same level. Therefore, the ARDL is the most suitable approach to estimate the long-run and short-run relationship among variables. The ARDL technique, developed by Pesaran et al. (1996), enables long-run estimation and is applicable regardless of the stationary features of the variables in the sample.

### 4.2. Lag Length Criteria

After identifying the level of integration for all variables in the model estimation using the unit root test, the following step is determining the number of lags to estimate the ARDL bound test. This study chose the lag length based on the AIC criteria. Figure 1 presents the 20 best ARDL models. Based on the figure, the optimal leg lags selected for estimation is ARDL (2, 0, 2, 0, 2, 2).

### 4.3. ARDL Bound Test for Co-Integration

After determining the number of lags, we proceed to the cointegration test based on the bound test procedure (Table 4). The bound test procedure is based on the following hypotheses:

$H_0$: $\theta_0 = \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5$ ($H_0$ hypothesis: no existence of long run relationship)
$H_0$: $\theta_0 \neq \theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5$ ($H_1$ hypothesis: The existence of long-run relationship).

Table 4 presents the ARDL cointegration test results for six systems: GDP, CAP, FDI, NRE, RE, and $CO_2$. The test compares the value of the F-statistic and upper bound of Narayan's (2005) critical value at all significant levels. Ho is rejected if the F-statistic is higher than the upper bound I(1) at 5%; the cointegration exists and vice versa. Based on Table 4, the value of F-statistics is 3.72 higher than upper bound I(1) at 5%, 3.38. Thus, it can be concluded that $H_0$ is rejected, which means that cointegration exists in the model.

**Table 2: Descriptive statistics**

| Indicators | LnGDP | LnCAP | LnNRE | LnRE | $LnCO_2$ | LnFDI |
|---|---|---|---|---|---|---|
| Mean | 7.778 | 34.275 | 1.548 | −2.651 | 6.032 | 19.690 |
| Median | 7.705 | 34.275 | 1.604 | −2.670 | 6.063 | 22.311 |
| Maximum | 8.266 | 36.215 | 2.086 | −0.461 | 6.628 | 23.946 |
| Minimum | 7.302 | 31.789 | 0.732 | −4.533 | 5.211 | 0.000 |
| SD | 0.299 | 1.505 | 0.391 | 1.143 | 0.414 | 7.660 |
| Skewness | 0.263 | −0.157 | −0.529 | 0.074 | −0.349 | −2.155 |
| Kurtosis | 1.762 | 1.610 | 2.125 | 2.417 | 1.939 | 5.848 |
| Jarque-Bera | 2.412 | 2.708 | 2.513 | 0.481 | 2.148 | 35.599 |
| Probability | 0.299 | 0.258 | 0.284 | 0.785 | 0.341 | 0.000 |
| Sum | 248.9 | 1096.821 | 49.560 | −84.845 | 193.054 | 630.105 |
| Sum square deviation | 2.774 | 70.293 | 4.758 | 40.514 | 5.334 | 1819.411 |
| Observations | 32 | 32 | 32 | 32 | 32 | 32 |

LnGDP: Logarithm gross domestic product, LnNRE: Logarithm nonrenewable energy, LnFDI: Logarithm foreign direct investment, LnRE: Logarithm renewable energy, SD: Standard deviation

**Table 3: Unit root test result**

| Variables | ADF test | | | | | PP test | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Level | | 1st difference | | Results | Level | | 1st difference | | Results |
| | T-statistic | P | T-statistic | P | | T-statistic | P | T-statistic | P | |
| LnGDP | 1.015 | 0.995 | –4.155 | 0.003 | I (1) | 1.015 | 0.995 | –4.155 | 0.003 | I (1) |
| LnCAP | –2.623 | 0.009 | | | I (0) | 1.715 | 0.008 | | | I (0) |
| LnFDI | –1.429 | 0.555 | –7.108 | 0.000 | I (1) | –1.249 | 0.641 | –8.175 | 0.000 | I (1) |
| LnNRE | –1.753 | 0.393 | –4.091 | 0.016 | I (1) | –2.098 | 0.246 | –8.052 | 0.000 | I (1) |
| LnRE | 2.014 | 0.999 | 2.552 | 0.009 | I (1) | 5.645 | 1.000 | –3.721 | 0.008 | I (1) |
| $LnCO_2$ | –0.449 | 0.888 | –5215 | 0.000 | I (1) | –0.300 | 0.913 | –10.72 | 0.000 | I (1) |

