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EXPLORING THE DRIVERS OF RENEWABLE ENERGY CONSUMPTION: THE ROLES OF INNOVATION, FINANCIAL GLOBALIZATION, AND UNCERTAINTY IN NEXT-11 COUNTRIES

Yenilenebilir Enerji Tüketimini Etkileyen Faktörlerin Analizi: Next-11 Ülkelerinde İnovasyon, Finansal Küreselleşme ve Belirsizliğin Rolleri

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Keywords:
Renewable Energy, Technological Innovation, Financial Globalization, Uncertainty, Next-11 Countries.

JEL Codes:
Q20, O33, C33, D81.

Abstract

The primary aim of this study is to comprehensively analyze the economic, financial, and technological dynamics shaping renewable energy consumption in the Next-11 countries. In this context, the effects of technological innovation, the financial globalization index, the world uncertainty index, and trade openness variables on renewable energy consumption are examined. Using data covering the period 1990-2021, the analysis was conducted through the Common Correlated Effects (CCE) method. The results indicate that technological innovation and global uncertainty negatively affect renewable energy consumption, whereas financial globalization increases the use of renewable energy. The findings suggest that structural and institutional constraints, limited access to technology, and investment risks arising from uncertainty restrict the renewable energy transition. Conversely, financial integration facilitates international capital flows and supports clean energy investments. The results of this research are significant for policymakers aiming to accelerate the energy transition and for financial institutions seeking to promote sustainable investments.

Anahtar Kelimeler:
Yenilenebilir Enerji, Teknolojik İnovasyon, Finansal Küreselleşme, Belirsizlik, Next-11 Ülkeleri.

JEL Kodları:
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Öz

Bu çalışmanın temel amacı, Next-11 ülkelerinde yenilenebilir enerji tüketimini şekillendiren ekonomik, finansal ve teknolojik dinamikleri kapsamlı biçimde analiz etmektir. Bu doğrultuda, teknolojik inovasyon, finansal küreselleşme endeksi, küresel belirsizlik endeksi ve ticaret açıklığı değişkenlerinin yenilenebilir enerji tüketimi üzerindeki etkileri incelenmiştir. 1990-2021 dönemine ait veriler kullanılarak Common Correlated Effects (CCE) yöntemiyle gerçekleştirilen analizde, teknolojik inovasyon ve küresel belirsizlik değişkenlerinin yenilenebilir enerji tüketimini olumsuz etkilediği; buna karşın finansal küreselleşmenin yenilenebilir enerji kullanımını artırdığı belirlenmiştir. Bulgular, yapısal ve kurumsal sınırlılıkların, teknolojiye erişim zorluklarının ve belirsizlik kaynaklı yatırım risklerinin yenilenebilir enerji dönüşümünü kısıtladığını göstermektedir. Buna karşılık, finansal entegrasyonun uluslararası sermaye akışlarını kolaylaştırarak temiz enerji yatırımlarını desteklediği görülmektedir. Araştırmadan elde edilecek sonuçlar, enerji dönüşümünü hızlandırmayı hedefleyen politika yapıcılar ile sürdürülebilir yatırımlara yönelen finansal kuruluşlar açısından önem taşımaktadır.

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1. Introduction

For today's societies, ensuring sustainability in different areas is one of the most multidimensional and complex issues. One of the most effective strategies in tackling this issue is to promote the use of cleaner energy sources that can replace fossil-based energy. The effort to achieve sustainable development goals also necessitates countries to transform their global energy systems. This transformation process does not merely represent technical alternatives; it symbolizes a significant transformation in how energy is produced and consumed, reflecting the pursuit of sustainability, resilience, and a more harmonious balance with nature (Hassan et al., 2024). The Intergovernmental Panel on Climate Change (IPCC) emphasized in its 2018 Special Report that limiting the increase in global average temperature to 1.5°C above pre-industrial levels is an urgent imperative for preventing potentially catastrophic environmental outcomes (IPCC, 2018). The urgency underscored in this report has directed countries toward renewable energy as the pathway to a sustainable future. Renewable energy consumption has taken center stage in countries' development strategies, particularly in terms of reducing carbon emissions, ensuring energy supply security, and addressing growing environmental concerns.

Global energy demand is increasing due to economic growth, rapid urbanization, industrialization, population growth, changes in the financial system, globalization, and rising prosperity levels (Stern, 2011; Sadorsky, 2013; Shahbaz, 2021; Shahbaz et al., 2024; Jalal, 2025). Since the 1850s, global energy demand has increased by approximately 2.5% per year, and there is still no evidence that this demand will decrease significantly in the near future (Sorrell, 2015). Today, the majority of this demand is met by fossil fuels, accounting for approximately 86% according to Energy Institute data, and these resources are expected to come under increasing under-consumption pressure over the medium and long term. Moreover, fossil fuel consumption is recognized as the main driving force behind carbon emissions, which are the primary cause of global climate change (Holechek, 2022). Usman and Balsalobre-Lorente (2022) have stated that climate change, energy security, depletion of natural resources, and environmental degradation pose serious threats worldwide. Adopting clean energy technologies to increase energy efficiency and meet energy demand is considered the most promising, rapid, and secure path. Projections indicate that approximately 50% of global energy demand is likely to be met through renewable energy sources by 2040 (EREC, 2006). While renewable energy plays a critical role in the transition to cleaner production models by reducing polluting emissions, its use remains limited. Currently, the global share of renewable energy stands at approximately 20% (World Bank, 2025). To expand this share, policy interventions—implementing the Kyoto Protocol, internalizing the external costs associated with conventional energy production, and phasing out subsidies for polluting sources—must be effectively adopted and operationalized. Technological innovation supports the technical feasibility of clean energy investments by increasing energy efficiency.

