



Macroeconomic Drivers and the Forecast of Renewable Energy Consumption in Indonesia Toward Achieving SDG 7

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ABSTRACT

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This study aims to analyze the macroeconomic factors that influence renewable energy consumption (REC) in Indonesia using the Autoregressive Distributed Lag model, and to forecast its future trajectory through 2030 under a business-as-usual scenario, with reference to the targets of SDG 7. Using annual data from 2000 to 2023, the study identifies four macroeconomic determinants: population, economic growth, non-renewable energy consumption (NREC), and technological innovation. In the short-run, REC is significantly influenced by its own past values, population, economic growth, and technological innovation, while NREC demonstrates a delayed but positive effect. In the long-run, population has a negative impact on REC, reflecting Indonesia's continued dependence on fossil energy sources. In contrast, economic growth, NREC, and technological innovation contribute positively and significantly, suggesting a gradual but constrained transition toward clean energy. The forecasting results indicate that REC in Indonesia may reach approximately 17.4% by 2030, still falling short of the 23% national target set for 2025, leaving a persistent gap of about 5.6 percentage points. These findings underscore the urgent need for stronger policy reform and increased investment in green technology and infrastructure, particularly to close the 5.6% REC gap.

1. INTRODUCTION

In recent decades, sustainable energy, particularly renewable energy consumption (REC), has become a central focus in global development discourse [1, 2]. This shift is driven by the urgent need to reduce reliance on environmentally harmful and increasingly scarce fossil fuels, while also addressing the challenges of the climate crisis, unequal access to energy, and geopolitical uncertainty in global energy markets [3-5]. REC offers a strategic solution that is not only environmentally friendly but also sustainable in the long-run [6-8]. Global commitment to this transition has been further reinforced through various international agreements, including the Paris Agreement and the United

Nations 2030 Agenda, which position clean energy as one of the core pillars of the Sustainable Development Goals (SDGs). Within this framework, SDG 7 explicitly targets universal access to affordable, reliable, sustainable, and modern energy by 2030 [9].

Indonesia, as a developing country with vast sustainable energy potential, holds a crucial role in Southeast Asia's energy transition landscape [10-12]. However, the reality reveals that Indonesia's progress remains far from expectations. As of 2023, the national energy mix is still dominated by fossil fuels, with REC contributing only around 13.08% [13]. This condition falls short of the target set in the National Energy Policy, which aims for a 23% REC share by 2025. On one hand, Indonesia possesses the world's second-

largest geothermal reserves, abundant solar energy potential, and widely distributed biomass resources [14, 15]. On the other hand, the utilization of these resources continues to face various structural challenges, including dependence on fossil fuel subsidies, underdeveloped clean energy distribution infrastructure, and a lack of regulatory alignment across government agencies [16, 17].

Amid these dynamics, a comprehensive understanding of the factors that drive or hinder REC is becoming increasingly important. Empirical studies in the international literature have consistently linked REC to various macroeconomic determinants. Key variables frequently analyzed include population (POP), economic growth (EG), non-renewable energy consumption (NREC), and technological innovation (TI). These factors are considered to have a significant influence on the demand for and adoption of REC across both developing and developed countries. POP is one of the primary determinants in the dynamics of global energy demand [18, 19]. An increase in POP directly raises energy needs for transportation, housing, industry, and public services [20]. In this context, especially developing countries ones, face the challenge of ensuring adequate energy availability without compromising environmental sustainability [21].

On the other hand, EG has a dual impact on energy consumption. In the early stages of development, increased EG generally drives intensive fossil fuel consumption, as the industrial and transportation sectors remain heavily reliant on conventional fuels [22-24]. However, as per capita income rises and awareness of climate change issues grows, countries tend to shift their energy consumption patterns from fossil-based sources to more environmentally friendly alternatives [25, 26].

Meanwhile, NREC often serves as a major barrier to the acceleration of REC [4, 27]. This challenge is further exacerbated by fossil fuel subsidies in many developing countries, which indirectly reduce the competitiveness of REC [28, 29]. However, global dynamics are beginning to shift due to growing international pressure to reduce carbon emissions, particularly through climate agreements such as SDG 7 [30, 31]. Equally important is the role of TI in the energy transition process. Advances in research and development have led to a significant reduction in the production costs of REC [32-34]. Moreover, improvements in energy storage efficiency have expanded access to and reliability of REC, even in remote areas [35, 36].

Nevertheless, when compared with other Southeast Asian countries, Indonesia's renewable energy transition remains underexplored in the literature. Vo and Vo [20] highlighted that population growth in Southeast Asian countries, including Vietnam and the Philippines, tends to slow renewable energy adoption due to infrastructure constraints. Similarly, Minh et al. [21] and Rahman et al. [26] noted that countries with structural characteristics comparable to Indonesia still face significant challenges in aligning their energy transitions with the SDG 7 agenda. In contrast, studies on Malaysia and Thailand suggest that policy instruments such as green subsidies and private investment incentives have begun to accelerate their renewable energy pathways. However, existing research on Indonesia has not sufficiently addressed whether similar dynamics apply, nor has it projected the country's future REC trajectory within the SDG 7 framework. This gap underscores the need for a country-specific study that combines macroeconomic determinants with forecasting analysis to provide more tailored policy insights.

This research aims to fill that gap by combining short- and long-run analysis using the Autoregressive Distributed Lag (ARDL) approach and extending it with projection simulations through 2030. Utilizing annual time-series data, this study examines how POP, EG, NREC, and TI influence the pattern of REC in Indonesia. The resulting ARDL model is then used to estimate the future trajectory of REC, particularly to assess whether the current trend is sufficient to meet the SDG 7 target or if a significant gap remains.

The main contribution of this study lies in its methodological approach, which integrates dynamic quantitative analysis with forward-looking, policy-oriented insights. Beyond providing empirical evidence on the determinants of REC, the findings offer a data-driven roadmap toward 2030. This roadmap can serve as a foundation for formulating more effective and responsive national energy policies. As such, the study is expected to deliver added value both academically and practically, particularly for policymakers, academics, and stakeholders in the energy sector who are committed to a sustainable energy transition in Indonesia.

2. LITERATURE REVIEW

Numerous previous studies have shown that REC is influenced by several macro-level factors such as POP, EG, NREC, and TI. Based on the view that energy demand increases with POP, the influence of POP on REC suggests that a larger POP can drive an increase in REC, provided it is supported by adequate policies and infrastructure. However, if the dependence on fossil fuels remains high, POP may actually hinder the transition to clean energy. Some studies have found that POP significantly impacts REC, both directly through increased energy demand and indirectly through changes in economic structure and energy policy. Shah et al. [37] stated that POP drives overall energy demand, but the transition to REC is highly dependent on economic conditions. A study by Cao [38] also found that in developed countries, POP accompanied by pro-environmental policies promotes REC adoption, whereas in developing countries, POP increases often lead to greater NREC due to limitations in green energy infrastructure. Another study by Adebayo and Akinsola [39] showed that urbanization—as a consequence of POP raises energy demand in the short-run, but in the long-run can improve energy efficiency and accelerate the clean energy transition.