LnGDP: Logarithm gross domestic product, LnNRE: Logarithm non-renewable energy, LnFDI: Logarithm foreign direct investment, LnRE: Logarithm renewable energy, ADF: Augmented dickey-fuller, PP: Phillips-perron

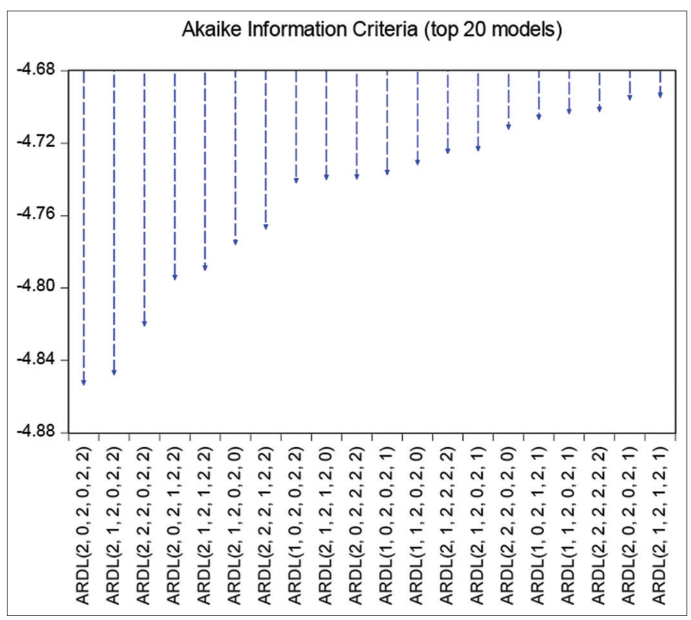
**Table 4: Bound test result for cointegration**

| K | Test statistic (F-statistic) | Critical value bounds | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 10% | | 5% | | 2.5% | | 1% | |
| | | I (0) | I (1) | I (0) | I (1) | I (0) | I (1) | I (0) | I (1) |
| 5 | 3.72 | 2.08 | 3 | 2.39 | 3.38 | 2.7 | 3.73 | 3.06 | 4.15 |

## 4.4. ARDL Estimation Results

The estimation process proceeds to the long-run equation after establishing the long-run co-movement among variables through bound testing. Table 5 presents the estimation result of the ARDL model. The long-run ARDL model is selected based on AIC criteria (2, 0, 2, 0, 2, 2). Table 5 reveals that, in general, all variables significantly affect per capita GDP except for the gross capital formation (CAP) variable. Non-renewable energy consumption has a positive and significant effect on economic growth. Interestingly, renewable energy consumption also possesses a positive effect on economic growth. However, the magnitude of NRE to economic growth is higher than RE consumption. These results indicate that NRE is still Indonesia's dominant energy source, and therefore, its contribution to economic growth is higher than renewable energy. However, these results support the growth hypothesis, which proposes that economic growth is affected by changes in energy policy and energy consumption.

**Figure 1:** Akaike information criteria




## 4.5. Long-run Estimation Results

In Table 6, we can see the long-term coefficients of the ARDL model. The results show that non-renewable energy consumption, $CO_2$ emissions, and FDI have a direct impact on economic growth. However, renewable energy consumption has an insignificant effect on economic growth in the long run, as indicated by the probability value that exceeds $\alpha$ at 5%. This can be attributed to the overwhelming use of non-renewable energy in Indonesia. According to the Indonesia Energy Outlook (2022), more than 80% of the total energy consumed in Indonesia comes from fossil fuels like oil, coal, and natural gas. Indonesia possesses significant potential for renewable energy, yet it remains underutilized due to a lack of priority in constructing the necessary infrastructure. Renewable energy development is a challenge in many developing nations, as it necessitates substantial funding investments. It has many renewable energy sources, such as hydro, wind, solar, geothermal, biomass, and biofuels. Nevertheless, the government has only been able to utilize 2.4% of the total energy from these sources. As a maritime country, Indonesia has enormous potential for ocean current energy, which is currently untapped.

According to the long-run model estimation results, a negative correlation exists between $CO_2$ emissions and economic growth, as reflected by GDP. This implies that the increasing levels of $CO_2$ emissions in Indonesia have had a harmful impact on the economy and society. In addition, the long-run elasticity of LnGDP concerning the effect of foreign direct investment is positive and statistically significant. These findings imply that foreign direct investment is important in spurring Indonesia's economic growth.