This study highlights the critical role of technological innovation and financial globalization in promoting renewable energy adoption, while also examining the influence of uncertainty in shaping these relationships. The theoretical framework and conceptual basis of this research are grounded in a series of economic and sustainability theories that suggest how these variables may influence renewable energy consumption. First, according to Schumpeter's theory of innovation, innovation is a process that creates revolution by changing the economic structure from within and, as in the energy sector, serves to bring about a more efficient market return

(Schumpeter, 1911). This is not confined to the creation of new products and services, but is also linked to the emergence of new production processes, organizational structures, employment, and markets. This theoretical framework is also evident in the processes of developing, disseminating, and reducing the costs of renewable energy technologies. For example, patent applications, technological developments, and innovative initiatives are used as important tools in determining countries' competitive strength. New production and storage processes based on renewable energy sources such as solar, wind, and biomass are creating a structural transformation in energy markets by replacing fossil fuel-based energy systems. Secondly, the Economic Policy Uncertainty (EPU) theory suggests that political, economic, and regulatory uncertainties can asymmetrically affect investment decisions, particularly in areas such as renewable energy (Baker et al., 2016). The EPU, symbolizing unpredictable uncertainties that affect economic activities and lead to changes in implemented policies, reflects economic fluctuations arising from the unpredictability of fiscal, political, regulatory, and monetary policies (Davis, 2016). Increasing global uncertainties raise the risk premiums of fragile economies and shape the spending and saving behaviors of economic agents. Increases in EPU coupled with the unpredictability of economic and financial decisions delay many investment and production decisions, thereby postponing the likelihood of recovery from recession (Al-Thaqeb and Algharabali, 2019). When uncertainty and instability coexist with a policy mix, rational actors postpone investment decisions (considering these investments to be fully or partially irreversible) until the uncertainty is resolved. EPU also discourages investment because it creates upward pressure on financing costs. The adverse effects of EPU hinder activities in the renewable energy sector due to investment challenges and the availability of cheaper energy sources, leading to volatility in the sector. Furthermore, in an environment of increasing uncertainty, policymakers are becoming reluctant to adopt policy decisions aimed at the renewable energy sector, preferring to stick with existing energy sources. Besides, there is also the view that EPU can make a positive contribution to the energy sector. Increasing uncertainty is expected to exacerbate energy price volatility by intensifying the imbalance between energy demand and supply. Consequently, adjustments in purchasing behavior may occur, as economic agents seek to hedge against potential risks and future price surges, ultimately amplifying energy demand and necessitating higher levels of energy production. Secondly, when policymakers recognize economic policy uncertainties through fluctuations in energy prices, they may respond by implementing additional monetary and fiscal measures targeting energy markets. At the same time, firms may be driven to foster innovation as they seek new solutions to minimize these risks.

While countries strive to achieve international sustainable development goals, they are also turning to the renewable energy sector as a way to gain a strategic superiority, reduce energy dependence, and position themselves as leading actors within the emerging green economy. This trend is likely to generate a substantial departure from historical geopolitical power structures, shift from ownership of energy resources to dominance in energy technologies, and thereby foster the emergence of new alliances and rivalries. Although the renewable energy sector has made progress in today's global energy market thanks to energy policies, incentives, falling technology costs, and globalization, countries such as the Next-11 face institutional and structural challenges. The Next-11 countries account for approximately 20% of the world's population and approximately 10% of its exports and imports (World Bank, 2025). Recognized as the fastest-growing nations globally with balanced growth potential, the Next-11 countries also draw attention due to their excessive energy consumption and contribution to environmental degradation. Based on the 2023 data from the European Commission's Emissions Database for

Global Atmospheric Research, five of the top 15 countries contributing most to global CO_2 emissions are Next-11 countries (EDGAR, 2024). As a result of increasing pressures, the governments of these countries are launching energy policy initiatives to revitalize the renewable energy sector. In summary, it is clear that the Next-11 countries need renewable energy as a solution for sustainable growth. On the other hand, Next-11 countries are home to some of the world's richest resource regions for the establishment of solar, wind, and geothermal energy sources. However, dependence on fossil fuels, lack of innovation and infrastructure, institutional factors, and insufficient capital are hindering these initiatives. In particular, within the financial context, a lack of capital and investors can affect the feasibility of renewable energy projects, while a lack of innovation can slow progress in the sector.

The main objective of this research is to analyze the economic, financial, and technological dynamics that shape renewable energy consumption in the Next-11 countries (Bangladesh, Indonesia, Iran, South Korea, Mexico, Nigeria, Pakistan, the Philippines, Turkey, Egypt, and Vietnam). The study examines the effects of technological innovation, financial globalization, global uncertainty, and trade openness on renewable energy consumption for the period 1990-2021 using the Common Correlated Effects (CCE) method. In this context, the research evaluates the energy transition not only from the perspective of environmental sustainability but also by considering the dimensions of economic stability, financial integration, and technological capacity. In the literature, studies on renewable energy consumption have generally focused on the axes of economic growth (Sadorsky, 2013; Shahbaz, 2021; Tithi, 2025), environmental degradation (Majeed et al., 2022). However, most of these studies concentrate on developed countries or high-income regions and do not comprehensively address the dynamics in developing economies. In this regard, the present study is one of the few that investigates this relationship within the context of the Next-11 countries.