EG also plays a crucial role in promoting REC. Developed countries tend to transition more rapidly due to greater fiscal capacity, while countries still reliant on heavy industry are more likely to continue depending on fossil fuels. Institutional and political factors in each country also shape this relationship. Banday and Aneja [40] found that EG has a positive impact on REC, particularly in developing countries, as rising per capita income encourages investment in clean energy technologies. Similar results were reported by Ugwu et al. [41], who noted that EG supports green energy growth, although the impact varies depending on energy policy and development level. Additionally, Chen et al. [16] identified a causal relationship between REC and EG in developed countries, indicating that increased use of REC is not only influenced by EG but can also contribute to long-term economic expansion. Nevertheless, structural factors such as fossil fuel subsidies, infrastructure availability, and regulatory

stability also determine the extent to which EG can drive REC growth [42].

Meanwhile, NREC is generally considered a major obstacle to the energy transition. The dominance of fossil fuels tends to reduce incentives for developing clean energy. However, in a mixed energy system, REC and NREC can coexist and even complement each other. The relationship between NREC and REC is a central topic in global energy transition research. Aboueata et al. [43] showed that high fossil fuel prices can encourage a shift toward REC, especially in countries with policies that support investment in sustainable energy. Conversely, research by Adhikari et al. [44] found that in developing nations, reliance on NREC hinders REC adoption due to fossil fuel subsidies and limited green energy infrastructure. Anwar and Elfaki [45] emphasized that the dynamics between NREC and REC are highly influenced by government policies and a country’s level of economic development.

In addition, TI plays a significant role in driving the development and adoption of REC. Robust innovation can improve energy infrastructure, reduce production costs, and enhance the efficiency and accessibility of clean energy. Advances in energy storage technologies and the development of smart grid technologies have increased the reliability of REC while reducing dependence on conventional energy sources [46]. Furthermore, improvements in solar panel efficiency and next-generation wind turbines have accelerated REC adoption in both industrial and residential sectors [47]. Other supporting factors include innovation policies such as research and development incentives and clean energy subsidies, which directly encourage investment in REC technologies [48].

Methodologically, several studies have employed the ARDL approach to analyze the dynamic relationship between macroeconomic variables and REC. For example, Udeagha and Ngepah [49] applied ARDL and found that the relationship between REC and macroeconomic variables is asymmetric in the long run. Similarly, Ali et al. [50] combined ARDL with dynamic simulations to evaluate the effects of EG and foreign direct investment on carbon emissions and REC in China. However, studies that utilize this approach to project REC within the context of SDG 7 particularly in developing countries like Indonesia.

While existing studies have provided valuable insights into the determinants of REC, several limitations remain. First, many empirical works applying ARDL or related approaches have predominantly focused on developed economies, where structural conditions, fiscal capacity, and regulatory

frameworks differ substantially from those in developing countries. Consequently, the applicability of their findings to the Indonesian context remains limited. Second, studies in developing countries often rely on static or cross-country panel approaches, which fail to capture country-specific dynamics and the short- versus long-run adjustments that are crucial in the energy transition process. Third, although some ARDL-based studies have examined the relationship between REC and macroeconomic factors, very few have extended their analysis toward explicit forecasting of REC in relation to SDG 7.

This study explicitly addresses these gaps in three ways. First, by applying the ARDL model to Indonesia, it captures both short-run and long-run dynamics that are often overlooked in panel-based research. Second, by incorporating key macroeconomic drivers—POP, EG, NREC, and TI—the study provides a more comprehensive framework that reflects Indonesia’s unique structural challenges. Finally, by extending the ARDL estimation into a forecasting exercise through 2030, the research not only explains past dynamics but also provides forward-looking evidence on whether Indonesia is on track to achieve its SDG 7 target. In addition, the study bridges theoretical and empirical gaps by integrating econometric rigor with policy-oriented analysis. It enriches the discourse on energy transition by situating Indonesia within broader debates on sustainable development. The approach also demonstrates how single-country time-series analysis can complement cross-country comparisons. Ultimately, this research contributes to advancing both methodological innovation and practical relevance in renewable energy studies.

3. METHODOLOGY

3.1 Data and variables

This study uses secondary time-series data from 2000 to 2023, with a focus on Indonesia. The variables are grouped into two categories: REC as the dependent variable, and POP, EG, NREC, and TI as the independent variables (see Table 1).

For the REC and NREC variables, the original data were obtained from the Statistical Review of World Energy, which reports REC and NREC in terajoules (TJ) per year. Since the dataset does not directly provide the annual percentage change, the authors calculated the annual growth rates by taking the year-to-year percentage differences in consumption. Accordingly, the operational definitions of REC and NREC in this study are derived from the raw energy consumption data.

Table 1. Operational definition of variables

Variable	Definition
REC	Annual percentage change in REC compared to the previous year
POP	Total POP over one year
EG	Annual growth rate of gross domestic product (GDP)
NREC	Annual percentage change in NREC compared to the previous year
TI	Patent applications per capita over one year

3.2 Analytical model

The analytical model in this study aims to assess the short-run and long-run effects of the selected macroeconomic variables on REC in Indonesia, as expressed in Eq. (1). As a dynamic econometric tool, the ARDL model is particularly well-suited for analyzing how variables interact over time,

including the effect of past (lagged) values of both dependent and independent variables on current outcomes. This allows for the identification of immediate (short-run) and persistent (long-run) relationships within the model.

$$\Delta REC_t = \alpha_0 + \sum_{i=1}^n \alpha_{1i} \Delta REC_{t-i} + \sum_{i=1}^n \alpha_{2i} \Delta POP_{t-i} \quad (1)$$

$$\begin{aligned}
& + \sum_{i=1}^n \alpha_{3i} \Delta EG_{t-1} + \sum_{i=1}^n \alpha_{4i} \Delta NREC_{t-1} \\
& \quad + \sum_{i=1}^n \alpha_{5i} \Delta TI_{t-1} + \theta_1 REC_{t-1} \\
& \quad + \theta_2 POP_{t-1} + \theta_3 EG_{t-1} + \theta_4 NREC_{t-1} \\
& \quad + \theta_5 TI_{t-1} + \varepsilon_t
\end{aligned}$$

where,

Δ : Lag (differencing)

α_0 : Constant

$\alpha_{1i} - \alpha_{5i}$: Coefficients for the short-run dynamic model

$\theta_1 - \theta_5$: Coefficients for the long-run dynamic model

ε : Residual

Furthermore, the ARDL model in the form of an error correction model (ECM) derived from the previous equation is presented in Eq. (2).

$$\begin{aligned}
\Delta REC_t = & \alpha_0 + \sum_{i=1}^n \alpha_{1i} \Delta REC_{t-1} + \sum_{i=1}^n \alpha_{2i} \Delta POP_{t-1} \\
& + \sum_{i=1}^n \alpha_{3i} \Delta EG_{t-1} + \sum_{i=1}^n \alpha_{4i} \Delta NREC_{t-1} \\
& + \sum_{i=1}^n \alpha_{5i} \Delta TI_{t-1} + \vartheta ECT_{t-1} + \varepsilon_t
\end{aligned} \quad (2)$$

where,

ϑECT_{t-1} : Error correction model (ECM) term lagged from the previous period

The ARDL specification in Eq. (1) was developed by determining the optimal lag length for each variable through the Akaike Information Criterion (AIC). This procedure ensures that the model captures the dynamic interactions among variables without the risk of overfitting. Then, Eq. (2) introduces the ECM, derived from the ARDL representation, which incorporates the ECT_{t-1} . The ECT captures the deviation of REC from its long-run equilibrium path. A negative and statistically significant coefficient on the ECT confirms both the existence of cointegration among variables and the system's ability to adjust back to equilibrium following short-run shocks.