**Table 5: Estimation results of autoregressive distributed lag (2, 0, 2, 0, 2, 2) model**

| Variables | Dependent variable: LnGDP | | | |
|---|---|---|---|---|
| | Coefficient | SE | T-statistic | P |
| C | −2.674 | 0.328 | –3.654 | 0.004 |
| LnGDP (−1) | 1.083 | 0.211 | 5.123 | 0.001 |
| LnGDP (−2) | −0.389 | 0.220 | –1.767 | 0.096 |
| LnCAP | −0.022 | 0.040 | –0.548 | 0.591 |
| LnNRE | 0.602 | 0.368 | 1.632 | 0.032 |
| LnNRE (−1) | −0.319 | 0.487 | –0.654 | 0.022 |
| LnNRE (−2) | −1.023 | 0.378 | –2.703 | 0.003 |
| LnRE | 0.010 | 0.021 | 0.481 | 0.236 |
| $LnCO_2$ | −0.107 | 0.361 | –0.297 | 0.769 |
| $LnCO_2$ (−1) | −0.065 | 0.438 | –0.148 | 0.883 |
| $LnCO_2$ (−2) | 1.147 | 0.374 | 3.068 | 0.007 |
| LnFDI | 0.003 | 0.001 | 4.028 | 0.001 |
| LnFDI (−1) | −0.003 | 0.001 | –2.676 | 0.016 |
| LnFDI (−2) | 0.002 | 0.001 | 2.005 | 0.062 |
| C | −1.611 | 0.919 | –1.752 | 0.098 |

LnGDP: Logarithm gross domestic product, LnNRE: Logarithm non-renewable energy, LnFDI: Logarithm foreign direct investment, LnRE: Logarithm renewable energy

**Table 6: Long-term coefficients of the autoregressive distributed lag model**

| Variables | Dependent variable: LnGDP | | | |
|---|---|---|---|---|
| | Coefficient | SE | T-statistic | P |
| LnCAP | −0.072 | 0.136 | −0.530 | 0.603 |
| LnNRE | 2.417 | 0.735 | 3.285 | 0.004 |
| LnRE | 0.033 | 0.063 | 0.527 | 0.605 |
| $LnCO_2$ | −3.183 | 1.194 | −2.664 | 0.017 |
| LnFDI | 0.009 | 0.003 | 2.616 | 0.018 |
| C | −5.261 | 3.131 | −1.680 | 0.112 |

SE: Standard error, LnGDP: Logarithm gross domestic product, LnNRE: Logarithm nonrenewable energy, LnFDI: Logarithm foreign direct investment, LnRE: Logarithm renewable energy

### 4.6. ECM Short-Run Estimation Results

Based on the co-integration results, we estimate error correction models (ECM) to examine the existence of error correction mechanisms and the short-run relationship between energy consumption, carbon emission, FDI, and economic growth. Table 7 presents the results of the short-run coefficient estimation through the ARDL approach. The table shows that non-renewable energy and FDI positively and significantly impact economic growth. On the other hand, there is a negative and significant relationship between $CO_2$ emissions and FDI in the past, indicating that high $CO_2$ emissions and FDI hinder economic growth. This finding highlights the need for environmentally sustainable economic policies that promote the use of renewable energy sources and limit carbon emissions.

Furthermore, Table 7 also presents the coefficient of error correction term (ECT) to confirm the existence of a correction mechanism to the short-term shock toward the long-term equilibrium level. The result shows that the coefficient of ECT is negative (–0.306) and statistically significant indicating that the error correction mechanism exists and confirming the validity of the cointegration relationship among variables. The coefficient of ECT informs that the speed of adjustment between short-run dynamics and long-run equilibrium is 30.6%. This means that 30% of the disequilibrium caused by the previous year's shock reverts to the present year's long-run equilibrium. It can be identified based on the negative sign of coefficient or error term (ECT) –0.306 and significant level at 1% level.

### 4.7. Diagnostic and Stability Tests of ECM

A summary of the diagnostic and stability test results is presented in Table 8. The Ramsey test shows a probability value of 0.961, accepting the null hypothesis of correct specification, confirming that the model successfully handles the problem of functional form misspecification. The result of the Breusch-Pagan-Godfrey test exposes that the error variance is constant (P = 0.278), indicating that the model is free from the heteroscedasticity problem. Furthermore, the Breusch–Godfrey serial correlation LM test indicates that the test outcome hints that the autocorrelation issue is unfounded. It is signified by the (P = 0.214), which is higher than alpha. The normality test becomes the last test of the diagnostic test. The residual error is normally distributed based on the (P = 0.781), higher than alpha at 5%.