The increasing complexity of the economic, financial, and technological dynamics shaping renewable energy consumption constitutes the main motivation of this research. The findings are expected to provide valuable insights for various stakeholders in developing effective strategies and informed decision-making. For energy policy makers, the study may offer guidance on how the transition to renewable energy should be approached, not only from an environmental perspective but also in connection with financial integration, technological advancement, and economic stability. In this way, countries may develop more comprehensive policies that balance financial openness with technological capacity in shaping their energy strategies. For financial regulators and investors, the research can serve as a reference in shaping capital flow management and investment planning. The results may help identify the conditions under which renewable energy investments can perform more stably and sustainably. By considering the dynamics of technology and financial globalization, investors could design more informed and resilient strategies for energy markets. From the perspective of international organizations and development agencies, the study can contribute to identifying which macroeconomic factors support or constrain the financing of global energy transition. Such insights can guide the design of more effective funding mechanisms for clean energy investments. Overall, this research aims to provide a practical framework that helps diverse stakeholders establish a stronger balance between the economic, technological, and financial dimensions of renewable energy policies.

The remaining structure of the study is organized as follows: Section 2 provides a comprehensive review of the relevant literature. Section 3 introduces the methodological framework, empirical model, and data sources. Section 4 reports the empirical findings. The final section provides the conclusions, policy implications, limitations, and several directions for future research.

2. Literature Review

2.1. Technological Innovation and Renewable Energy

In recent years, in line with sustainable development goals, the relationship between technological innovation and renewable energy consumption has emerged as a key focus of energy economics literature. Technological progress in energy systems is not only limited to reducing costs, but also provides critical contributions in terms of system integration, efficiency and resource diversity (Koç, 2025). Empirical studies typically measure technological innovation using variables such as the number of patents, R&D expenditures related to renewable energy, and the ratio of technology-intensive exports, and analyze the effect of these variables on renewable energy consumption. For example, Jiang and Khan (2023) have shown that innovations increase renewable energy consumption, thus necessitating improvements in technological innovations to obtain renewable energy sources and requiring an advanced level of innovation for energy efficiency.

There is a growing literature examining this relationship for different groups of countries. Geng and Ji (2016) demonstrated that renewable energy consumption in six major developed economies exhibits a long-run equilibrium relationship with technological innovation and other external driving factors. Wen et al. (2022), using panel data from 79 countries, found that renewable energy and energy efficiency significantly influence innovation performance at both aggregate and discrete levels. Both studies concluded that renewable energy consumption increases technological innovation. Conversely, they emphasized that technological advances positively affect renewable energy use. For instance, Solarin et al. (2022) demonstrated, using the Panel Quantile Regression approach for BRICS countries, that the impact of renewable energy innovation on renewable energy production is significantly positive across all quantiles. Rong and Qamruzzaman (2022) revealed that technological innovation positively influences renewable energy consumption in the five largest oil-importing countries. Similarly, Xinyu et al. (2025) noted that technological innovations have had a significant impact on renewable energy in one-third of EU countries, and that this impact stems from developments in promoting technological innovation and accelerating the growth of renewable energy. Kurt Cihangir (2025) found that financial innovations in OECD countries have increased renewable energy production by stimulating green technological innovation activities.

Studies that address this relationship in the context of G-10 and G-20 countries are as follows: Khan and Su (2023) revealed that in G-10 countries, technological innovation constitutes the most critical factor in the renewable energy transition due to their strong innovation bases and high R&D expenditures. Li et al. (2023) found that in G-10 countries, technological innovation has a limited effect on renewable energy when it remains below a certain threshold; however, once energy and technology expenditures expand beyond this threshold, this effect turns into a strong positive impact. Han et al. (2025) revealed that technological innovation significantly enhances the adoption of renewable energy in G-20 countries.

However, studies examining this relationship through individual country practices have also revealed that the results vary depending on country-specific differences. Jin et al. (2018)

indicate that, in China, technological innovation increases energy consumption in the short run, while the reverse effect does not occur; their long-term findings, however, show a positive and bidirectional relationship between energy consumption and technological innovation. Zheng et al. (2021) found that renewable energy technological innovation leads to renewable energy production in China. Khan et al. (2022) discovered that in Germany, technological innovation positively and negatively influenced renewable energy in multiple subsamples, while advances in renewable energy led to increased spending on technological innovation. In general, technological innovations have been seen to have a positive impact on renewable energy consumption, although the level of this effect varies depending on the economic structure and regulatory framework.

2.2. Financial Globalization and Renewable Energy

Financial globalization plays a particularly decisive role in increasing investment in developing countries that face fiscal constraints and have limited capacity to provide adequate investment credit to the private sector. Hence, capital inflows into the energy sector, driven by financial globalization, may be associated with potential increases in renewable energy consumption. More importantly, since it is widely accepted that inadequate funding allocated to renewable energy initiatives often limits the renewable energy transition process, financial globalization can serve as a mechanism to attract foreign direct investment in renewable energy to alleviate local investment constraints. Hence, a country's annual renewable energy consumption levels are likely to be encouraged by financial globalization. On the other hand, financial instability, speculative investment behavior, and EPU may hinder the development of renewable energy, particularly in developing economies with weak regulatory frameworks.

