Energy Engineering

Tech Science Press

http://doi.org/10.32604/ee.2026.084804

ARTICLE

Energy Consumption, Renewable Energy and Economic Growth: The Case of BRICS Countries

Perihan Hazel Kaya[1,*], Coşkun Kuş[2], Mustafa Çoklu[3] and Mustafa Göktuğ Kaya[4]

[1]Department of Economics, Selçuk University, Konya, Türkiye
[2]Department of Statistics, Selçuk University, Konya, Türkiye
[3]Department of Economics, Institute of Social Sciences, Selçuk University, Konya, Türkiye
[4]Presidency of Tax Inspection Board, Ministry of Treasury and Finance, Ankara, Türkiye
*Corresponding Author: Perihan Hazel Kaya. Email: perihaner@selcuk.edu.tr

Received: 06 May 2026; Accepted: 16 June 2026; Published: 30 August 2026

ABSTRACT: This study examines the relationship between energy consumption, renewable energy supply, and economic growth in BRICS countries over the period 2000–2023 within the framework of panel data analysis. In the analysis, economic growth is represented by gross domestic product, while total energy consumption and renewable energy supply are used as the main energy-related variables. The study contributes to the literature by evaluating the energy-growth nexus together with both total energy use and renewable energy dynamics in BRICS economies. Since BRICS countries may be affected by common global shocks, cross-sectional dependence is considered in the empirical framework. The stationarity properties of the variables are examined, and it was determined that all series become stationary after taking first differences. The residual-based panel cointegration test does not indicate a long-run equilibrium relationship among the variables. Therefore, the analysis focuses on short-run dynamics using first-difference panel models rather than long-run equilibrium effects. The findings show that renewable energy supply positively affects total energy consumption in the short run, while economic growth is associated with higher energy demand. The Dumitrescu-Hurlin panel causality results indicate a unidirectional causal relationship from renewable energy supply to energy consumption and from energy consumption to economic growth. Consequently, energy consumption continues to play a significant role in short-term economic growth in BRICS countries, while renewable energy investments indirectly support growth by expanding total energy supply. These findings suggest that sustainable growth policies should combine renewable energy expansion with energy efficiency, grid modernization, and demand-side management strategies.

KEYWORDS: Energy consumption; renewable energy; economic growth; BRICS; panel data; Driscoll-Kraay standard errors; panel Granger causality

JEL Classification: C23; O13; Q42; Q43

1 Introduction

Energy is an indispensable input for the sustainability of economic activities and the continuity of production processes. While industrialization, technological progress, urbanization, and population growth continuously increase countries' energy demand, the relationship between energy consumption and economic growth has long been a central topic of debate in the economic literature. This situation demonstrates that energy resources are of critical importance for the continuation of economic activities.

For this reason, energy is regarded not merely as an intermediate input but also as a strategic determinant of economic growth. However, there is no complete consensus in the literature regarding the direction and nature of the relationship between energy consumption and economic growth. The validity of energy-growth hypotheses varies depending on country groups, types of energy used, time periods, and econometric methods. Consequently, the energy-growth relationship exhibits a contextual structure rather than a universal one. In traditional studies, energy consumption has mostly been addressed through the lens of fossil fuels and evaluated as a factor supporting economic growth. However, the fossil fuel-based growth model has resulted in problems such as rising carbon emissions, environmental degradation, climate change, and energy supply security. These developments have made it imperative that energy policies be designed not only to support growth but also to prioritize environmental sustainability. In this context, renewable energy sources have come to the forefront due to their potential to reduce environmental impacts and ensure long-term energy supply security.

The relationship between renewable energy consumption and economic growth has been the subject of increasing attention in the literature in recent years. It has been argued that renewable energy consumption can support economic growth by contributing to cleaner energy use, energy security, and sustainable development [1]. However, the relationship between renewable energy and economic performance may vary depending on income levels, energy demand, and country-specific conditions [2]. This suggests that the relationship between renewable energy and growth is influenced by temporal and country-specific factors.

In the context of these discussions, the BRICS countries (Brazil, Russia, India, China, and South Africa) occupy a prominent position in the literature on energy and economic growth. BRICS economies account for a significant portion of global GDP and world energy consumption; at the same time, they are characterized by rapidly growing energy demand due to rapid industrialization, urbanization, and population growth. However, the BRICS countries are quite heterogeneous in terms of their energy supply structures. While Russia and Brazil are in a relatively advantageous position in terms of energy resources, China and India have high energy import dependencies. This heterogeneous structure leads to variations in the effects of energy consumption and renewable energy use on economic growth across countries [3]. Empirical studies on BRICS countries indicate the existence of long-term relationships between renewable energy consumption and economic growth; however, no consensus has yet been reached regarding the direction and strength of this relationship. For example, while some studies demonstrate that renewable energy consumption supports economic growth, others show that this effect may vary by country [1,4]. Furthermore, it is observed that many studies cover relatively short time periods and do not sufficiently account for the issue of cross-sectional dependence that may arise due to global shocks [5]. BRICS countries may be simultaneously affected by global commodity prices, fluctuations in energy markets, financial crises, and international regulations regarding climate policies. This situation leads to a weakening of the assumption of independence among countries in panel data analyses. Therefore, in analyzing the relationship between energy consumption, renewable energy, and economic growth, the use of panel methods that account for cross-sectional dependence is important for the reliability of the results obtained.