**Table 7: Error correction representation of the autoregressive distributed lag model**

| Dependent variable: LnGDP | | | | |
|---|---|---|---|---|
| Variable | Coefficient | Std. error | T-statistic | Prob. |
| D (LnGDP [−1]) | 0.389 | 0.110 | 3.528 | 0.002 |
| D (LnNRE) | 0.602 | 0.249 | 2.411 | 0.028 |
| D (LnNRE [−1]) | 1.023 | 0.307 | 3.332 | 0.004 |
| D ($LnCO_2$) | −0.107 | 0.244 | −0.440 | 0.665 |
| D ($LnCO_2$ [−1]) | −1.147 | 0.291 | −3.931 | 0.001 |
| D (LnFDI) | 0.003 | 0.001 | 6.637 | 0.000 |
| D (LnFDI [−1]) | −0.002 | 0.001 | −3.136 | 0.001 |
| ECT (−1)* | −0.306 | 0.051 | −5.991 | 0.000 |

ECT=LnGD – (0.072LnCAP – 2.417×LnNRE – 0.033LnRE+3.183×$LnCO_2$ – 0.009×LnFDI+5.261). ECT: Error correction term, LnGDP: Logarithm gross domestic product, LnNRE: Logarithm nonrenewable energy, LnFDI: Logarithm foreign direct investment

**Table 8: Results of diagnostic and stability tests**

| Types of test | Diagnostic test | Test statistic | P |
|---|---|---|---|
| Functional form | Ramsey reset test | F (1–15) = 0.050 | 0.961 |
| Serial correlation | Breusch-Godfrey serial correlation LM test | F (2–14) = 1.722 | 0.214 |
| Heteroscedasticity | Breusch-pagan-godfrey test | F (13–16) = 1.356 | 0.278 |
| Normality | Jarque-Bera | Jarque-Bera=0.492 | 0.781 |

**Figure 2:** The plot of the cumulative sum of recursive residuals

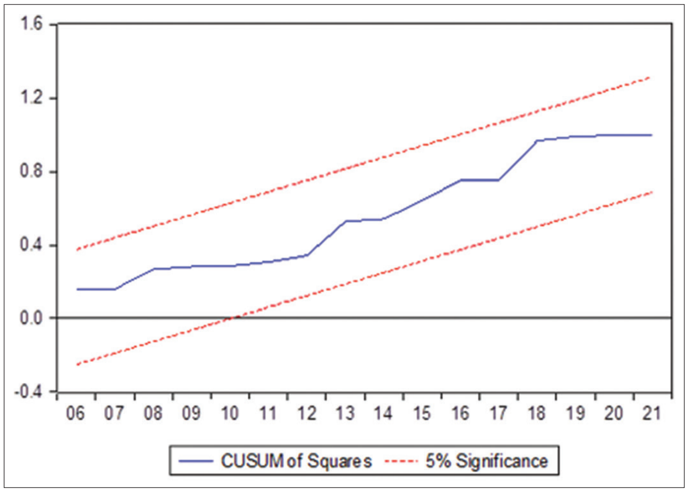
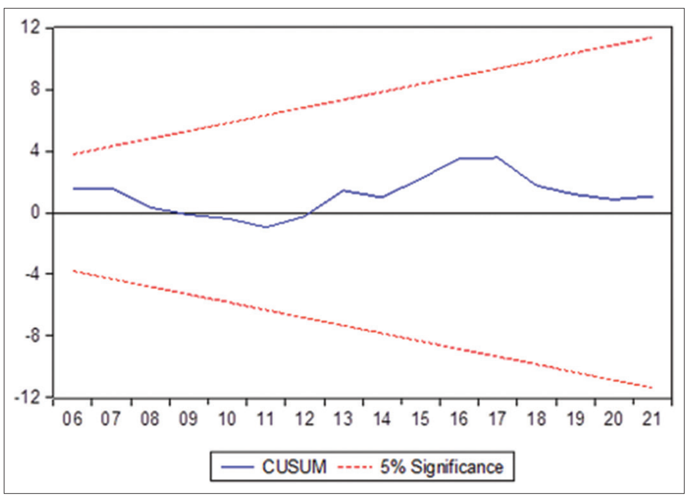



**Figure 3:** The plot of the cumulative sum of squares of recursive residuals




Moreover, the residual test was also performed to detect the stability of the model. The findings of the residual test uncover that the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUM of squares) of recursive residuals are within the boundaries of the 5% confidence interval of parameter stability. This can be evidenced by the movement of the blue line, which is consistent between the red lines (Figures 2 and 3). Therefore, based on the result gained, the instability issue in the model is absent, and the model is appropriate to be used as an essential consideration in analyzing the impact of renewable and non-renewable energy consumption, gross capital formation, foreign direct investment, and $CO_2$ on economic growth in Indonesia.