In addition, this study also incorporates a forecasting analysis to project the future trajectory of REC in Indonesia up to the year 2030. Using the estimated long-run coefficients of the ARDL model, the forecast provides an empirical outlook on whether Indonesia is on track to meet its SDG 7. The forecasting model is constructed using the estimated ARDL equation, allowing for both baseline and policy scenario simulations. By integrating both econometric estimation and forward-looking forecasting, the analytical model of this study contributes not only to academic understanding of the determinants of REC, but also provides policy-relevant insights into Indonesia's pathway toward a sustainable energy future.

3.3 Data analysis techniques

Data analysis in this study begins with the ARDL approach by conducting stationarity tests on all variables using the Augmented Dickey-Fuller (ADF) or Phillips-Perron (PP) methods, in order to avoid spurious estimation results caused by non-stationary data. Once the appropriate order of integration for each variable is confirmed, the optimal lag length is determined based on the AIC to prevent overfitting. The ARDL model is then constructed using the selected optimal lags, followed by a bounds testing procedure to identify the existence of long-run relationships among the

variables. If a long-run relationship is found, the estimation proceeds to include both short-run and long-run modeling, along with the incorporation of an ECM to measure the speed of adjustment toward long-run equilibrium. The stability of the resulting model is then tested using the Cumulative Sum of Recursive Residuals (CUSUM) test to ensure the robustness of its forecasting performance over time.

The forecasting stage is carried out in two main steps. First, a scenario for the predictor variables (independent variables) is developed using the Business-as-Usual (BAU) approach, which assumes that historical trends will continue without the introduction of new policies, major innovations, or significant behavioral changes. The Average Annual Growth Rate (AAGR) for each exogenous variable (POP, EG, NREC, and TI) is calculated based on historical data from 2000 to 2023, as shown in Eq. (3).

$$AAGR = \left(\frac{X_t - X_0}{X_0 \times n} \right) \quad (3)$$

where,

X_t : Value in the final year of the period

X_0 : Value in the initial year of the period

n : Number of observation years

The resulting AAGR is then applied iteratively to project the values of POP, EG, NREC, and TI for the period 2024-2030. The reliability of this projection is supported by the use of consistent historical data sourced from international institutions such as the World Bank, United Nations, and the Statistical Review of World Energy. However, the AAGR approach also has limitations, as it assumes that past growth patterns will continue linearly without external shocks, policy changes, or disruptive innovations. The second step involves calculating the projected values of REC as the dependent variable using the previously estimated ARDL model. This is done by substituting the projected values of POP, EG, NREC, and TI into the long-run equation. The projections begin in 2024 and are iterated annually through 2030, allowing the model to forecast the dynamics of future REC and assess Indonesia's trajectory toward achieving SDG 7.

4. RESULTS AND DISCUSSION

4.1 ARDL analysis

4.1.1 Data stationarity

The stationarity test results, using both the ADF and PP methods, are summarized in Table 2. Each variable is examined at both the level form ($I(0)$) and the first difference ($I(1)$) to determine the presence of a unit root. A variable is considered stationary if its significance value is equal to or less than the 0.05 threshold, which indicates that the null hypothesis of a unit root is rejected. This procedure ensures that the data used in subsequent analysis are properly classified according to their order of integration, thereby minimizing the risk of spurious regression and enhancing the validity of econometric modeling.

As shown in Table 2, the REC, EG, and NREC are stationary at $I(0)$, with significance values below 0.05 in both the ADF and PP tests. The POP is non-stationary at $I(0)$ under the ADF test but becomes stationary at $I(1)$, while the PP test suggests it is already stationary at $I(0)$. The TI is non-stationary at $I(0)$ but achieves stationarity at $I(1)$ in both tests.

Table 2. Data stationarity test results

Variable	ADF				PP			
	I(0)		I(1)		I(0)		I(1)	
	t-Statistics	Prob.	t-Statistics	Prob.	t-Statistics	Prob.	t-Statistics	Prob.
REC	-6.602093	0.0000***	-	-	-6.390471	0.0000***	-	-
POP	-3.001423	0.0511*	-4.624973	0.0015***	-7.545656	0.0000***	-	-
EG	-3.633329	0.0130**	-	-	-3.640071	0.0128**	-	-
NREC	-5.643289	0.0001***	-	-	-6.235756	0.0000***	-	-
TI	-0.526261	0.8680	-9.423517	0.0000***	-0.916752	0.7642	-9.327008	0.0000***

where, *** and ** indicate significance at 0.001 and 0.05, respectively

4.1.2 Optimal lag selection

Figure 1 summarizes the results of the optimal lag selection test used in this study based on the AIC approach. According to Figure 1, the optimal lag chosen is the ARDL (3, 0, 3, 0, 2) model. This model indicates the maximum lag length for each variable as follows: REC (3), POP (0), EG (3), NREC (0), and TI (2).

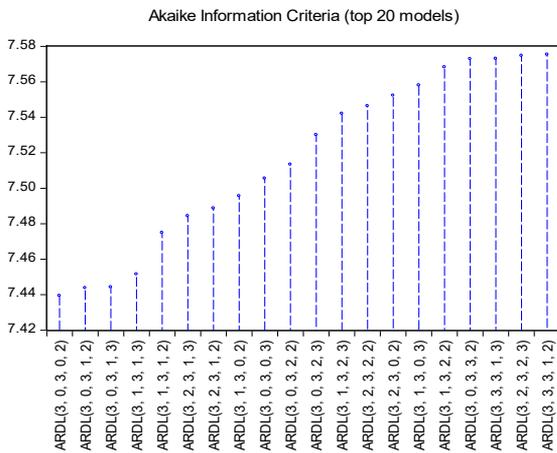


Figure 1. Optimal lag test results

Table 3. ARDL model results (3, 0, 3, 0, 2)

Variable	Coefficient	Std. Error	T-Statistic	Prob.*
REC(-1)	-1.929394	0.323425	-5.965503	0.0003***
REC(-2)	-2.127076	0.404054	-5.264337	0.0008***
REC(-3)	-1.106946	0.411597	-2.689395	0.0275**
POP	-7.110039	1.709620	-4.158842	0.0032***
EG	0.252785	2.943662	0.085874	0.9337
EG(-1)	4.940158	3.175800	1.555563	0.1584
EG(-2)	7.671198	3.044898	2.519362	0.0358**
EG(-3)	7.440285	1.643364	4.527473	0.0019***
NREC	1.899334	0.924369	2.054736	0.0740*
TI	-10.13353	16.65149	-0.608566	0.5597
TI(-1)	4.040620	9.912744	2.112473	0.0431**
TI(-2)	5.611973	4.262772	4.444170	0.0001***
C	12.84471	8.158637	5.950380	0.0000***

where, * indicates significance at the 0.10

Table 3 shows that REC is significantly influenced by its own past values (REC(-1), REC(-2), and REC(-3)), with the negative coefficients indicating a short-run declining trend. POP has a negative and significant effect on REC, suggesting that higher POP levels tend to reduce REC. EG, in its second and third lags (EG(-2) and EG(-3)), has a positive and significant impact, implying that its influence on REC emerges over time. Conversely, NREC shows a positive but statistically insignificant effect, indicating that increased use of NREC does not directly promote REC. Over the past two decades,

TI(-1) and TI(-2) have had a positive and significant impact on REC.

