Symmetric and Asymmetric Response of the Renewable Energy Market to Indonesian Economic Trends

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Keywords

Renewable Energy; GDP; Inflation; Exchange Rate; FDI; Asymmetric.

Abstract

This study digs into the complex interplay between renewable energy market development and Indonesian economic trends. Our rigorous study aims to investigate the impact of crucial economic indicators, including gross domestic product (GDP), exchange rates, inflation, real interest rates, net inflow of foreign direct investment (FDI), and urbanisation, on the renewable energy landscape in Indonesia between 1973 and 2022. This study provides a novel insight by investigating both symmetric and asymmetric impacts in the context of Indonesia. While previous studies have limited scope with linear relationships, this study fills a gap by capturing the dynamic interplay between renewables and economic indicators. By employing a robust econometric model, we reveal interesting patterns highlighting the multidimensional nature of the renewable energy market's responses to economic trends and find that there is a long-term interplay among the variables under linear and non-linear models. We found empirical evidence indicating that the nexus is asymmetric. However, in the long term, GDP exhibits an asymmetric positive impact on renewable energy consumption in the linear model. This shows that economic growth positively correlates with Indonesia's adoption of sustainable renewable energy sources. Similarly, urbanisation shows a positive response, with expanding cities boosting demand for cleaner and greener energy. Surprisingly, exchange rates show an asymmetric response, demonstrating that depreciation of local currency has a disproportionate negative impact on renewable energy investment during economic downturns. Inflation also exhibits a negative asymmetric response due to eroding purchasing power that reduces investment in renewables. Meanwhile, net inflow of FDI emerges as a critical driver in favourable economic conditions, dramatically amplifying renewable energy capacities. Therefore, during economic recessions, FDI's impact diminishes and emphasises the significant importance of tailored interventions. Based on the findings of this study, which demonstrate the profound interplay of how the Indonesian economy shapes and is affected by the renewable energy market, we encourage the adoption of policies that promote sustainable energy development while increasing economic resilience. We recommend that policymakers support renewable energy diversification to lessen the vulnerability of exchange rate fluctuations. Attracting FDI is also crucial, as policies can help strengthen the investment climate and bolster the renewable energy sector. Inflation-indexed incentives can help maintain confidence and foster economic growth

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https://doi.org/10.56529/mber.v3i1.271

1. Introduction

Globally, the constraints of growth and the 1973 and 1979 oil shocks raised concerns about the impact of energy utilisation on economic growth, as measured through increases in gross domestic product (GDP), and environmental quality. Numerous nations, including Indonesia, have industrialised without considering environmental impact alongside economic growth. The 1992 Rio Earth Summit concluded that economies should prioritise environmental preservation alongside development. Energy has been crucial in economic growth, but it is essential to consider the environmental impact of energy consumption. Forster (1973) and Luptacik and Shubert (1975) claimed that the association between energy consumption and economic growth cannot be fully understood without considering environmental impact. Meadows' (1972) study, as well as studies by Georgescu-Roegen (1975), Hall *et al.* (1986), and Kaufmann (1987), were among the first to address environmental issues in economics. The inclusion of environmental concerns in growth analysis led to the idea of sustainable development.

The association between economic growth and environmental sustainability remains a hot topic of deliberation among scholars and politicians. According to the theory of economics, economic development and environmental deterioration are positively related. In the early stages of economic growth, increased economic activity leads to increased consumption of non-renewable energy sources, which has a negative environmental impact. Therefore, attaining appropriate economic growth can contribute to environmental sustainability if the whole economic system is modified. It is noted that when the economy starts growing, income inequality decreases, resulting in an inverted U-shaped curve. In contrast, the relationship between economic growth and the environment is known as the environmental Kuznets curve (EKC). Kuznets (1955) introduced the EKC; he argued that income inequality rises and falls when economic growth accelerates. Grossman and Krueger (1991) also supported this argument and highlighted the similar relationship between economic growth and the environment. Thus, empirical investigation was carried out to look deeper into the actual relationship between energy consumption, economic growth, and environmental sustainability.

Alshehry & Belloumi (2023) also emphasised the EKC theory, suggesting that when the economy grows, it causes increased environmental degradation until it starts to decrease. This has been analysed to investigate the relationship between economic growth and carbon dioxide from energy consumption. The author further analyses the multidimensional impacts of positive and negative economic shocks on renewable energy consumption. For instance, Rahaman *et al.* (2023) found that their negative economic shocks have a higher impact on reducing renewable energy consumption than positive shocks do on increasing it. This illustrates how economic changes impact renewable energy consumption in the short-term and long-term. The renewable energy market's response to economic considerations might be either symmetrical or asymmetrical. Symmetric reactions mean that the market for renewable energy responds precisely the same way to both positive and negative economic events. Asymmetric reactions, on the other hand, imply that the market reacts differently depending on whether the economic shift is favourable or harmful (Baz *et al.*, 2021).

Indonesia has set ambitious goals for renewable energy, aiming for 23% of total power output from renewable sources by 2025 and 31% by 2050 (Indonesian Renewable Energy Market Insights, n.d.). Currently, the renewable energy consumption achieved 13.1% in 2023, while the target was 17.9% (Adji, 2024). The country's renewable energy sector is predicted to expand dramatically, with solar energy experiencing rapid expansion due to Indonesia's solar solid potential (Ventures, 2023). However, problems such as the country's high reliance on fossil fuels and geographical limitations resulting from its archipelagic character have hampered the rise of renewable energy. Despite these limitations, combining intelligent grids and battery energy storage systems will likely open up new potential in Indonesia's renewable energy sector.

As Indonesia plans its trajectory towards sustainable growth, understanding the interplay between economic activities and renewable energy development is crucial to ensure that growth endeavours remain congruent with environmental sustainability. Indonesia's economy is strongly reliant on conventional energy sources, making it critical to understand how economic variation impacts renewable energy sources, as this is mainly expected to increase growth significantly. Thus, this understanding might encourage and motivate strategic planning and investment decisions, ensuring that economic goals are crucially aligned with sustainable energy efficiency paths. The findings from this study therefore provide detailed insights for policymakers on designing incentives and support mechanisms to boost renewable energy proliferation, particularly during economic recession. Finally, this study provides valuable insights into the role of renewable energy in Indonesia's energy blend, which is anticipated to rise in coming years.