The primary objective of this study is to empirically examine the effects of energy consumption and renewable energy use on economic growth in BRICS countries during the 2000–2023 period. The study tests prominent hypotheses from the energy-growth literature specifically for BRICS countries, while addressing both short- and long-term dynamics. Furthermore, the study tests for cross-sectional dependence and uses robust standard errors in the final fixed-effects specification. In these respects, the study aims to make original contributions to the literature by (i) covering a current and long time span for BRICS countries, (ii) analyzing energy consumption and renewable energy together, and (iii) accounting for cross-sectional dependence in the empirical framework. The findings are expected to guide policy design for sustainable growth and energy transition in BRICS countries. During the manuscript preparation process, AI-assisted tools were used for language editing and R coding support.

2 Literature Review

The relationship between energy consumption and economic growth has been one of the central areas of research in the economic literature for many years. This relationship has been extensively studied from both theoretical and empirical perspectives, particularly due to the central role of energy use in production processes. Energy is not merely a production input but also a critical determinant of the sustainability of economic activities.

According to the growth hypothesis, energy consumption is the primary determinant of economic growth. In this context, an increase in energy supply supports economic growth by expanding production capacity. In contrast, the conservation hypothesis argues that economic growth increases energy demand. The feedback hypothesis, on the other hand, argues that there is a bidirectional relationship between energy consumption and economic growth. The neutrality hypothesis, meanwhile, suggests that there is no significant relationship between the two variables.

Initial studies largely focused on the relationship between total energy consumption and economic growth. Particularly during periods when the energy mix was dominated by fossil fuels, it was found that increases in energy consumption were strongly correlated with increases in production and income. However, as environmental issues have escalated, carbon emissions have posed a global threat, and sustainable development goals have come to the forefront, interest in renewable energy sources has grown in the literature. In this context, the impact of renewable energy consumption on economic growth has emerged as a distinct area of research [1]. Recent studies have shown that renewable energy is playing an increasingly important role in promoting sustainable economic growth, particularly in developing economies. Expanding renewable energy capacity contributes not only to environmental sustainability but also to energy security and economic resilience against external shocks. Furthermore, renewable energy investments support economic development by creating jobs, fostering technological innovation, and reducing dependence on energy imports [6,7].

These developments have heightened academic interest in the effects of energy consumption on economic growth and have led to a significant increase in the number of studies focusing specifically on the role of renewable energy sources. While traditional studies have primarily focused on total energy consumption and fossil fuel use, the consumption of renewable energy has gained increasing prominence in the literature amid growing environmental concerns and discussions on climate change. Studies on the effects of renewable energy on economic growth generally indicate a positive relationship, although the strength of this effect may vary across countries and empirical settings [4]. Empirical studies focusing specifically on BRICS countries support the existence of long-term relationships between renewable energy consumption and economic growth; however, they yield differing results regarding the direction and magnitude of these relationships. Some studies indicate that renewable energy supports growth and that there is bidirectional causality between the variables [3], while others highlight heterogeneous results across countries. This situation can be attributed to the differences in the energy supply structures and economic characteristics of the BRICS countries.

Recent studies continue to provide evidence supporting the role of renewable energy in promoting sustainable economic growth. A systematic literature review concluded that renewable energy consumption generally contributes positively to economic growth, although the magnitude of the effect differs across countries and development levels [8].

More recent evidence from BRICS economies indicates that renewable energy investments and green energy adoption not only stimulate economic performance but also contribute to environmental sustainability and employment generation [9].

Furthermore, studies employing advanced panel data techniques that account for cross-sectional dependence report that different forms of energy consumption maintain significant long-run relationships with economic growth in BRICS countries, highlighting the importance of energy transition policies for sustainable development [10].