Doytch and Narayan (2016) indicated that, in 74 countries, foreign direct investment inflows -used as a proxy for financial globalisation- have a reducing effect on non-renewable energy consumption, while having a positive impact on renewable energy consumption. Kang et al. (2021) found a significant and negative relationship between financial globalization and renewable energy in their study of selected South Asian countries. In a study conducted on 19 developing countries, Ilarslan (2021) found that while the level of financial development has a positive effect on renewable energy production, this effect is not statistically significant at any quantile level. Majeed et al. (2022) revealed that financial globalization promotes renewable energy consumption in BRICS economies. Murshed et al. (2022) found that direct foreign investment inflows, which they used to represent financial globalization in Bangladesh, increased the share of renewable electricity production in the country's total electricity production levels. Chen and Zhang (2023) found that financial globalization positively influenced renewable energy investments in China in both the short and long run under both linear and nonlinear model specifications. Alam et al. (2024) concluded that as India becomes more financially globalized, non-renewable energy consumption decreases in the short run but increases in the long run, while renewable energy consumption remains unaffected in the short run and is hindered in the long run. The same study also revealed that technological innovation positively affects non-renewable energy consumption in the short run but reduces it in the long run, while gradually increasing renewable energy consumption. Finally, it has been highlighted that financial globalization has contributed to narrowing the gap between India's non-renewable and renewable energy consumption in the short run, whereas technological innovation plays a more pronounced role in the long run.

Some studies suggest that industries with high pollution levels in developed countries tend to relocate to developing countries with more lenient environmental regulations, as they are constrained by stricter environmental policies at home. That is, financial globalization results in higher carbon emissions by stimulating increased industrial activity and resource extraction, which in turn increases primary energy consumption. Gyamfi et al. (2022) demonstrated that foreign direct investment adversely affects environmental quality in E7 economies, thereby supporting the pollution haven hypothesis. They argue that globalization has drawn the attention of foreign investors to developing countries, where production activities are likely to be restructured using technologies reliant on fossil fuels lacking sustainable development, and thus renewable energy consumption in these countries may relatively decrease. Ghosh et al. (2024) confirmed that financial globalization has increased the shift toward carbon-intensive sectors rather than clean energy, which could lead to a significant increase in production for 10 selected newly industrialized countries, and that primary energy consumption has increased significantly. Shodrokova et al. (2024) found that for six developing countries, increased economic activity driven by financial globalization and international trade has encouraged the expansion of the industrial sector and greater mobility, thereby increasing dependence on fossil fuels. Sümerli Sarıgül and Çetin (2025) emphasize that while the use of renewable energy in the Japanese economy improves environmental quality by increasing the load factor, financial globalization has the opposite effect.

2.3. Uncertainty and Renewable Energy

Uncertainty stands out as a decisive external factor shaping the dynamics of renewable energy. The unpredictability of economic and regulatory policies increases risk perception -particularly for clean energy projects that require long-term investment commitments- and thereby adversely affects capital allocation. The literature demonstrates that both rising and declining levels of uncertainty exert discouraging effects on the adoption of renewable energy technologies. Furthermore, it highlights that a stable, predictable, and consistent policy framework is vital for the sustainability and efficiency of energy transition processes. Empirical findings consistently reveal that rising uncertainty undermines investor confidence, erodes support mechanisms for renewable energy policies, and ultimately delays the integration of these technologies into national energy portfolios.

Shafiullah et al. (2021) found a strong nonlinear causality in both directions and a negative long-term relationship between uncertainty and renewable energy consumption in the United States. In other words, higher uncertainty reduces renewable energy consumption. Wei et al. (2021) found a stationary and cointegration relationship between uncertainty and energy production in China, and that this relationship is a significant positive cointegration at high frequencies (short term) but a weaker cointegration at low frequencies (long term). Lei et al. (2022) examined the asymmetric effects of uncertainty and financial development on renewable energy consumption in China and concluded that EPU significantly increases renewable energy consumption in the short term but has a negative impact on renewable energy in the long term. Qamruzzaman (2024) found that trade and economic policy uncertainties play a detrimental role in clean energy demand in both the short and long run for China and the United States.

Zhang et al. (2021) concluded that uncertainty in BRIC countries negatively affects renewable energy consumption in both the long and short term. Similarly, Rong and

Qamruzzaman (2022) found that in the five largest oil-importing countries, uncertainty exerts an adverse impact on renewable energy consumption, particularly in the long term. Su et al. (2022) found that uncertainty across all sectors in G7 economies had a negative impact on renewable energy. Khan and Su (2022) investigate that uncertainty in G7 countries has a negative effect on renewable energy across all countries, arguing that uncertainty disrupts the macroeconomy, which in turn leads to a decline in renewable energy. Borozan (2022) concluded that uncertainty in G7 countries creates an asymmetric effect on renewable energy consumption in the long term, and that both negative and positive shocks in delayed uncertainty reduce renewable energy consumption.

3. Data and Theoretical Framework

3.1. Data

In this study, the relationship between renewable energy consumption, technological innovation, financial globalization, and uncertainty is examined within the framework of causality analysis using data from the Next-11 countries for the period from 1990 to 2021. In the study, renewable energy consumption serves as the dependent variable, while technological innovation, financial globalization, and the uncertainty index constitute the independent variables. Since patents are regarded as an outcome of countries' technological capacities, they are used as a proxy for technological innovation. Trade openness, by contrast, is incorporated into the model as a control variable. In this context, the following model has been developed to estimate the relationship.

$$REC_{it} = \beta_0 + \beta_1 TI_{it} + \beta_2 FGI_{it} + \beta_3 WUI_{it} + \beta_4 TO_{it} + \varepsilon_{it} \quad (1)$$

In equation (1), $i = 1,\ldots, N$ represents cross-sectional units and $t = 1,\ldots, T$ represents the time dimension, while ε_{it} denotes idiosyncratic error term. The coefficient β_0 is the fixed intercept, whereas $\beta_1, \beta_2, \beta_3$ and β_4 represent the slope parameters that quantify the marginal effects of the independent variables on the dependent variable, as summarized in Table 1. Next-11 countries based on this study: Bangladesh, Egypt, Indonesia, Iran, Mexico, Pakistan, Philippines, South Korea, Türkiye, and Vietnam, respectively. The study utilizes annual data covering the period from 1990 to 2021.