Notable knowledge gaps highlight the importance of this research endeavour. Specifically, while existing literature is extensive worldwide, there is a notable lack of information about Indonesia's specific setting, which is fraught with economic and topographical problems. Furthermore, there is a tangible gap in comprehending the Indonesian renewable energy market's asymmetric responses to positive and negative economic perturbations—an aspect critical for informed decision-making and policy creation. Previous studies have largely ignored the long-term consequences of economic fluctuations on renewable energy in Indonesia; this study seeks to fill this gap via rigorous investigation and analysis. Therefore, we highlight the critical concerns for Indonesia in transitioning to renewable energy, as well as regulatory loopholes, as high reliance on fossil fuels calls for a more comprehensive regulatory framework. The study also has implications for the need to understand the critical economic consequences of renewable energy development, including the potential for cost reduction and the impact on consumer prices and subsidies.

The study aims to assess comprehensively the complex relationship amid economic uncertainty besides renewable energy consumption in Indonesia. This will analyse the influence of economic development on renewable energy consumption by identifying both symmetric and asymmetric responses. This study objective is critical to understanding the renewable energy market's response to both positive and negative economic indicators. Moreover, this study evaluates the resilience of the energy sector in Indonesia to economic shocks, both positive and negative. The study also examines the market's adaptation and stability in the face of economic fluctuation as well as provides significant insights on the potential role of renewable energy as a stabilising force for the Indonesian economy. Additionally, the study assesses the long-term viability of renewable energy programmes in the face of economic fluctuations, which is critical to determine the success and longevity of renewable energy initiatives to promote sustainable economic growth while encouraging environmental conservation.

The fundamental research questions for this study were as follows: Is the response of the renewable energy market to the Indonesian economy symmetric or asymmetric? What is the long-term relationship among the renewable energy markets and Indonesian economy? What implications does that have for the Indonesian economy? This investigation is significant given Indonesia's energy industry, which is now at a crossroads. The nation's increasing commitment to improving renewable energy consumption not only tackles severe environmental problems but also has ramifications for economic stability and progress. Thus, analysing market behaviour in the face of economic changes helps us understand the durability and flexibility of the renewable energy sector in Indonesia.

The remainder of this paper includes a literature review, methodology used in this study, data collection processes, and the econometric model. The results section presents findings from the econometric analysis. The discussion contextualises results within the Indonesian economic situation, compares them with previous studies, and explores implications for policymaking. The conclusion synthesises key findings, reflects on study limitations, and suggests avenues for further research.

2. Literature Review

The EKC model is a popular tool for investigating the link between the natural environment, energy, and growth in the economy. A significant amount of research employing this approach has determined that emissions rise alongside growing economies, reaching a breaking point at which the link between pollution and growth reverses, demonstrating a reversible U-shaped curve. Grossman and Krueger (1991) developed the EKC, which is typically understood within two distinct manners: representing the early and later stages of economic growth. Throughout the initial stages, economic growth is restricted, with the harm to the environment worsening owing to polluting technologies, a deficiency of ecological consciousness, and a focus on growth. In the following stages, nations transition towards information- and technology-intensive sectors, resulting in less environmental impact and an emphasis on lowering carbon dioxide emissions. However, some scholars have criticised the EKC theory and advocated alternate methodologies, such as carbon deconstruction. Stern (2004) stated that the EKC is not Pareto efficient as well as that the development route seems costly in terms of resources, perhaps causing irreversible adverse effects on the environment. Notwithstanding these concerns, the EKC continues to be a useful framework for understanding the link underlying GDP growth and the degradation of the environment.

Since the 1990s, several studies have been conducted to investigate the association between GDP and carbon dioxide (CO2) levels, utilising cross-sectional, time series, and panel data, aside from other ecological approaches along with variables. The conclusions of these studies are contentious, irrespective of the country or group of countries. Some research supports the EKC notion, whereas others might not. Several investigations (Hamit-Haggar, 2012; Alvarado *et al.*, 2018; Alharthi *et al.*, 2021) support the EKC notion, while others (Nasir *et al.*, 2021; Kongkuah *et al.*, 2021) do not. Multiple investigations have provided collective outcomes (Ahmad *et al.*, 2017; Hove & Türsoy, 2019; Majeed, 2020).

Hamit-Haggar (2012) used cointegration methods to determine long-term equilibrium links between emissions of greenhouse gasses, energy consumption, and economic development across the Canadian manufacturing industry from 1990 until 2007. This piece represented one of the earliest studies to support the EKC theory. The results suggest that energy consumption exerts a noteworthy influence on greenhouse gas releases, confirming the concept. Alshehry and Belloumi (2014) utilised the cointegration method developed by Johansen to investigate economic development and total and disaggregate consumption of gas and oils, with atmospheric CO2 emission levels, employing annual data spanning 1971 to 2012 in Saudi Arabia. Researchers identified a long-term connection between all factors. Meanwhile, data suggests a bidirectional connection between the consumption of natural gas and CO2 emissions, in addition to a unidirectional causal relationship connecting economic growth to the release of CO2 in the short and long terms.

Alvarado *et al.* (2018) employed panel methods to analyse the link between growth, energy consumption, and environmental impact in 151 different nations spanning 1980 to 2016. Their results confirmed the validity of the EKC theory, proving that energy use has an substantial impact on overall ecological gauges. Alharthi *et al.* (2021) employed quantitative techniques to investigate the influence of actual revenue, both renewable and fossil fuel usage, and urbanisation on CO2 emissions in Middle Eastern and North African nations from 1990 to 2015. The authors observed that increased usage of renewable energy lowered greenhouse gas emissions and excessive non-renewable energy consumption resulted in high CO2 emissions. Their analysis supported the EKC idea for the Middle East and North Africa region.