4.1.3 Bound test

Table 4 presents the bounds test results, showing an F-statistic of 4.28—above the 5% critical value for I(1) (4.01). This confirms the presence of cointegration, indicating a valid long-run relationship among the variables within the ARDL model. In other words, the selected macroeconomic variables move together in the long run, reinforcing the robustness of the estimated coefficients. Thus, all prior analyses satisfy the requirements for applying the ARDL approach and provide a solid foundation for interpreting both the short-run dynamics and long-run equilibrium relationships in subsequent sections. Moreover, the confirmation of cointegration ensures that the ARDL framework is appropriate for capturing both dynamic adjustments and equilibrium tendencies. This methodological strength increases confidence in the model’s predictive capacity and policy relevance.

Table 4. Bound test results

K	F-Statistics	Significance							
		10%		5%		2.5%		1%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
4	4.28	2.45	3.52	2.86	4.01	3.25	4.49	3.74	5.06

where, is the number of independent variables

4.1.4 Short-run analysis

The short-run test results presented in Table 5 show that REC in the short-run is influenced by various factors, including previous REC, POP, EG, NREC, and TI.

Table 5. Short-run test results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(REC(-1))	3.234022	0.774724	4.174419	0.0031***
D(REC(-2))	1.106946	0.411597	2.689395	0.0275**
D(POP)	-7.110039	1.709619	-4.158844	0.0032***
D(EG)	0.252785	2.943662	0.085874	0.9337
D(EG(-1))	-7.671198	3.044898	-2.519362	0.0358**
D(EG(-2))	-7.440285	1.643364	-4.527473	0.0019***
D(NREC)	1.899334	0.924369	2.054736	0.0740*
D(TI)	-1.013352	1.665149	-0.608565	0.5597
D(TI(-1))	-8.561196	3.426276	-2.498688	0.0370**
CointEq(-1)	-6.163416	1.074163	-5.737879	0.0004***

REC exhibits strong persistence, where an increase in consumption in the previous period (D(REC(-1))) tends to continue into the next period. Even consumption from two periods prior (D(REC(-2))) still has a positive impact, albeit with a smaller effect. This indicates inertia in REC patterns, where past energy decisions continue to influence current consumption.

Conversely, POP has a significantly negative effect on REC. As POP, demand often shifts toward NREC due to its accessibility and existing infrastructure. Meanwhile, the shift to REC may lag behind because of investment and infrastructure constraints.

Meanwhile, short-run EG does not show a significant effect on REC. However, in the previous period ($D(EG(-1))$ and $D(REC(-1))$), it had a significantly negative impact. This suggests that key economic drivers such as industry, manufacturing, and transportation remain highly dependent on fossil fuels rather than REC.

Interestingly, NREC appears to promote REC in the short-run. This suggests that increased fossil fuel use may trigger greater investment in REC. The gradual implementation of energy transition policies may contribute to this relationship.

In the short-run, TI does not immediately increase REC. In fact, $D(TI(-1))$ shows a negative effect, suggesting a delayed impact. This may be due to the time required for TI adoption to influence energy use, as early innovations often prioritize improving NREC efficiency before supporting the shift to REC.

Despite various factors influencing short-run REC, there is a strong correction mechanism within the system toward long-run equilibrium. Any imbalance in REC is adjusted at a rate of approximately 61.63% within one period.

4.1.5 Long-run analysis

Table 6. Long-run test results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
POP	-0.153587	0.051399	-2.988132	0.0028***
EG	0.294346	0.093361	3.152773	0.0021***
NREC	0.308163	0.128835	2.391919	0.0186**
TI	1.383664	0.269412	5.135866	0.0000***
C	2.083729	0.510557	4.081286	0.0000***

The long-run estimates in Table 6 show that REC is significantly affected by POP, EG, NREC, and TI. POP has a negative and significant relationship with REC. Increasing POP naturally drives higher energy demand to support economic activities. However, in the context of Indonesia, rising POP levels contribute to a decline in REC. This is due to the country's continued heavy reliance on NREC sources, which are relatively cheaper and have more extensive distribution infrastructure. This can be explained by the fact that the increase in POP is still accompanied by a strong dependence on fossil energy, which is cheaper and supported by an established distribution infrastructure. In practical terms, this means that without aggressive energy substitution policies, the rise in POP will further increase the demand burden on fossil-based energy, thereby slowing down the penetration of clean energy. In other words, the energy transition in Indonesia is not only a matter of the availability of renewable energy sources, but also closely related to consumption patterns that remain locked into fossil energy. From a practical perspective, local governments also play a critical role in this transition. They are responsible for facilitating the adoption of renewable energy at the community level through regional energy planning, supporting local REC-based initiatives such as micro-hydro or solar village programs, and ensuring alignment between national targets and regional implementation. Strengthening local regulatory frameworks, capacity building, and budget allocations at the provincial and district levels are therefore essential to accelerate REC penetration and reduce structural dependence on fossil energy in Indonesia. These

findings align with the research of Sharma et al. [51], which suggests that an energy system still dominated by fossil fuels creates structural barriers to transitioning toward clean energy. Additionally, Sinsel et al. [52] found that limited investment, suboptimal policy incentives, and challenges in developing REC technology and infrastructure further slow the transition process.

On the other hand, EG not only drives production and consumption but also supports REC by enabling greater investment in green innovation, clean energy infrastructure, and policy incentives in Indonesia. This positive effect can be explained by the fact that sustained EG increases fiscal capacity and expands both public and private sector resources to finance clean energy projects. In practical terms, higher national income creates room for greater allocation to research and development in REC technologies, as well as the expansion of transmission and distribution networks that are often underdeveloped. At the same time, EG enhances the government's ability to implement and maintain policy instruments such as subsidies, feed-in tariffs, or tax incentives that directly stimulate REC adoption. Furthermore, at the local government level, stronger fiscal capacity allows provinces and districts to design and implement region-specific initiatives, such as community-based REC programs, localized incentives for small and medium enterprises to adopt clean energy, and partnerships with local universities to advance applied research on green technologies. These measures are crucial for addressing the spatial disparities in energy infrastructure across Indonesia's archipelagic regions. In other words, the role of EG goes beyond fueling economic activities—it also functions as a structural enabler that creates financial and institutional capacity—both nationally and locally—for accelerating the energy transition. These findings are consistent with Murshed et al. [53], who found that rapid EG can enhance a country's financial capacity and investment potential, including in the energy sector. Moreover, Bekun et al. [54] also discovered that countries with strong economies can implement market mechanisms.