Table 1. Variables, Descriptions, and Data Sources

Variable	Abbreviation	Unit of the variable	Source
Renewable Energy Consumption	REC	Renewable Energy Consumption (% of total final energy consumption)	World Bank
Technological Innovation	TI	Patent Applications	World Bank
Financial Globalization Index	FGI	KOF Globalisation Index	KOF
World Uncertainity Index	WUI	World Uncertainity Index	World Bank
Trade Openness	TO	Trade (% of GDP)	World Bank

3.2. Amprical Framework

If cross-sectional dependence (CSD) is not taken into account in panel data analysis, the results produced by the estimated panel models may be biased and inconsistent (Phillips and Sul, 2003). In this study, Breusch-Pagan's LM test (Breusch and Pagan, 1980), Pesaran scaled LM

(CD_{LM}) and Pesaran CD tests (Pesaran, 2004), and Bias-Corrected Scaled LM (LM_{adj}) test (Pesaran et al., 2008) were applied to test the CSD. If there is a CSD between the series, the null (H_0) hypothesis is rejected for these tests. These four performed tests are expressed as given in equations (2)-(5), respectively:

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \tag{2}$$

$$CD_{LM} = \sqrt{1/N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{\rho}_{ij}^2 - 1) \tag{3}$$

$$CD = \sqrt{2T/N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho_{ij}}\right) \tag{4}$$

$$LM_{adj} = \sqrt{2/N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{(T-k)\hat{\rho}_{ij}^2 - \mu_{Tij}}{\upsilon_{Tij}} \sim N(0,1) \tag{5}$$

The stationarity of data has been investigated by conducting a unit root test. Various approaches exist in the literature to assess stationarity. In the presence of CSD, second-generation panel unit root tests should be employed. In the study, considering the CSD test results, the Cross-sectional Augmented Dickey-Fuller (CADF) panel unit root test (Pesaran, 2007) was preferred. Pesaran (2007) used the expanded version of the ADF unit root test with the lagged cross-sectional averages. Furthermore, applying the first-difference transformation to the regression helps remove CSD across units. The H_0 of the unit root test is that the variables are not stationary and the H_1 is that the variables are stationary. Pesaran (2007) used equations (6) and (7) for the CADF unit root test:

$$y_{it} = (1-\phi_i)\mu_i + \phi_i y_{i,t-1} + u_{it} \tag{6}$$

$$u_{it} = \gamma_i f_t + \varepsilon_{it} \tag{7}$$

It is convenient to write (6) and (7) as:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i f_t + \varepsilon_{it} \tag{8}$$

After determining the CSD and ensuring stationary, Westerlund and Edgerton's (2007) Panel LM bootstrap cointegration test was chosen as the appropriate cointegration test based on the findings obtained. This test, based on the Lagrange test statistic developed by McCoskey and Kao (1998), has the null hypothesis (H_0) 'There is a cointegration relationship' and the alternative hypothesis (H_1) 'There is no cointegration relationship'. Westerlund and Edgerton (2007) used equations (9) and (10) for the Panel LM bootstrap cointegration test:

$$y_{it} = \alpha_i + x_{it}'\beta_i + z_{it} \tag{9}$$

$$z_{it} = u_{it} + v_{it} \; with \; v_{it} = \sum_{j=1}^{t}\eta_{it} \tag{10}$$

where η_{it} denotes an independent and identically distributed (i.i.d.) process with zero mean and variance $var(\eta_{it}) = \sigma_i^2$. As pointed out by McCoskey and Kao (1998), in the case of cross-sectional independence, this hypothesis can be tested using the test statistic in equation (11):

$$LM_N^+ = \frac{1}{NT^2} \sum_{i=1}^{N} \sum_{j=i+1}^{T} \widehat{\omega}_i^{-2} S_{it}^2 \tag{11}$$

where S_{it} is the partial sum process of $\hat{z}_{it}$, the fully modified estimate of z_{it}, and $\widehat{\omega}_i^2$ is the estimated long-run variance of u_{it} conditional on Δx_{it}.

To obtain reliable cointegration coefficients, it is essential to apply estimators that explicitly account for CSD among the units in the panel. For this purpose, the CCE estimator introduced by Pesaran (2006) is employed, as it incorporates unobserved common factors into the estimation process. The general structure of the CCE approach can be expressed as follows:

$$\gamma_{it} = \alpha_i' d_t + \beta_i' x_{it} + e_{it} \tag{12}$$

In equation (12), *d* represents the observable common factors, while *x* refers to the set of explanatory variables included in the model. The corresponding error component associated with this specification is expressed as follows in equation (13):

$$e_{it} = \gamma_i' f_t + \varepsilon_{it} \tag{13}$$

Finally, the Dumitrescu-Hurlin panel bootstrap causality test (Dumitrescu and Hurlin, 2012) is employed to identify causal relationships among the relevant variables. Dumitrescu and Hurlin's (2012) causality test yields accurate outcomes in unbalanced and heterogeneous panels, in cases of N > T or T > N, and CSD. Furthermore, this test addresses the limitations arising from the homogeneity assumption inherent in the standard Granger causality test (Dogan and Seker, 2016). The Dumitrescu-Hurlin panel bootstrap causality test is shown in equation (14):

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \tag{14}$$

4. Empirical Findings

In this section of the study, detailed information on the observation numbers, mean, minimum, and maximum values of the variables and standard deviations of the variables employed in the analysis are summarized as descriptive statistics in Table 2.