Nasir *et al.* (2021) examined the impacts of economic progress and energy consumption on CO2 emissions in Australia from 1980 until 2014. They studied various manageable factors, including industrial development, openness to trade, and financial growth. Their conclusion was that the EKC theory is not supported, finding that financial development, energy consumption, and trade openness have long-term positive effects on carbon dioxide emissions in Australia. Correspondingly, Kongkuah *et al.* (2022) examined the unpredictable causation link between energy consumption, economic growth, and CO2 emissions in China, using urbanisation and global commerce as controlling factors. The primary results suggest that the theory of EKC is unsupported despite the fact that both economic development and energy consumption are beneficial and have a substantial long-term impact on the Chinese greenhouse gas emissions.

Ahmad *et al.* (2017) used an (autoregressive distributed lag) ARDL model to assess the reliability of the EKC concept in Croatia from 1992 to 2011. The findings showed that EKC is confirmed in the long term but not in the short term. Hove and Tursoy (2019) analysed the EKC for 24 developing countries from 2000 to 2017 using a panel data model with the generalised method of moments (GMM). They found that actual GDP exerts a significant negative influence on CO2 emissions but positively affects carbon monoxide production. Furthermore, the non-linear impact of GDP in real terms increases the release of CO2 despite decreases in nitrogen oxide emissions. From 1961 to 2018, Majeed and Mazhar (2022) used the EKC theory in 76 nations with high, medium, and low-income nations. Their conclusions varied based on the evidence, methodologies, and countries analysed.

The present investigation investigated the potential asymmetrical impacts of the consumption of energy upon ecological indicators in Indonesia. Existing literature has explored this in other contexts. For example, Azam *et al.* (2021) used panel fixed-effect and random-effect methods to analyse the non-linear impacts of disaggregate energy (natural gas, nuclear energy, and renewable energy) on economic development and CO2 emissions across a collection of polluting countries from 2000 to 2016. Their primary conclusion was that using renewable sources reduces CO2 emissions in the countries investigated. Majeed *et al.* (2021) utilised a nonlinear autoregressive distributed lag (NARDL) model to study the potential asymmetrical impacts of disaggregate energy consumption and economic growth on environmental quality in Pakistan from 1971 to 2014. Researchers noticed that rises in natural gas and oil consumption improve the environment as a whole, whereas adverse developments possessed the reverse effect. Liu *et al.* (2022) employed multiple time series techniques to explore the unequal effects of economic development and energy consumption on CO2 emissions in China between 1990 and 2020. The Granger causality test results revealed that fossil fuel usage contributes to both economic growth and greenhouse gas emissions. Moreover, the results from the impulse response pathways highlight that energy consumption and agricultural production growth have a significant impact on China's CO2 emissions.

In the Middle East and North Africa, several studies have examined the EKC hypothesis. Kahia *et al.* (2019) employed the panel autoregressive (PVAR) model to investigate the relationship and the response of renewable energy consumption (REC) and GDP (representing economic growth) to CO2 emissions for 1980-2012. Thus, the findings suggest that GDP growth significantly contributes increasingly to CO2 emissions, while renewable REC reduces CO2. Like the above study, Dkhili (2022) utilised panel data analysis and investigated the relationship between CO2 emissions and GDP and REC, including trade openness and FDI; the author took samples from 1990 to 2018. This study's results demonstrate that the relationship between CO2 and REC has decreased over time. In the most recent literature, Al-Kasasbeh *et al.* (2023) employed panel cointegration approaches as well as Dumitrescu and Hurlin causality approaches to investigate the impact of REC and GDP on CO2 emissions in five Middle Eastern and North African countries between 1980 and 2020. The results suggest a long-term relationship between the three variables in the presence of structural cracks, and that economic growth harmed the natural environment in the countries investigated.

In Indonesia, Sriyana (2019) examined the impact of energy use, electricity, and renewable energy consumption on the Indonesian economy from 1990 to 2017, employing the ARDL model. The findings suggest significant long-term impact of energy use on GDP, while the results from the error correction model suggest a significant positive short-term impact of electricity consumption and labour participation on GDP. The energy use shows a symmetric impact over both long-term and short-term periods. At the same time, an asymmetric impact was found between electricity and REC. Shahbaz *et al.* (2020) examined the impact of renewable energy on economic growth in 38 countries that had significant consumption of renewable energy from 1990 to 2018. The author employed dynamic ordinary least square (DOLS), fully modified least square (FMOLS), and heterogeneous non-causality models, and the results suggest that there is a long-term relationship between REC and GDP for 58% of the sample nations, including Indonesia.

This literature review summarises ongoing arguments on the impact of energy use and economic growth on environmental indicators. However, it also shows that there is a gap in the literature with respect to the symmetric and asymmetric responses of renewable energy on the Indonesian economy. This research provides findings and suggests policy measures for accelerating an increased share of renewable energy consumption in Indonesia. Overall, empirical research on the EKC hypothesis produces conflicting results, which differ depending on the nation, region, study period, data type, and econometric approaches. In addition, previous research focuses on linear modelling of the interplay between renewable energy and economic growth. This study addresses a vacuum in the literature by examining the symmetric and asymmetric response of the renewable energy market to the Indonesian economy.

3. Material and Methods

3.1. Data Description

This study employs quantitative research methods to analyse the symmetric and asymmetric responses of the renewable energy market to the Indonesian economy. Time series data was collected from the International Energy Agency (IEA), International Monetary Fund (IMF), and World Data Indicator (WDI) for the period of 1973 to 2022. This study uses the data for variables such as renewable energy consumption, GDP, FDI, consumer price index, exchange rates, interest rates, urbanisation, and renewable electricity. Table 1 shows variable descriptions and sources

Table 1. Variables Used in This Study

No	Variables	Notation	Measurement	Unit	Source
	Dependent Variables				
1	Renewable Energy Consumption	REC	Share of renewable energy in total final energy consumption	% of total final energy consumption	IEA
	Independent Variable				
2	Gross Domestic Product	GDP	Gross domestic product of Indonesia in IDR	current local currency unit	WDI
3	Foreign Direct Investment	FDI	Net inflow percentage of GDP	net inflows (% of GDP)	IMF
4	Consumer Price Index	CPI	Consumer price index (2010 = 100)	index (2010 = 100)	IMF
5	Exchange Rate	ER	Official exchange rate (local currency unit per USD, period average)	period average	World Bank
6	Interest Rate	IR	Real interest rate (percentage)	percentage	IMF
7	Urbanisation	URB	Urban population (percentage of total population)	% of total population	WDI

Note: IEA (International Energy Agency), WDI (World Data Indicators), IMF (International Monetary Fund)

The dependent variable REC is measured as the percentage of total final energy consumption; the dependent variable GDP is taken as current local currency unit (LCU); FDI is net inflow percentage of GDP; and consumer price index (CPI) is measured on the index of 2010=100, as is the exchange rate (ER). Interest rate (IR) is the real interest rate in percentage form, while urbanisation is the urban annual growth rate in percentage. Exchange rate is measured as the official United States Dollar to Indonesian Rupiah rate. The time trend of individual variables is displayed in the Figure 1 and Figure 2.