NREC not only contributes to the current energy supply but also serves as a bridge to promoting REC. This relationship can be explained through two main mechanisms. First, the overall increase in energy consumption reflects EG and the rising demand for energy, which in turn encourages energy source diversification to ensure long-run energy security. In the Indonesian context, this implies that as industrialization and urbanization expand, reliance solely on fossil fuels creates vulnerability to price volatility and supply risks, thereby making REC a strategic complement. Second, revenue generated from the NREC sector is often used to finance investments in REC technology development. For instance, fiscal resources and cross-subsidies derived from fossil energy have been allocated to support renewable energy programs, ranging from geothermal exploration to solar panel installation. This indicates that, although NREC remains the dominant source in the short- and medium-term, it indirectly supports the energy transition by providing the financial and structural foundation for REC expansion. In addition, local governments in Indonesia play a crucial role in operationalizing this strategy, particularly by channeling regional energy revenues and budget allocations into decentralized REC initiatives. For example, provincial and district governments can strengthen incentives for community-based solar, micro-hydro, and biomass projects, while also ensuring regulatory support and streamlined licensing. By actively engaging local

governments, the national agenda for energy transition can be grounded in regional realities, creating a more inclusive and regionally adaptive pathway toward SDG 7. These findings align with Brini [55], who noted that in many cases, NREC remains the primary energy source, while RE is gradually developed to replace it, allowing both to operate in parallel for a certain period. Additionally, Al-Silefanee [56] highlighted that NREC is essential in facilitating the shift toward REC during the energy transition.

Furthermore, TI is key to advancing REC, starting with efficiency improvements that enable greater REC output at lower costs. Additionally, reducing costs and technical barriers to REC is a key factor driving broader adoption. In practical terms, TI has reduced production costs and improved the reliability of REC. For instance, the development of smart grids enables more efficient integration of REC into the national electricity system, while advancements in energy storage technologies expand REC access in remote areas that were previously highly dependent on diesel. These findings highlight that investment in research, innovation, and technology transfer serves as a key catalyst for accelerating the energy transition in Indonesia. Furthermore, policy incentives to support domestic innovation as well as international collaboration in clean energy technologies are crucial factors in optimizing the contribution of TI to REC growth. At the regional level, local governments in Indonesia also play a pivotal role in implementing these TI advances. Practical implications include facilitating the adoption of decentralized REC solutions such as microgrids in rural communities, promoting local partnerships with universities and startups to pilot REC innovations, and allocating regional budgets to support clean energy infrastructure. Strengthening the capacity of local institutions in planning and managing REC projects is equally essential to ensure that technological innovation can be effectively translated into real progress at the grassroots level. These findings align with Sinsel et al. [52], who identified a significant breakthrough in TI as the development of advanced batteries capable of storing energy for extended periods. Moreover, Carley and Konisky [57] found that the implementation of smart grid systems, as a form of TI, can optimize REC utilization.

4.1.6 Model stability

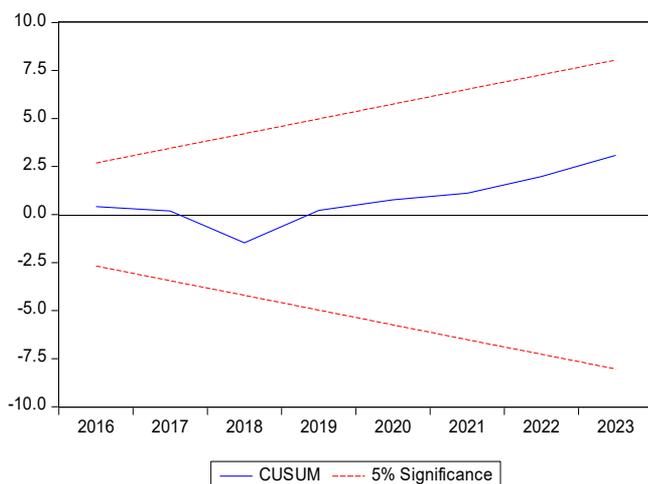


Figure 2. Model stability test results

The CUSUM test results in Figure 2 show that the blue line stays within the 5% significance bounds (red dashed lines) throughout the period, indicating long-run model stability. Although minor fluctuations occurred around 2018, the line remained within critical limits, confirming the model's reliability in capturing variable relationships.

4.2 Forecasting analysis

This section presents the forecasting process for REC, based on the long-run estimated model using the ARDL approach. The projection is carried out by substituting the values from the BAU scenario for the years 2024 to 2030, namely, POP, EG, NREC, and TI. The calculation begins with the year 2024 and proceeds iteratively for the subsequent years through 2030. The results of the year-by-year REC forecasts are visually presented in the following Figure 3. The graph distinguishes between historical data (2000-2023) and projected values (2024-2030). The solid blue line represents observed REC trends over the historical period, while the dashed orange line reflects the forecasted REC under the BAU scenario.

The forecasting results provide an overview of how REC in Indonesia is expected to evolve if historical growth patterns continue without the introduction of new policy interventions. The projected REC trajectory demonstrates consistency with past dynamics while also indicating the direction of medium-term development. This outcome serves as an initial benchmark for assessing Indonesia's progress toward achieving SDG 7. Furthermore, the distinction between historical observations and projected values offers a clear visual transition point between the two periods. Such information is crucial for policymakers to identify potential gaps and design strategies that accelerate the transition toward sustainable energy.

Figure 3 shows a consistent increase in REC over the past two decades, reflecting a gradual shift toward a cleaner and more sustainable energy mix. In the early 2000s, the share of REC in national energy consumption was only around 5 percent. However, this trend has steadily increased, surpassing 15 percent by 2023. Future projections indicate that this figure may reach approximately 17.4 percent by 2030. Although this represents a positive trajectory, the growth remains insufficient to meet the ambitious target set by the National Energy Policy, which aims for a 23 percent share of REC in the national energy mix by 2025. Even by 2030, the projected REC share still falls short of this target, highlighting the persistent gap between national aspirations and the current pace of progress.

The upward trend in REC is closely aligned with efforts to achieve SDG 7, which emphasizes the importance of access to affordable, reliable, sustainable, and modern energy for all. A key indicator of SDG 7 is the increasing proportion of REC in total final energy consumption. However, as of 2023, the contribution of REC in Indonesia remains at only around 12-13 percent, revealing a substantial gap between policy targets and actual on-the-ground achievements. This gap is driven by various structural challenges, including limited investment in clean energy infrastructure, a high dependence on fossil fuels and traditional biomass, as well as regulatory and institutional barriers that hinder the adoption of green technologies. Furthermore, the low level of private sector participation and restricted access to green technologies continue to impede the acceleration of the national energy transition.