Table 2. Descriptive Statistics of Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
REC	320	25.55125	20.87426	0.4	75.9
TI	314	11874.96	36110.52	16	186245
FGI	320	46.75625	13.91116	10	76
WUI	320	0.0068281	0.005833	0.001	0.019
TO	320	56.9812	28.87786	18.88983	186.6758

To identify the magnitude and strength of the relationship between two variables and to reveal the direction of the relationship between the variables, the two-way correlations for the variables employed in the analysis are given in Table 3. In bivariate correlations, a coefficient value closer to 1 indicates a stronger relationship, whereas a coefficient value closer to 0 reflects a weaker relationship.

Table 3. Correlation Matrix

	REC	TI	TO	FGI	WUI
REC	1.0000				
TI	-0.3651	1.0000			
TO	-0.0137	0.2045	1.0000		
FGI	0.1577	0.1833	0.4118	1.0000	
WUI	-0.5830	0.5503	0.0182	0.3518	1.0000

Pesaran (2006) emphasized that substantial bias and size distortions result if CSD is omitted. Thus, the existence of CSD should be tested before analysis. The results of the CSD tests, including the Breusch-Pagan LM, Pesaran scaled LM, bias-corrected scaled LM, and Pesaran CD tests, are presented in Table 4. Empirical results indicate that the H_0 hypothesis of CSD is rejected at the 1% significance level for all variables in the tests, confirming the presence of CSD among all variables. This implies that shocks occurring in one of the Next-11 countries are likely to propagate to the others. Therefore, as noted in Usman et al. (2022), when CSD exists among variables, second-generation techniques yield reliable, robust, efficient, and consistent results.

Table 4. Cross-Sectional Dependence Tests Results

Variable	Breusch-Pagan LM	p-value	Pesaran scaled LM	p-value	Bias-corrected Scaled LM	p-value	Pesaran CD	p-value
REC	774.5055	0.0000	75.84254	0.0000	75.68125	0.0000	16.88781	0.0000
TI	801.9783	0.0000	78.73842	0.0000	78.57713	0.0000	27.29132	0.0000
FGI	372.4121	0.0000	33.45817	0.0000	33.29688	0.0000	2.850064	0.0044
WUI	903.0815	0.0000	89.39564	0.0000	89.23435	0.0000	25.92351	0.0000
TO	295.7571	0.0000	25.37803	0.0000	25.21674	0.0000	3.761934	0.0002

The stationarity of data has been investigated by conducting a unit root test. Several approaches for testing stationarity have been documented in the literature. Panel unit root tests are classified into first- and second-generation categories. The test results so far points to CSD and heterogeneity. In this situation, first-generation panel unit root tests may fail to yield reliable results due to their low statistical power. To resolve this issue and account for CSD, we employed the second-generation Cross-Sectionally Augmented Dickey-Fuller (CADF) unit root test, developed by Pesaran (2007). The results of CADF unit root test are reported in Table 5. The results of this test confirm that the levels of all series (I(0)) are not stationary; however, after taking the first differences, all series become stationary at the I(1) level. Therefore, it is appropriate to examine the long-term equilibrium relationship among the series.

Table 5. CADF Unit Root Test Results

Level	**Constant**		**Constant & Trend**	
Variables	**Stat**	**Prob.**	**Stat**	**Prob.**
REC	0.9018	0.1408	0.2701	0.3825
TI	0.7063	0.7013	0.0001	0.6075
FGI	0.2679	0.5187	0.0333	0.8864
WUI	0.8078	0.3104	0.0987	0.4748
TO	0.1128	0.1759	0.0384	0.3988
First Difference	**Constant**		**Constant & Trend**	
Variables	**Stat**	**Prob.**	**Stat**	**Prob.**
REC	0.0000	0.0002***	0.0001	0.0014***
TI	0.0040	0.0169**	0.0003	0.0658*
FGI	0.0007	0.0011***	0.0043	0.0050***
WUI	0.2255	0.0431**	0.5293	0.3189
TO	0.0000	0.0001***	0.0000	0.0010***

Note: (*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%

Based on the CSD and stationarity findings, the long-term equilibrium relationship between the series was tested using Westerlund and Edgerton's (2007) Panel LM bootstrap cointegration test. The bootstrap p-value should be considered due to the presence of CSD among the series. Since the bootstrap p-value in the model exceeds 0.10, the null hypothesis (H_0) of the Westerlund and Edgerton's (2007) Panel LM bootstrap test is not rejected. The results presented in Table 6 indicate the existence of a cointegration relationship.

Table 6. Westerlund-Edgerton's LM Bootstrap Cointegration Test Results

Test	**LM Statistics**	**Asymptotic-p Value**	**Bootstrap-p Value**
LM_N^+	13.29	0.0005	0.809

In panel regression, while examining the relationship between multiple independent variables and the dependent variable, all independent variables potentially exhibiting interdependencies. The interdependencies lead to the standard least squares estimator to develop biases and in efficiencies (Xu and Lieuea, 2025). These problems are addressed through the implementation of CCEs that account for correlation (Westerlund, 2007). Their estimator (CCE) can generate more accurate standard errors for coefficients without any loss of efficiency in practical research settings. CCEs serve to adjust the standard error estimates of parameter coefficients by accounting for correlations among data observations. This approach aims to improve the accuracy of both estimated coefficients and standard errors, thereby enhancing their reliability (Persyn and Westerlund, 2008). CCEs are based on the assumption that the errors are independently and normally distributed, conditional on the other panel variables. The standard errors are adjusted by a factor that accounts for interdependence among observations, regardless of whether the researcher chooses method A or B (Xu and Lieuea, 2025). This procedure enhances the accuracy and reliability of the estimated coefficients, allowing for more robust and dependable inferential conclusions.