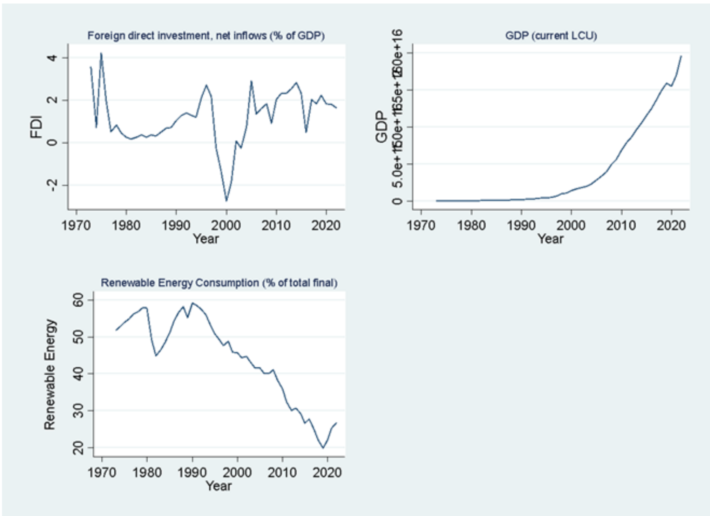

Figure 1. Time Trend Graph of Variables (1973-2022)

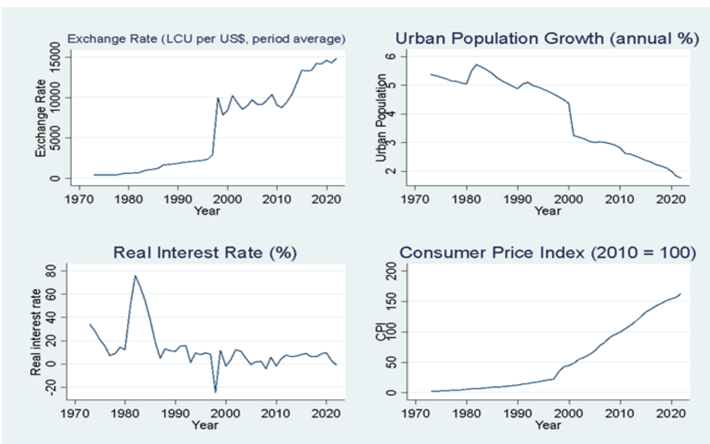

Figure 2. Time Trend Graph of Variables (1973-2022)

3.2 Model Specification

We relied on the existing empirical literature to guide us in specifying a model for this study. Following the studies of Alshehry and Belloumi (2023) and Apergis and Payne (2010), the following model was developed to examine the symmetric and asymmetric effects of the Indonesian economy on renewable energy consumption.

$$REC_t = \delta_0 + \delta_1 GDP_t + \delta_2 FDI_t + \delta_3 CPI_t + \delta_4 ER_t + \delta_5 IR_t + \delta_6 URB_t + \in_t$$

Where:

REC_t denotes the renewable energy consumption at time t; GDP_t is the gross domestic product at current market price; FDI_t is the foreign direct investment net inflow; CPI_t represents the consumer price index; ER_t is the exchange rate; IR_t is the real interest rate; URB_t is the urban annual growth rate; and $\in_t$ is the stochastic error term. $\delta_0 + \delta_6$ are the coefficients of the model.

The novelty of this study is the way we allow both positive and negative economic shocks to influence renewable energy demand. It is expected that a positive shock from GDP should impact positively on renewable energy. This is because as economic output progresses over time, demand for energy use rises while the economy is assumed to be buoyant enough to increase investment in renewables as a strategy towards transition to green energy and growth. The literature tends to assume that FDI could have a two-way effect on the renewable market. Technology transfer around renewable energy into Indonesia may have a significantly positive influence on renewable energy use; however, if such investment is tailored towards other activities, especially activities that involve cost saving strategies from the investors, this may yield a negative effect on renewables because firms could employ cheap fossil sources as a cost saving strategy. CPI is considered to be a proxy for inflation, as high prices may deter consumers away from renewables; this is because inflation is considered as economic evil that requires the attention of monetary and fiscal authorities to keep it within bearable limits. Since most renewable energy technology is sourced from outside Indonesia, exchange rates could affect the market condition depending on whether the rate increases or falls over time. Furthermore, interest rates may exert positive or negative influences on the renewable market depending on the government policy decisions on renewables. Finally, urban expansion is expected to lead to increases in energy demand. Careful selection of energy sources by consumers, due to different cost implications, could change the direction of the causality.