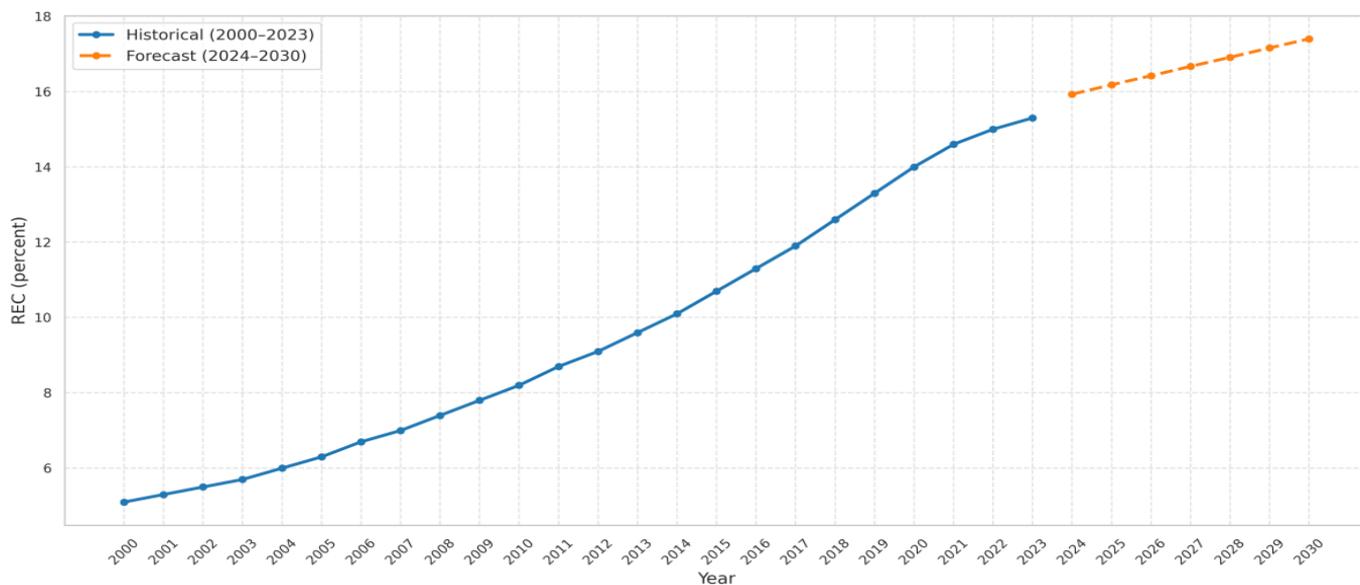


Figure 3. Historical and forecast REC in Indonesia

Projections through 2030 also imply that without stronger, more targeted, and transformative policy interventions, the growth of REC is likely to remain linear and show no significant acceleration. In other words, while REC will continue to increase gradually, its growth will not be sufficient to keep pace with the rising energy demand driven by POP, EG, NREC, and TI. This situation indicates that existing policies may not be ambitious enough to address structural barriers such as fossil fuel subsidies, limited investment, and inadequate infrastructure. It also suggests that Indonesia risks locking itself into a fossil-dependent pathway that could undermine long-term sustainability goals. From a policy perspective, this underscores the urgency of designing interventions that not only expand REC capacity but also enhance accessibility and affordability. Strengthening institutional coordination across national and local governments becomes crucial to ensure that REC policies are effectively implemented. Moreover, the role of private sector participation and community-based initiatives should be elevated to accelerate adoption at multiple levels of society.

5. CONCLUSION

Based on the analysis using the ARDL model with Indonesia's time-series data from 2000 to 2023, this study finds that REC is significantly influenced by key macroeconomic variables. In the short-run, REC exhibits strong dependence on its own historical values. POP has a significant negative effect, indicating that POP has not been accompanied by an increase in the use of REC. In contrast, over the long-run, EG, NREC, and TI have a significant positive impact on REC. This suggests that as income rises and technology advances, there are growing opportunities to expand the use of clean energy in the future. However, the long-run negative contribution of POP to REC indicates that energy demand driven by a growing POP still primarily relies on conventional energy sources.

Projections through 2030 indicate that although the trend in REC continues to rise steadily, the growth rate remains insufficient to meet the REC mix target of 23 percent by 2025, as set forth in the National Energy Policy. By 2030, REC is

projected to reach only around 17.4 percent, still far from the expected achievement of SDG 7. These findings imply that without stronger, more targeted, and transformative policy interventions, the growth of REC is likely to remain linear and show no significant acceleration. In other words, while REC will continue to increase gradually, its growth will not be sufficient to keep pace with the rising energy demand driven by POP, EG, NREC, and TI, thereby reinforcing the persistent gap between clean energy targets and actual outcomes.

This study recommends that the government and policymakers strengthen incentives for the adoption of REC through supportive fiscal policies, such as subsidies, tax incentives, or attractive feed-in tariff schemes for clean energy producers. Additionally, accelerating the development of green technology should be pursued by enhancing the national research and innovation ecosystem, promoting technology transfer, and increasing support for REC-based incubators and startups. These efforts are not only essential for reducing the production costs of REC but also for creating new, inclusive, and sustainable economic opportunities. Furthermore, strategic partnerships with the private sector should be expanded through innovative financing mechanisms such as public-private partnerships, green bonds, and blended finance.

Therefore, future studies are encouraged to explore in greater depth the interactions among institutional governance, progressive and equitable energy pricing structures, and fiscal policy dynamics, including incentives and disincentives in driving the transition toward REC. Such research is expected to provide a more comprehensive policy foundation to achievement of SDG 7 targets in Indonesia.

REFERENCES

- [1] Harjanne, A., Korhonen, J.M. (2019). Abandoning the concept of renewable energy. *Energy Policy*, 127: 330-340. <https://doi.org/10.1016/j.enpol.2018.12.029>
- [2] Jurasz, J., Canales, F.A., Kies, A., Guezgouz, M., Beluco, A. (2020). A review on the complementarity of renewable energy sources: Concept, metrics, application and future research directions. *Solar Energy*, 195: 703-724. <https://doi.org/10.1016/j.solener.2019.11.087>