## 5. CONCLUSION AND POLICY IMPLICATION

The study aims to identify how renewable and non-renewable energy consumption, gross capital formation, foreign direct investment, and $CO_2$ emission affect economic growth in the case of Indonesia during the period 1990-2021. This study draws several conclusions by employing the ARDL approach to investigate short- and long-run relationships. First, during the observation period, the long-term equilibrium relationship confirmed between economic growth, nonrenewable energy consumption, renewable energy consumption, $CO_2$ emission, and foreign direct investment in Indonesia. Second, non-renewable energy consumption and investment could improve income levels in the long run. Contrary to what was expected, it turns out that the consumption of renewable energy does not impact the Indonesian people's per capita income in the long term. Third, more varied results are seen in short-term relationships where changes have significantly influenced the rise in Indonesia's per capita income in the current consumption of non-renewable energy and FDI. In addition, the current income per capita has been positively impacted by historical GDP fluctuations and the use of non-renewable energy in the previous period. Meanwhile, economic growth has been harmed by the $CO_2$ emissions and investments made in the past.

The study's findings make it abundantly evident that energy, especially non-renewable, plays a significant role in Indonesia's economic growth. Thus, it is very crucial to increase the production of energy continuously in order to spur the economic growth of Indonesia. Otherwise, economic growth and people's income will be hindered due to the lack of energy sources.

Although this research confirms that fossil energy consumption is the main variable that supports people's income, excessive consumption of fossil energy produces large amounts of $CO_2$, which causes massive environmental damage through greenhouse gases and global warming. Therefore, a government policy is needed for several related industries to reduce carbon emissions in Indonesia. In addition, there must be an interrelated policy with one vision to reduce carbon emissions between energy producers, automotive manufacturers, and the government as a provider of public facilities. Energy producers must be encouraged to produce more renewable energy than fossil energy. Meanwhile, as the largest polluting sector, automotive manufacturers should increase the production of environmentally friendly vehicles such as electric vehicles as soon as possible. Moreover, the government must invest in a short time to provide environmentally friendly public transportation facilities because this can minimize people's desire to use their private vehicles.

Switching energy sources from fossil to renewable energy in the short term is very risky to hamper Indonesia's economic growth. The result can conclude it or short-run ECM analysis. However, moving from fossil to renewable energy must continue in the long run. It ensures that the next generation living in Indonesia could feel better environment quality. The government of Indonesia could also promote local producers to foreign investors. This is because FDI is confirmed as one of the variables that can support the economy of Indonesia based on the result.

Indonesia's air pollution has significantly increased due to the country's recent rapid growth in fossil fuel consumption. The Indonesian government should be motivated to swiftly implement energy-saving measures to enhance environmental quality and support economic growth. Since renewable energy is still growing extremely slowly, the environment is not currently being negatively affected in a big way. Therefore, a more proactive strategy is required through the forced transformation of energy consumption for the industrial and transportation sectors responsible for most of Indonesia's air pollution.

This study suggests that Indonesia should invest massively in the renewable energy sector, bearing in mind the large amount of potential renewable energy resources in Indonesia that have not been exploited, especially wind, hydro, and geothermal power, where Indonesia has one of the largest geothermal potentials in the world. The government must make significant investments to create mass transit that employs renewable energy sources in the context of transportation, Indonesia's most polluting industry. A comfortable public transportation system will encourage people to minimize the use of private vehicles.

Although the findings of this study have revealed interesting findings in Indonesia's case, there are also limitations of the research. This study only uses a proxy for carbon emissions ($CO_2$) as Indonesia's sole cause of environmental damage. Several indicators, like rising temperatures, rising sea levels, deforestation, and others, can be used. This study also recommends broadening the scope of the investigation by including additional macroeconomic elements, such as population, technology advancements, or even financial and banking variables.

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