3.3 Estimation Techniques

Most macroeconomic variables – such as cycles, trends, random walks, or a mix – in time series analysis display non-stationary behaviour, making them unpredictable. Therefore, it is crucial to apply some preliminary econometric tests to select the appropriate model to fulfil the requirements of this research. Thus, as the first step, this study intends to investigate the variables' integration order before ARDL model because it is the main assumption of ARDL that requires all the variables require to be integrated either I(0) or I(1). In order to accomplish this, the Augmented Dicky-Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests for unit root are employed for the analysis. Dickey and Fuller present three types of unit root test equations using a null hypothesis of $\varphi = 0$ versus the alternative hypothesis of $\varphi < 0$, i.e.:

$$\Delta y_t = \varphi y_{t-1} + \sum_{i=1}^{p} \beta_i y_{t-1} + \mu_t ..(1)$$

$$\Delta y_t = \alpha_0 + \varphi y_{t-1} + \sum_{i=1}^{p} \beta_i y_{t-1} + \mu_t ..(2)$$

$$\Delta y_t = \alpha_0 + p_t + \varphi y_{t-1} + \sum_{i=1}^{p} \beta_i y_{t-1} + \mu_t ..(3)$$

The ARDL model developed by Pesaran *et al.* (2001) is employed to investigate the symmetric response of renewable energy consumption to Indonesian economy. The ARDL model is more resilient and efficient for small sample sizes. Moreover, it is true irrespective of whether the variables included in the model are purely I(0), solely I(1), or mutually cointegrated. Yet, the model fails in the presence of the I(2) series. The ARDL model can handle asymmetry in the relationships between variables, which is important in many economic scenarios where the impact of a change in a variable may not be symmetric. It effectively addresses the issue of distributed lag effects, where the impact of a change in a variable is not immediate but is spread over future periods. This is particularly useful in analysing economic scenarios where changes in one variable can have long-term effects on others.

The ARDL model provide an expression of the symmetric association between the variables as follows:

$$\Delta REC_t = \beta_0 + \gamma REC_{t-1} + \rho_1^{-} GDP_{t-1}^{-} + \rho_2 FDI_{t-1} + \rho_3 CPI_{t-1} + \rho_4 ER_{t-1} + \rho_5 IR_{t-1} + \rho_6 URB_{t-1} + \rho_7 RE_{t-1} + \sum_{i=0}^{q} \delta_1 REC_{t-1} + \sum_{i=0}^{q} \delta_2 GDP_{t-1} + \sum_{i=0}^{q} \delta_3 FDI_{t-1} + \sum_{i=0}^{q} \delta_4 CPI_{t-1} + \sum_{i=0}^{q} \delta_5 ER_{t-1} + \sum_{i=0}^{q} \delta_6 IR_{t-1} + \sum_{i=0}^{q} \delta_7 URB_{t-1} + ECT_t + \mu_t ..(4)$$

The error correction model that captures the complex short-run dynamics is as follows:

$$\Delta REC_t = \sum_{i=0}^{q} \delta_1 REC_{t-1} + \sum_{i=0}^{q} \delta_2 GDP_{t-1} + \sum_{i=0}^{q} \delta_3 FDI_{t-1} + \sum_{i=0}^{q} \delta_4 CPI_{t-1} + \sum_{i=0}^{q} \delta_5 ER_{t-1} + \sum_{i=0}^{q} \delta_6 IR_{t-1} + \sum_{i=0}^{q} \delta_7 URB_{t-1} + ECT_t + \mu_t ..(5)$$

Where Δ is the 1st difference operator, γ and ρ are the long-term parameters, β is constant term, while δ represents the short-term parameters. *q* indicates the lags. ECT_{i-1} reflects the error correction factor in equation (2), which indicates the speed that the model adjusts to long-term equilibrium after an economic shock. Thus, the ARDL model captures the relationship between renewable energy consumption and Indonesian economy, it does so under the explicit scenario that provided the linear and symmetrical relationship. Such presumptions do not align alongside the primary goal of this study, which is to explore Indonesia's asymmetric response to energy consumption trends. This study employs the non-linear autoregressive distributed lag (NRDL) proposed by Shin et al (2014) model, an asymmetric extension of the linear ARDL to achieve its objective. To specify the ARDL model, the change in renewable energy consumption ΔREC_{t-i} is split into its positive and negative segments that are denoted by ΔREC^{+} and ΔREC^{-} respectively. Segments are further stated as follows:

$$\Delta REC^{+} = \sum\nolimits_{i=t}^{t} \Delta REC^{+} = \sum\nolimits_{i=t}^{t} max(\Delta REC_i, 0)..(6)$$

$$\Delta REC^{-} = \sum\nolimits_{i=t}^{t} \Delta REC^{-} = \sum\nolimits_{i=t}^{t} min(\Delta REC_i, 0)..(7)$$

As defined by Shin *et al.* (2014), the asymmetric cointegrating relationship between variables is specified.

$$\Delta REC_t = \beta_0 + \gamma REC_{t-1} + \rho_1^{-} GDP_{t-1}^{-} + \rho_2 FDI_{t-1} + \rho_3 CPI_{t-1} + \rho_4 ER_{t-1} + \rho_5 IR_{t-1} + \rho_6 URB_{t-1} + \rho_7 RE_{t-1} + \sum_{i=0}^{q} \delta_1 REC_{t-1} + \sum_{i=0}^{q} \delta_2 GDP_{t-1} + \sum_{i=0}^{q} \delta_3 FDI_{t-1} + \sum_{i=0}^{q} \delta_4 CPI_{t-1} + \sum_{i=0}^{q} \delta_5 ER_{t-1} + \sum_{i=0}^{q} \delta_6 IR_{t-1} + \sum_{i=0}^{q} \delta_7 URB_{t-1} + ECT_t + \mu_t ..(8)$$

The asymmetric error correction model is as follows:

$$\Delta REC_t = \sum_{i=0}^{q} \delta_1 REC_{t-1} + \sum_{i=0}^{q} \delta_2 GDP_{t-1} + \sum_{i=0}^{q} \delta_3 FDI_{t-1} + \sum_{i=0}^{q} \delta_4 CPI_{t-1}$$
$$+ \sum_{i=0}^{q} \delta_5 ER_{t-1} + \sum_{i=0}^{q} \delta_6 IR_{t-1} + \sum_{i=0}^{q} \delta_7 URB_{t-1} + ECT_t + \mu_t ..(9)$$

Where Δ is the 1st difference operator, ρ^- and ρ^+ indicates the asymmetric parameters for long-term positive and negative shocks in renewable energy consumption, while δ^- and δ^+ shows the positive and negative deviation parameters in REC. ECT_{i-1} represents the error correction term in the equation (6).