- [3] Chien, F. (2022). How renewable energy and non-renewable energy affect environmental excellence in N-11 economies? *Renewable Energy*, 196: 526-534. <https://doi.org/10.1016/j.renene.2022.07.013>
- [4] Güneş, T. (2019). Renewable energy, non-renewable energy and sustainable development. *International Journal of Sustainable Development & World Ecology*, 26(5): 389-397. <https://doi.org/10.1080/13504509.2019.1595214>
- [5] Mujtaba, A., Jena, P.K., Bekun, F.V., Sahu, P.K. (2022). Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries. *Renewable and Sustainable Energy Reviews*, 160: 112300. <https://doi.org/10.1016/j.rser.2022.112300>
- [6] Aimon, H., Kurniadi, A.P., Amar, S. (2021). Analysis of fuel oil consumption, green economic growth and environmental degradation in 6 Asia Pacific countries. *International Journal of Sustainable Development and Planning*, 16(5): 925-933. <https://doi.org/10.18280/ijstdp.160513>
- [7] Hakim, D.L., Aji, M.P., Kurniadi, A.P., Suhendra, A., Firdaus, I.A. (2025). How does economic growth moderate the impact of energy consumption on carbon emissions in the evaluation of Sustainable Development Goal 13? *International Journal of Innovative Research and Scientific Studies*, 8(1): 1910-1920. <https://doi.org/10.53894/ijriss.v8i1.4827>
- [8] Kurniadi, A.P., Aimon, H., Amar, S. (2022). Analysis of green economic growth, biofuel oil consumption, fuel oil consumption and carbon emission in Asia Pacific. *International Journal of Sustainable Development & Planning*, 17(7): 2247-2254. <https://doi.org/10.18280/ijstdp.170725>
- [9] Aimon, H., Kurniadi, A.P., Amar, S. (2023). Scenario of reducing carbon emission through shifting consumption of non-renewable energy to renewable energy in Asia Pacific 2023-2030. *IOP Conference Series: Earth and Environmental Science*, 1151(1): 012016. <https://doi.org/10.1088/1755-1315/1151/1/012016>
- [10] Aimon, H., Kurniadi, A.P., Sentosa, S.U., Abd Rahman, N. (2023). Production, consumption, export and carbon emission for coal commodities: Cases of Indonesia and Australia. *International Journal of Energy Economics and Policy*, 13(5): 484-492. <https://doi.org/10.32479/ijeep.14798>
- [11] Kasman, K., Anggi Putri, K., Nasfi, N., Indriani, N., Helmawati, H., Sumiati, S., Mai, Y., Okfi, R., Helia, S. (2025). How does the endogeneity of energy financing, carbon emissions, and energy transition affect the upper-middle- income countries in ASEAN? *International Journal of Energy Economics and Policy*, 15(2): 746-755. <https://doi.org/10.32479/ijeep.18085>
- [12] Kurniadi, A.P., Aimon, H., Salim, Z., Ragimun, Sonjaya, A., Setiawan, S., Siagian, V., Nasution, L.Z., Nurhidajat, R., Mutaqin, Sabtohadhi, J. (2024). Analysis of existing and forecasting for coal and solar energy consumption on climate change in Asia Pacific: New evidence for sustainable development goals. *International Journal of Energy Economics and Policy*, 14(4): 352-359. <https://doi.org/10.32479/ijeep.16187>
- [13] Ministry of Energy and Mineral Resources of Indonesia. (2024). *Handbook of energy & economic statistics of Indonesia*. Kementerian Energi Dan Sumber Daya Mineral. <https://www.esdm.go.id/id/publikasi/handbook-of-energy-economic-statistics-of-indonesia>, accessed on Jan. 31, 2025.
- [14] Khan, S.A.R., Zhang, Y., Kumar, A., Zavadskas, E., Streimikiene, D. (2020). Measuring the impact of renewable energy, public health expenditure, logistics, and environmental performance on sustainable economic growth. *Sustainable Development*, 28(4): 833-843. <https://doi.org/10.1002/sd.2034>
- [15] Wu, D., Yang, Y., Shi, Y., Xu, M., Zou, W. (2022). Renewable energy resources, natural resources volatility and economic performance: Evidence from BRICS. *Resources Policy*, 76: 102621. <https://doi.org/10.1016/j.resourpol.2022.102621>
- [16] Chen, H., Shi, Y., Zhao, X. (2022). Investment in renewable energy resources, sustainable financial inclusion and energy efficiency: A case of US economy. *Resources Policy*, 77: 102680. <https://doi.org/10.1016/j.resourpol.2022.102680>
- [17] Fan, W., Hao, Y. (2020). An empirical research on the relationship amongst renewable energy consumption, economic growth and foreign direct investment in China. *Renewable Energy*, 146: 598-609. <https://doi.org/10.1016/j.renene.2019.06.170>
- [18] Akintande, O.J., Olubusoye, O.E., Adenikinju, A.F., Olanrewaju, B.T. (2020). Modeling the determinants of renewable energy consumption: Evidence from the five most populous nations in Africa. *Energy*, 206: 117992. <https://doi.org/10.1016/j.energy.2020.117992>
- [19] Aydin, M., Bozatli, O. (2023). The impacts of the refugee population, renewable energy consumption, carbon emissions, and economic growth on health expenditure in Turkey: New evidence from Fourier-based analyses. *Environmental Science and Pollution Research*, 30(14): 41286-41298. <https://doi.org/10.1007/s11356-023-25181-8>
- [20] Vo, D.H., Vo, A.T. (2021). Renewable energy and population growth for sustainable development in the Southeast Asian countries. *Energy, Sustainability and Society*, 11(1): 30. <https://doi.org/10.1186/s13705-021-00304-6>
- [21] Minh, T.B., Ngoc, T.N., Van, H.B. (2023). Relationship between carbon emissions, economic growth, renewable energy consumption, foreign direct investment, and urban population in Vietnam. *Heliyon*, 9(6): e17544. <https://doi.org/10.1016/j.heliyon.2023.e17544>
- [22] Eren, B.M., Taspinar, N., Gokmenoglu, K.K. (2019). The impact of financial development and economic growth on renewable energy consumption: Empirical analysis of India. *Science of the Total Environment*, 663: 189-197. <https://doi.org/10.1016/j.scitotenv.2019.01.323>
- [23] Cai, Y., Sam, C.Y., Chang, T. (2018). Nexus between clean energy consumption, economic growth and CO2 emissions. *Journal of Cleaner Production*, 182: 1001-1011. <https://doi.org/10.1016/j.jclepro.2018.02.035>
- [24] Destek, M.A., Sinha, A. (2020). Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic co-operation and development countries. *Journal of Cleaner Production*, 242: 118537. <https://doi.org/10.1016/j.jclepro.2019.118537>