The CCE results presented in Table 7 indicate that renewable energy consumption (REC) is influenced by several economic and global variables in different directions. Technological innovation (TI) exhibits a negative and statistically significant relationship with REC, suggesting that increases in innovation are associated with lower levels of renewable energy use. Financial globalization (FGI), on the other hand, has a positive and significant effect on REC, implying that greater financial integration supports the uptake of renewable energy. The World Uncertainty Index (WUI) also shows a negative and significant impact, indicating that rising global uncertainty tends to reduce REC. Although the coefficient of trade openness (TO) is negative, it is not statistically significant, and therefore no meaningful inference can be drawn. Overall, the results suggest that REC is particularly sensitive to changes in financial integration and global stability indicators.

Table 7. Common Correlated Effects (CCE)

REC	Coefficient	Std. Err	z	P>|z|
TI	-0.00316	0.00021	-2.125	0.035
FGI	0.06142	0.02542	2.654	0.012
WUI	-2.2542	2.0548	-4.326	0.000
TO	-0.00952	0.00258	-0.684	0.458
C	1.2195	1.02148	3.255	0.000

The CCE estimation results present a framework that is broadly consistent with the dominant empirical findings in the literature. In particular, the positive and statistically significant effect of financial globalization on renewable energy consumption aligns with studies emphasizing that financial integration facilitates access to capital and thereby encourages investments in renewable energy (Doytch and Narayan, 2016; Majeed et al., 2022; Chen and Zhang, 2023). This finding supports the view that external financing channels play a critical role in the energy transition, especially in developing economies. Similarly, the negative effect associated with global uncertainty is in line with prior research highlighting the discouraging role of uncertainty through heightened risk perceptions and delayed investment decisions (Shafiullah et al., 2021; Zhang et al., 2021; Su et al., 2022; Borozan, 2022). These results reinforce the importance of a stable and predictable macroeconomic environment for renewable energy dynamics.

The findings related to technological innovation also fit within strands of the literature that report conditional and country specific effects. Although many studies document a positive link between innovation and renewable energy outcomes, it has been widely acknowledged that the magnitude and even the direction of this relationship may vary depending on structural characteristics, the composition of technological progress, and time specific factors (Jin et al., 2018; Khan et al., 2022). From this perspective, the estimated effects do not contradict the broader empirical evidence but rather underscore the role of economic structure and technology orientation. The statistically insignificant impact of trade openness similarly corresponds with empirical contributions suggesting that the trade–energy nexus is not uniform across countries. Overall, the results highlight the central importance of financial integration and uncertainty channels in shaping renewable energy consumption patterns, in a manner that remains consistent with the existing literature.

Finally, the causal relationships among the variables were examined. The Dumitrescu-Hurlin panel bootstrap causality test defines two standardized test statistics: A test statistic based on the exact asymptotic movements of individual Wald statistics and a test statistic based on the approximate movements for finite T samples (Dumitrescu and Hurlin, 2012). When Table 8 is evaluated, there is a bidirectional causality relationship between REC and both TI and WUI, while there is a unidirectional causality relationship between REC and both FGI and TO. It is observed that the bidirectional causality between REC and TI is aligned with the studies of Wen et al. (2022), Xinyu et al. (2025), and Han et al. (2025). A bidirectional causality relationship between REC and WUI appears to be consistent with the results of Qamruzzaman (2024) for ABD and China economies, Zhang et al. (2021) for the BRIC economies, and Su et al. (2022) for the G7 economies. A unidirectional causality relationship between REC and FGI is consistent with the studies Jóźwik et al. (2025), Alam et al. (2024), however, it is not compatible with the study of Fan and Usman (2025), which found bidirectional causality. A unidirectional causality relationship between REC and TO appears to be consistent with the results of Jóźwik et al. (2025), and Zeren and Akkuş (2020).

Table 8. Dumitrescu-Hurlin Panel Causality Tests

Null Hypothesis	W-Statistic	Zbar-Statistic	Prob.	Causality
REC→TI	3.98663	5.67379	0.0000	Yes
TI→REC	2.61829	3.00384	0.0027	Yes
REC→FGI	2.36981	2.53096	0.0114	Yes
FGI→REC	1.71462	1.24835	0.2119	No
REC→WUI	3.75726	5.24704	0.0000	Yes
WUI→REC	2.56573	2.91448	0.0036	Yes
REC→TO	1.51320	0.85406	0.3931	No
TO→REC	1.97769	1.76334	0.0778	Yes

5. Conclusion

The empirical findings for the Next-11 countries indicate that renewable energy consumption is shaped by a complex and multilayered interaction of macroeconomic, financial, and technological factors. In this respect, the results are broadly consistent with certain expectations commonly emphasized in the literature, while also pointing to specific divergences that require careful interpretation. In particular, the negative and statistically significant effect of technological innovation on renewable energy consumption does not fully align with the dominant view that innovation directly accelerates the energy transition. However, rather than weakening the theoretical importance of innovation, this outcome highlights the critical role of the direction, quality, and sectoral allocation of innovative activities.

From the perspective of Schumpeterian innovation theory, technological progress is regarded as a fundamental driver of structural transformation and long-term productivity gains. Yet, in developing and structurally transforming economies, innovation efforts may not necessarily be concentrated in energy efficiency or clean energy technologies. Instead, innovation may be directed toward expanding output or supporting conventional sectors, which can increase overall energy demand or reinforce fossil fuel-intensive production structures in the short run. Within this context, the negative relationship observed in the Next-11 countries suggests that technological innovation may not be sufficiently oriented toward renewable energy systems. Consequently, the findings underscore the context-dependent nature of innovation effects and demonstrate that technological advancement cannot be evaluated independently of countries' economic structures and institutional settings.