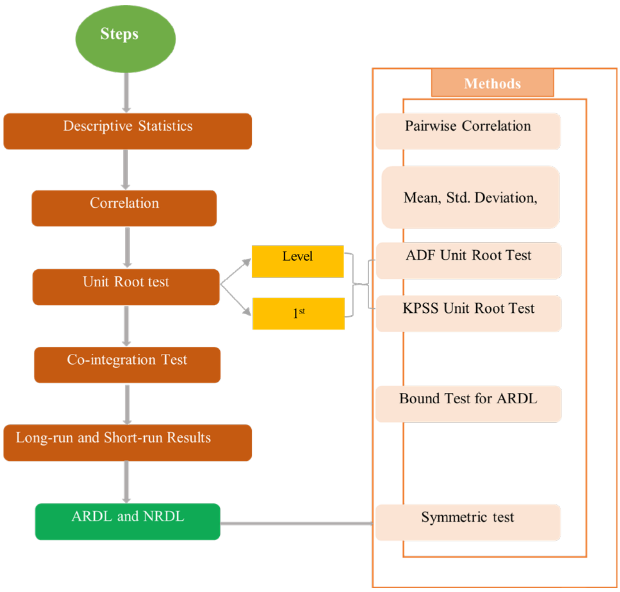

Figure 5. The Methodological Foundation of the Study

Figure 4 depicts the methodological framework. We first performed a unit root test to ensure that the data for this investigation was stationary. The Johansen Cointegration test was used to determine cointegration and then to determine if the variables were related. Further, we employed the ARDL and NARDL model to examine the symmetric and asymmetric relationships among the variables. The Bond test for ARDL was used to find the long-term association.

4. Result and Discussion

This section presents the results from the estimations of the econometric models specified in the third section. This includes descriptive statistics, pairwise correlation, unit root test, symmetric model, asymmetric model, and symmetric coefficients test.

4.1 Descriptive Statistics

The mean GDP growth rate over the observed period is 3.991billion LCU with a standard deviation of 5.630, indicating substantial variability in GDP values. The minimum and maximum GDP values are 6.753 and 1.959 respectively, showcasing a wide range of economic activity during the period. The average FDI value is 1.168 with a standard deviation of 1.287, suggesting moderate variability in FDI. The minimum and maximum FDI values are -2.757 and 4.241 respectively, indicating fluctuations in foreign investment flows. The mean CPI value is 54.956 with a standard deviation of 54.012, reflecting considerable variation in price levels. The CPI ranges from a minimum of 1.681 to a maximum of 163.072, illustrating diverse inflationary pressures during the period. The average urban annual growth rate is 4% with a standard deviation of 1.304, suggesting relatively stable urbanisation trends. The growth rate ranges from a minimum of 1.754 to a maximum of 5.717, indicating moderate fluctuations in urban expansion. The mean renewable energy consumption is 44.133 with a standard deviation of 11.713, indicating moderate variability in renewable energy usage. Renewable energy consumption ranges from a minimum of 19.77 to a maximum of 59.18, showing fluctuations in the adoption of renewable energy sources. The average real interest rate is 13.002 with a standard deviation of 17.534, indicating substantial variability in interest rate levels. The real interest rate ranges from a minimum of -24.6 to a maximum of 76.182, illustrating significant fluctuations in borrowing costs. The mean exchange rate is 6106.186 with a standard deviation of 5165.121, suggesting considerable variability in currency exchange values. Exchange rates range from a minimum of 415 to a maximum of 14,849.854, reflecting fluctuations in the value of the local currency against other currencies.

Table 2. Descriptive Statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
GDP	50	3.991e+15	5.630e+15	6.753e+12	1.959e+16
FDI	50	1.168	1.287	-2.757	4.241
CPI	50	54.956	54.012	1.681	163.072
Urban growth rate	50	4	1.304	1.754	5.717
Renewable energy	50	44.133	11.713	19.77	59.18
Real interest rate	50	13.002	17.534	-24.6	76.182
Exchange rate	50	6106.186	5165.121	415	14849.854

4.2. Unit Root Test Results

Examining the stationarity of the variables under investigation is necessary. Not only because their random behaviour over time helps in determining the model to be estimated, but regressions without critical study of stationarity status produce a spurious result in most cases. Against this backdrop, we employed the popular ADF and KPSS unit root tests. It worth noting that the two tests have different null hypothesis – the null for ADF test says that an underlying variable has a unit root or non-stationary, while KPSS null hypothesis states that a particular series is stationary. Table 3 presents the results of both estimations, where renewable energy consumption under both tests conditions is considered to be stationary after first difference, with an integration order of one. Similarly, consumer price index, urban population growth, official exchange rate and real interest rate are not stationary at level, but their first difference are stationary. FDI is a stationary under both test conditions. Conversely, the results for GDP yield a conflicting result; ADF rejects the null hypothesis of unit root at 1% level, while the null of stationarity is rejected under KPSS test. Summarily, GDP is considered to be of integration order zero and one under ADF and KPSS, respectively.

Table 3. Unit Root Tests

Variables	**ADF**	**KPSS**	**Integration order**		
	level	1st difference	level	1st difference	
Renewable energy	-2.1450	-4.9445*	0.2002**	0.1784	I(1)
GDP	-4.2248*		0.1829**	0.1002	I(0), I(1)
FDI	-3.6839*		0.1081		I(0)
CPI	-1.5877	-4.9335*	0.2400***	0.1381	I(1)
Urban growth rate	-1.9614	-5.9185*	0.1620**	0.0801	I(1)
Exchange rate	-2.9427	-8.2771*	0.8891*	0.0468	I(1)
Real interest rate	-2.480	-7.139*	0.089	0.032	I(1)

*,**,*** signifies the rejection of the null hypothesis at 1%, 5% & 10% respectively. ADF's null hypothesis: a named series has a unit root. KPSS's null hypothesis: a named series is stationary. Source: Authors computation.