- [25] Gozgor, G., Lau, C.K.M., Lu, Z. (2018). Energy consumption and economic growth: New evidence from the OECD countries. *Energy*, 153: 27-34. <https://doi.org/10.1016/j.energy.2018.03.158>
- [26] Rahman, M.R., Rahman, M.M., Akter, R. (2023). Exploring the link between green energy, CO2 emissions, exchange rate and economic growth: Perspective from emerging South Asian countries. *International Journal of Renewable Energy Development*, 12(5): 930-941. <https://doi.org/10.14710/ijred.2023.53168>
- [27] Chen, Y., Wang, Z., Zhong, Z. (2019). CO2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. *Renewable Energy*, 131: 208-216. <https://doi.org/10.1016/j.renene.2018.07.047>
- [28] Islam, M.M., Irfan, M., Shahbaz, M., Vo, X.V. (2022). Renewable and non-renewable energy consumption in Bangladesh: The relative influencing profiles of economic factors, urbanization, physical infrastructure and institutional quality. *Renewable Energy*, 184: 1130-1149. <https://doi.org/10.1016/j.renene.2021.12.020>
- [29] Kurniadi, A.P., Aimon, H., Amar, S. (2021). Determinants of biofuels production and consumption, green economic growth and environmental degradation in 6 Asia Pacific countries: A simultaneous panel model approach. *International Journal of Energy Economics and Policy*, 11(5): 460-471. <https://doi.org/10.32479/ijeep.11563>
- [30] Opeyemi, B.M. (2021). Path to sustainable energy consumption: The possibility of substituting renewable energy for non-renewable energy. *Energy*, 228: 120519. <https://doi.org/10.1016/j.energy.2021.120519>
- [31] Sohail, M.T., Xiuyuan, Y., Usman, A., Majeed, M.T., Ullah, S. (2021). Renewable energy and non-renewable energy consumption: Assessing the asymmetric role of monetary policy uncertainty in energy consumption. *Environmental Science and Pollution Research*, 28(24): 31575-31584. <https://doi.org/10.1007/s11356-021-12867-0>
- [32] Ahmad, T., Zhang, D., Huang, C., Zhang, H., Dai, N., Song, Y., Chen, H. (2021). Artificial intelligence in sustainable energy industry: Status quo, challenges and opportunities. *Journal of Cleaner Production*, 289: 125834. <https://doi.org/10.1016/j.jclepro.2021.125834>
- [33] Alam, M.M., Murad, M.W. (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. *Renewable Energy*, 145: 382-390. <https://doi.org/10.1016/j.renene.2019.06.054>
- [34] Anton, S.G., Nucu, A.E.A. (2020). The effect of financial development on renewable energy consumption. A panel data approach. *Renewable Energy*, 147: 330-338. <https://doi.org/10.1016/j.renene.2019.09.005>
- [35] Olabi, A.G., Abdelkareem, M.A. (2022). Renewable energy and climate change. *Renewable and Sustainable Energy Reviews*, 158: 112111. <https://doi.org/10.1016/j.rser.2022.112111>
- [36] Østergaard, P.A., Duic, N., Noorollahi, Y., Mikulcic, H., Kalogirou, S. (2020). Sustainable development using renewable energy technology. *Renewable Energy*, 146: 2430-2437. <https://doi.org/10.1016/j.renene.2019.08.094>
- [37] Shah, A.A., Hussain, M.S., Nawaz, M.A., Iqbal, M. (2021). Nexus of renewable energy consumption, economic growth, population growth, FDI, and environmental degradation in South Asian countries: New evidence from Driscoll-Kraay standard error approach. *IRASD Journal of Economics*, 3(2): 200-211. <https://doi.org/10.52131/joe.2021.0302.0037>
- [38] Cao, H. (2025). Exploring the link between CO2 emissions, economic growth, urbanization and transportation infrastructure in China: Evidence from the ARDL model. *International Journal of Renewable Energy Development*, 14(4): 657-667. <https://doi.org/10.61435/ijred.2025.61247>
- [39] Adebayo, T.S., Akinsola, G.D. (2021). Investigating the causal linkage among economic growth, energy consumption and CO2 emissions in Thailand: An application of the wavelet coherence approach. *International Journal of Renewable Energy Development*, 10(1): 17-26. <https://doi.org/10.14710/ijred.2021.32233>
- [40] Banday, U.J., Aneja, R. (2020). Renewable and non-renewable energy consumption, economic growth and carbon emission in BRICS: Evidence from bootstrap panel causality. *International Journal of Energy Sector Management*, 14(1): 248-260. <https://doi.org/10.1108/IJESM-02-2019-0007>
- [41] Ugwu, J., Odo, K.C., Oluka, L.O., Salami, K.O. (2022). A systematic review on the renewable energy development, policies and challenges in Nigeria with an international perspective and public opinions. *International Journal of Renewable Energy Development*, 11(1): 287-308. <https://doi.org/10.14710/ijred.2022.40359>
- [42] Salahuddin, M., Alam, K., Ozturk, I., Sohag, K. (2018). The effects of electricity consumption, economic growth, financial development and foreign direct investment on CO2 emissions in Kuwait. *Renewable and Sustainable Energy Reviews*, 81: 2002-2010. <https://doi.org/10.1016/j.rser.2017.06.009>
- [43] Aboucata, W., Hijawi, U., Al-Kababji, A., Mohieddine, A., Choe, P. (2021). Statistical analysis of renewable and non-renewable energy consumption against population growth. *IOP Conference Series: Earth and Environmental Science*, 726(1): 012003. <https://doi.org/10.1088/1755-1315/726/1/012003>
- [44] Adhikari, D.R., Techato, K., Jariyaboon, R. (2024). A systematic literature review on renewable energy technologies for energy sustainability in Nepal: Key challenges and opportunities. *International Journal of Renewable Energy Development*, 13(2): 206-222. <https://doi.org/10.61435/ijred.2024.60032>
- [45] Anwar, N., Elfaki, K.E. (2021). Examining the relationship between energy consumption, economic growth and environmental degradation in Indonesia: Do capital and trade openness matter? *International Journal of Renewable Energy Development*, 10(4): 769-778. <https://doi.org/10.14710/ijred.2021.37822>
- [46] Rahman, M.M., Velayutham, E. (2020). Renewable and non-renewable energy consumption-economic growth nexus: New evidence from South Asia. *Renewable Energy*, 147: 399-408. <https://doi.org/10.1016/j.renene.2019.09.007>
- [47] Qamruzzaman, M. (2025). How do economic freedom, trade freedom, and digitization influence renewable energy consumption in G20 nations: What is the role of

- innovation? *International Journal of Renewable Energy Development*, 14(5): 882-899. <https://doi.org/10.61435/ijred.2025.61147>
- [48] Wellum, C. (2023). *Energizing Neoliberalism: The 1970s Energy Crisis and the Making of Modern America*. JHU Press.
- [49] Udeagha, M.C., Ngepah, N. (2022). Disaggregating the environmental effects of renewable and non-renewable energy consumption in South Africa: Fresh evidence from the novel dynamic ARDL simulations approach. *Economic Change and Restructuring*, 55(3): 1767-1814. <https://doi.org/10.1007/s10644-021-09368-y>
- [50] Ali, U., Guo, Q., Kartal, M.T., Nurgazina, Z., Khan, Z.A., Sharif, A. (2022). The impact of renewable and non-renewable energy consumption on carbon emission intensity in China: Fresh evidence from novel dynamic ARDL simulations. *Journal of Environmental Management*, 320: 115782. <https://doi.org/10.1016/j.jenvman.2022.115782>
- [51] Sharma, G.D., Tiwari, A.K., Erkut, B., Mundi, H.S. (2021). Exploring the nexus between non-renewable and renewable energy consumptions and economic development: Evidence from panel estimations. *Renewable and Sustainable Energy Reviews*, 146: 111152. <https://doi.org/10.1016/j.rser.2021.111152>
- [52] Sinsel, S.R., Riemke, R.L., Hoffmann, V.H. (2020). Challenges and solution technologies for the integration of variable renewable energy sources-A review. *Renewable Energy*, 145: 2271-2285. <https://doi.org/10.1016/j.renene.2019.06.147>
- [53] Murshed, M., Saboori, B., Madaleno, M., Wang, H., Doğan, B. (2022). Exploring the nexuses between nuclear energy, renewable energy, and carbon dioxide emissions: The role of economic complexity in the G7 countries. *Renewable Energy*, 190: 664-674. <https://doi.org/10.1016/j.renene.2022.03.121>
- [54] Bekun, F.V., Emir, F., Sarkodie, S.A. (2019). Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. *Science of the Total Environment*, 655: 759-765. <https://doi.org/10.1016/j.scitotenv.2018.11.271>
- [55] Brini, R. (2021). Renewable and non-renewable electricity consumption, economic growth and climate change: Evidence from a panel of selected African countries. *Energy*, 223: 120064. <https://doi.org/10.1016/j.energy.2021.120064>
- [56] Al-Silefanee, R. (2024). The role of economic complexity in shaping the energy-growth nexus: Evidence from cross-country panel data. *International Journal of Renewable Energy Development*, 13(2): 256-269. <https://doi.org/10.61435/ijred.2024.60055>
- [57] Carley, S., Konisky, D.M. (2020). The justice and equity implications of the clean energy transition. *Nature Energy*, 5(8): 569-577. <https://doi.org/10.1038/s41560-020-0641-6>