The positive and statistically significant impact of financial globalization on renewable energy consumption, by contrast, is more closely aligned with theoretical expectations. Greater financial integration can ease capital constraints and facilitate investment flows, particularly for renewable energy projects that are typically characterized by high initial costs. This result supports the view that international financial linkages may play a complementary role in the energy transition. Nevertheless, the effects of financial globalization should not be considered uniform across countries. The sectoral allocation of financial inflows, along with institutional quality and financial stability conditions, remains decisive in determining whether financial integration ultimately promotes sustainable energy outcomes.

The results related to uncertainty further reveal the sensitivity of renewable energy consumption to macroeconomic and global stability conditions. The negative influence of rising uncertainty is consistent with theoretical arguments emphasizing risk perception and the partially irreversible nature of long-term investments. Renewable energy projects, given their capital-intensive structure and extended payback periods, are particularly vulnerable to heightened uncertainty. This finding illustrates that the dynamics of renewable energy adoption are shaped not only by technological and financial factors but also by broader expectations, confidence, and stability considerations.

Taken together, the findings provide a contextually grounded contribution to the literature on the determinants of renewable energy consumption. In heterogeneous and structurally evolving economies such as the Next-11 countries, variables that are theoretically expected to exert positive effects may generate different outcomes depending on economic and institutional conditions. This observation highlights the limitations of universal generalizations and confirms that renewable energy dynamics must be evaluated within the specific structural characteristics and development trajectories of country groups.

5.1. Policy Implication

From a policy perspective, these empirical results underscore several implications. First, the findings indicate that a multidimensional approach is required to enhance renewable energy utilization in Next-11 economies. Policymakers should prioritize ensuring the stability of macroeconomic conditions to reduce uncertainty and create the groundwork for renewable energy investments. Long-run renewable energy targets should be supported with transparent and stable rules that minimize risk for investors. The pronounced negative effect of the WUI on REC suggests that periods of volatility or policy inconsistencies may significantly hinder the diffusion of renewable energy. Regulatory frameworks should encourage transparency, accountability, and sustainability metrics for financial products, which will increase investor confidence. Second, the positive effect of financial globalization implies that deeper integration into global financial markets may facilitate access to the capital, technology, and expertise required for renewable energy infrastructure. Therefore, the establishment of green bond markets, sustainability-linked credit mechanisms, and international investment partnerships should be prioritized. Moreover, although technological innovation currently exhibits a negative relationship with REC, this may reflect a structural lag in the diffusion of clean technologies. Therefore, policies that promote R&D and tax incentives in renewable energy systems, patent support, technology transfer, and innovation are crucial to reversing this trend. The development of a strong green finance ecosystem is another critical pillar policymakers need to set the stage to enable climate finance to thrive through supportive instruments, including green bonds, sustainable infrastructure funds, and concessional finance facilities for renewable energy.

Third, governments should direct R&D incentives, technology transfer programs, and innovation subsidies towards clean energy production and storage technologies. Finally, the weak but negative linkage between trade openness and REC indicates that trade liberalization alone does not guarantee the diffusion of green energy. Increasing trade openness promotes REC and facilitates access to high-technology products, thereby potentially contributing to the strengthening of policy measures aimed at enhancing energy efficiency. Furthermore, strengthening trade ties with countries that have demonstrated successful performance in renewable energy can enable this transformation process to occur more rapidly. Incorporating environmental standards into trade agreements and promoting the exchange of renewable technologies can ensure that trade openness supports sustainable development rather than reinforcing dependence on fossil fuels. In conclusion, it is emphasized that financial globalization, technological progress, and macroeconomic stability are interrelated dimensions of the transition to renewable energy. Therefore, to ensure a sustainable energy transition in Next-11 countries, a comprehensive policy framework integrating macroeconomic stability, green finance, and technology-focused industrial strategies is required to accelerate the adoption of renewable energy and strengthen long-term energy security.

5.2. Limitations and Future Research

Although this study provides significant insights into the economic, financial, and technological dynamics influencing renewable energy consumption, it also has certain limitations. The analysis focuses on average effects across countries; however, it does not fully capture the unique political, institutional, and structural characteristics of each nation. In particular, differences in energy policies, regulatory frameworks, and institutional capacities play a critical role in shaping the transition to renewable energy. Therefore, future studies that incorporate country-specific microdata, policy indicators, and sectoral energy efficiency measures could enhance the depth and contextual accuracy of the findings.

Furthermore, the study examines the determinants of renewable energy consumption but does not account for the possible mutual interactions and feedback mechanisms among these factors. For instance, while technological innovation may influence renewable energy consumption, increased adoption of renewable energy could, in turn, stimulate innovation. Future research should therefore develop structural models that address such bidirectional relationships, providing a more comprehensive understanding of energy transition processes.

In addition, analyzing trade openness only in aggregate form may overlook the distinct impacts of exports and imports on renewable energy consumption. Differentiating these effects could contribute to the development of more targeted policy implications within the context of global value chains and green trade policies. Finally, incorporating variables such as environmental uncertainty, green finance opportunities, and carbon pricing mechanisms in future studies would allow for a more holistic evaluation of the effectiveness of renewable energy policies.

Declaration of Research and Publication Ethics
This study which does not require ethics committee approval and/or legal/specific permission complies with the research and publication ethics.

Researcher's Contribution Rate Statement
I am a single author of this paper. My contribution is 100%.

Declaration of Researcher's Conflict of Interest
There is no potential conflicts of interest in this study.

Declaration of Artificial Intelligence Usage
The author did not use any artificial intelligence tools during the preparation of this manuscript.

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