Table 4. Symmetric Model Estimates

Variables	**Coefficients**	**Standard error**
Long Term Estimates		
GDP	0.448	0.597
FDI	-3.299*	0.925
CPI	-0.231*	0.039
Urban Growth Rate	-6.576*	2.150
Exchange rate	-0.002*	0.0005
Real interest rate	-0.288*	0.047
Short run estimates		
Renewable (-1)	0.510*	0.142
Renewable (-2)	0.460*	0.130

GDP	-18.167*	5.199
GDP (-1)	-7.803	6.277
GDP (-2)	-23.968*	5.500
FDI	-1.876*	0.357
FDI (-1)	0.462***	0.270
Urban growth rate	4.978*	1.604
Urban growth rate (-1)	5.460*	1.707
Urban growth rate (-2)	7.082*	1.549
Urban growth rate (-3)	7.460*	1.486
Exchange rate	-0.0009*	0.0002
Exchange rate (-1)	0.00126	0.0003
Real interest rate (-1)	0.176*	0.044
Real interest rate (-2)	0.079*	0.030
Error correction term	-1.017*	0.154
Bound test (F-statistics)	4.166**	
BP serial correlation	2.904***	
BPG heteroscedasticity	0.242	
Cusum test	Stable	
Cusum of square test	Stable	
Selected model based on AIC	ARDL(3,2,2,0,4,3,3)	

*,**,*** signifies the rejection of the null hypothesis at 1%, 5% & 10% respectively. Source: Authors computation.

4.3 Symmetric Model of the Renewable Energy Market and Indonesian Economy

One of the key contributions of this study to the extant literature is to examine the symmetric relationship between the renewable energy market (with aggregate renewable energy consumption as proxy) as a percentage of the total final energy consumption and key Indonesian macroeconomic indicators, such as gross domestic product at current market prices, foreign direct investment, inflation, exchange rates, and real interest rates, with urban growth rate as a control variable. In Table 5, we report the results of the estimation of equations 4 and 5. In the long term, economic growth (using GDP as proxy) is found to have a positive impact on renewable energy consumption, although this is not statistically significant. Initially, it the authors expected that as economic growth increased, there would be a corresponding increase in renewable energy consumption. This expectation stems from the assumption that higher economic output would enable more resources and investment in cleaner energy sources like wind, solar, and hydroelectric power. This explains the dominance of fossil fuel consumption, particularly coal, for the generation of energy in Indonesia. This particular finding is in agreement with Apergis and Payne (2010) but contradicts the Apergis and Payne (2012) study of developing countries, where the authors posit that renewable energy has a negative effect in developing countries, while its response in developed economies is positive

There is a significant negative relationship between FDI and renewable energy in the long term. This implies that as more FDI flows into a economy, the renewable energy market is negatively affected. One possible explanation is that FDI is often directed towards industries that are relatively intensive in their use of non-renewable energy sources, such as manufacturing and service sectors. As renewable energy may not be cost-effective, as a result, FDI inflows may lead to increased use of fossil fuels, which in turn hinders the transition to renewable energy sources. This is particularly relevant for developing countries that are predominantly fossil fuel intensive, such as Indonesia. Murshed *et al.*, (2021) and Tasnim (2020) report similar findings.

Further scrutiny reveals that inflation has a significant devasting effect on the renewable energy sector in Indonesia (Table 4). Firstly, inflation can lead to increased energy prices, making renewable sources less competitive than non-renewable sources. This can hinder the adoption and expansion of renewable energy. Secondly, inflation can impact the government's ability to invest in renewable energy infrastructure. As inflation increases, the government may need to allocate more resources to addressing immediate economic challenges, such as stabilising prices and maintaining economic stability. This can lead to reduced investment in renewable energy projects and a slower transition to cleaner energy sources. This is contrary to the study of Nugroho Guntur *et al.* (2023), who found that inflation has a positive impact on the renewable energy sector in Indonesia.

Similarly, exchange rates and real interest rates are found to have significant negative impacts on renewable energy consumption. An appreciation in exchange rates can lead to higher energy prices, making renewable energy sources less competitive, and can increase the cost of investment financing, which can discourage investments in renewable energy projects. Real interest rates can also have a negative impact on renewable energy consumption, as higher rates can increase the cost of borrowing for renewable energy projects, making them less attractive to investors. As with an appreciation in exchange rates, higher real interest rates can lead to decreased investment and a slower transition overall (see Samour and Pata 2022; Shah *et al.* 2022). In the long-term estimate, urbanisation is found to have a significant negative influence on the consumption of renewable energy. This relationship is complex and multifaceted. Firstly, higher population density in urban Indonesia is expected to increase energy consumption (of both or either renewables and non-renewables); however, increased uptake of renewable energy is motivated by incentives or policies aim at enhancing its market share. Similarly, urban areas tend to have better access to renewable technologies, yet the cost of technology is a major challenge, which may reduce the share of renewables as urban populations expand.

In the short term, the response of renewable energy to GDP is significantly negative. This contradicts the long-term coefficient. This is likely because in the short term, renewable energy consumption may be affected by factors such as economic conditions, energy prices, and government policies. For example, during periods of economic growth, there may be increased demand for energy, which could lead to higher energy prices and a consumer preference for non-renewable energy sources due to their lower cost and higher availability. Additionally, in the short term, government policies may prioritise economic growth over environmental concerns, leading to reduced investment in renewable energy infrastructure. Surprisingly, all the time lag effect of economic growth are negative on renewable energy consumption in the short term.

Meanwhile, the bound test determines whether there is cointegration among the variables. The null hypothesis of the test states that there is no level relationship among the variables, while the decision rule of rejection depends on whether the f-bound statistics is greater than the critical values. However, the F-statistics (Table 5) are found to be greater than the critical value at all conventional level, leading to the rejection of the null hypothesis and conclusion that there is long term level relationship among renewable energy consumption, economic growth, inflation, interest rates, exchange rates, and annual urban growth. The error correction term that measures the speed of adjustment to the long-term equilibrium is negative and statistically significant as expected, but greater than one. This implies the variables are explosive and there will be over correction when there are short term shocks to the economy.

The robustness of the model reported in the tables indicates that the model at 5% level is free from serial correlation, as shown by the Breusch-Pagan-Godfrey (BPG) test results. However, at all conventional levels of significant, BPG test results fail to reject the null hypothesis of homoscedasticity. This means that the residual of the model has a constant variation. The stability of the coefficients of the model is tested using the CUSUM test and CUSUM square, and the outcome is reported in the appendices section. We inferred from the figures that the model coefficients are stable over time

4.4 Asymmetric Relationship between Renewable Energy and the Indonesian Economy

One of the main objectives of this study is to examine the asymmetric response of renewable energy to the Indonesian economy. While in the methodology section, we specify equations 8 and 9, for which the results are reported in table 5. It could be recalled that the non-linear autoregressive distributed lag model allows for the dissection of the explanatory variables into positive partial sum and negative partial sum.

In the long term, the positive economic shocks have an insignificant negative effect on renewable energy consumption. Economic theory often posits that as economies grow, there is typically an increased demand for energy, including renewable sources, as countries seek to meet their growing energy needs (sustainably or otherwise). However, this finding indicates that despite positive economic growth shocks, there is no significant increase in renewable energy consumption. This anomaly can be attributed to several factors, including the persistently high costs associated with renewable technologies. Additionally, the availability of cheaper alternatives, such as coal, for energy production in Indonesia, further reduces the incentive for widespread adoption of renewable energy. Negative economic shocks also have negative impacts on renewable energy, and is statistically significant at a 10% level. This suggests that economic downturns can lead to reduced investment in renewable energy infrastructure and a consumer preference for non-renewable energy sources due to their lower cost and higher availability.

Interestingly, the response of renewable energy use to FDI, inflation (using CPI as proxy), urban growth rate, exchange rates, and real interest rates are negative in the long term, as they are in the symmetric model. However, only inflation is proven to be statistically significant, at the 1% level.

In the short term, the asymmetric effect of inflation on renewable energy is significantly positive, indicating that inflationary shocks can lead to increased renewable energy consumption. However, interest rates and exchanges rates have devastating negative impacts on renewable energy consumption, suggesting that these factors can hinder the transition to cleaner energy sources. Given these findings, the speed of the adjustment to the long term equilibrium in the event of any economic shocks is corrected at a rate of 23.3% annually. This implies that the economy slowly adjusts to the long-term equilibrium after experiencing short-term shocks, with renewable energy consumption responding to changes in macroeconomic factors over a relatively long period.

At the bottom of Table 5, we report the bound F-statistics that examine cointegration among the variables. The F-statistics value of 5.304 is proven to be greater than critical values at all the conventional levels. This implies that there is a long-run relationship between renewable energy consumption, asymmetric GDP, and accompanying explanatory variables. The NARDL model estimated is found to be free from serial correlation and heteroskedasticity as shown by the BP and BPG statistics reported in the table. To check whether the model coefficients are stable overtime, we report the outcome of the CUSUM and CUSUM square test in the appendices. It was observed that the model is stable over time.

Table 5. Asymmetric Model Estimates

Variables	Coefficients	Standard error
Long Term Estimates		
GDP+	-0.009	0.039
GDP-	-27.629***	15.557
FDI	-0.037	0.031
CPI	-0.008*	0.002
URBGR	-0.153	0.112
EXC	-0.003	0.0032
Real interest rate	-0.025	0.002
Short run estimates		
Exchange rate	-0.001*	0.00
CPI	0.005*	0.002
Real interest rate	-0.003*	0.000
Error correction term	-0.233*	0.031
Bound test (F-statistics)	5.304*	
BP serial correlation	0.049	
BPG heteroscedasticity	0.920	
Cusum test	Stable	
Cusum of square test	Stable	
Selected model based on AIC	ARDL(1,1,1,1,0,0,0)	

*,**,*** signifies the rejection of the null hypothesis at 1%, 5% & 10% respectively. Source: Authors computation.

4.5 Asymmetric Test

The ways in which renewable energy consumption responds to positive and negative economic shocks may differ in the long term. This necessitates testing for symmetric relationship in the post estimation of the NARDL model. Table 6 displays the results of the symmetric test. At 1% level, we reject the null hypothesis of the GDP coefficient's symmetric effect on renewable energy consumption. This suggests that the relationship between economic growth and renewable energy consumption is not symmetrical. This means that the effect of a positive economic shock on renewable energy consumption is different from the effect of a negative economic shock on renewable energy consumption.

Table 6. Asymmetric Tests Results

Variable	Test statistics	Inference
GDP	23.894*	Long run asymmetric

*,**,*** signifies the rejection of the null hypothesis at 1%, 5% & 10% respectively. Source: Authors computation.

5. Conclusions and Policy Recommendations

This study explores the relationship between the Indonesian economy and the renewable energy market, shedding light on both symmetric and asymmetric responses to economic factors such as inflation, exchange rates, and real interest rates. Firstly, we find that economic growth, as measured by GDP, exhibits an asymmetric positive impact on renewable energy consumption in the long term. This suggests that while economic expansion fosters the adoption of sustainable energy sources, the response to positive and negative economic shocks differs, emphasising the need for slight policy responses for instance developing and promoting financial mechanisms such as renewable energy investment funds, insurance products for renewable energy projects, and low-interest loans to support the sector through economic cycles.

Secondly, urbanisation emerges as a pivotal driver of renewable energy consumption, with expanding cities boosting demand for cleaner energy sources. This underscores the significance of integrating sustainability principles into urban development policies to meet the escalating energy needs of urban populations. As a sign of commitment to sustainability, governments could install renewable energy systems in public buildings, schools, hospitals, and other facilities, and also provide incentives for household use and adoption. This not only reduces the carbon footprint but also serves as a demonstration of commitment to sustainability.

However, the vulnerability of the renewable energy sector to currency fluctuation is evident, with depreciations in local currency disproportionately impacting renewable energy investment during economic downturns. To mitigate this risk, effective currency risk management strategies and policy interventions are essential.

Finally, the role of FDI in driving renewable energy growth is paramount, particularly during favourable economic conditions. However, the diminishing impact of FDI during economic downturns underscores the necessity for tailored interventions to sustain renewable energy growth. Inflation also poses challenges, with its negative asymmetric response hindering renewable energy development by eroding purchasing power. Addressing these challenges and leveraging the opportunities highlighted in our study through targeted policy interventions can help Indonesia achieve its renewable energy targets and transition towards a sustainable and resilient energy future.

As no research is flawless, this study is bedevilled with the limitation of data; the higher the historical data, the better the performance of the estimated coefficients. Future research on the study of the renewable energy market and the Indonesian economy could delve into household socio-economic characteristics, including through extension to a panel of Asian countries or developing economies.

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