On the other hand, a significant methodological issue in the literature is that cross-sectional dependence is often overlooked in panel data analyses. Global energy prices, financial crises, and common policy shocks increase inter-country dependence, particularly in integrated economies such as the BRICS countries. Consequently, panel data studies should account for cross-sectional dependence, particularly when countries may be affected by common shocks [5]. While the literature generally demonstrates that energy consumption and the use of renewable energy are closely linked to economic growth, it also indicates that comprehensive studies on BRICS countries, utilizing long-term, up-to-date data and accounting for cross-sectional dependence, are limited. This study aims to fill this gap by analyzing the relationship between energy consumption, renewable energy, and economic growth in BRICS countries within an up-to-date panel framework that considers cross-sectional dependence.

A significant portion of early research addressed energy consumption primarily in terms of total energy use or fossil fuel consumption. In this context, energy consumption has been regarded as a critical factor in sustaining economic activities and supporting production processes. A significant portion of empirical findings indicates that, particularly in developing economies and those accelerating their industrialization processes, increases in energy consumption expand production volumes, support total factor productivity, and provide indirect contributions to trade capacity. However, it is acknowledged that the relationship between energy consumption and growth is not merely a matter of quantitative increase but is also influenced by variables such as the continuity of energy supply, price stability, the degree of external dependence, and energy intensity. For this reason, it is noted that an increase in energy consumption does not always generate growth to the same extent; while it may enhance productivity in some countries, in others it can limit growth through cost pressures, import dependency, and current account balance issues.

As discussions on environmental degradation, climate change, carbon emissions, and sustainable development have intensified, the literature has begun to focus not only on total energy consumption but also on the composition of energy consumption. This shift has led to a rapid increase in studies examining the impact of renewable energy sources on economic growth. Sources such as solar, wind, hydroelectric, biomass, and geothermal energy are viewed not only as alternatives that reduce environmental costs but also as factors that enhance energy supply security, create new investment opportunities, generate employment, and promote technological innovation. In this context, the impact of renewable energy use on economic growth is explained primarily through three channels. First, renewable energy investments generate direct economic activity through infrastructure, engineering, equipment production, and maintenance activities. Second, they can have a positive impact on the current account balance by reducing reliance on energy imports. Third, by facilitating the transition to a low-carbon production structure, they align with long-term sustainable growth strategies. The introduction and literature review sections of the current study also emphasize that renewable energy investments can support growth through mechanisms such as employment, technology transfer, innovation, and the reduction of energy import dependency.

However, it cannot be said that the relationship between renewable energy and economic growth is linear or always positive. The literature also indicates that renewable energy projects can have a constraining effect on growth, particularly in the short term, due to high fixed investment costs, technology imports, storage limitations, grid integration issues, and supply discontinuities. Especially in developing countries, high financing costs can cause renewable energy projects to impose an additional burden on the public budget or the private sector in the initial stages. Furthermore, the contribution of renewable energy investments to growth depends not only on increases in installed capacity but also on the efficiency of that capacity, the success of its integration into the grid system, the level of domestic technology development, and the consistency of energy policies. Consequently, the literature includes studies that argue renewable energy supports growth, as well as those that contend the effect may weaken depending on the country, time period, and policy framework. This situation demonstrates that the energy-growth relationship, particularly in the context of renewable energy, is dynamic, multi-layered, and sensitive to country-specific conditions.

2.1 The Relationship between Energy Consumption and Economic Growth

The relationship between energy consumption and economic growth is regarded in the economic literature as one of the fundamental dynamics of production processes. Energy serves as a complementary factor that enhances the efficiency of production factors such as capital and labor, and plays a critical role in the sustainability of economic activities. The increase in energy demand resulting from industrialization, technological advancements, and urbanization has become one of the key determinants of economic growth. In this context, studies examining the direction and nature of the relationship between energy consumption and economic growth occupy a significant place in both theoretical and empirical literature.

In the literature, the relationship between energy consumption and economic growth is generally addressed within the framework of four main hypotheses: the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis. According to the growth hypothesis, energy consumption is the primary driving force of economic growth, and an increase in energy supply directly boosts production capacity. This approach finds particularly strong support in developing countries. In contrast, the conservation hypothesis argues that economic growth increases energy demand. The feedback hypothesis posits a bidirectional relationship between energy consumption and economic growth, while the neutrality hypothesis states that there is no significant relationship between the two variables.

Empirical studies show that the relationship between energy consumption and economic growth varies across country groups. In particular, the impact of energy consumption on economic growth appears to be more pronounced in developing countries. The primary reason for this is that production processes in these countries rely heavily on energy-intensive sectors, and increases in energy supply directly expand production capacity.

The impact of energy consumption on economic growth is significant not only in terms of quantity but also in terms of the composition of energy sources. While energy consumption based on fossil fuels can support production growth in the short term, it may lead to problems such as environmental costs and external dependency in the long term. Conversely, factors such as energy supply security, price stability, and sustainability are among the key elements determining the impact of energy consumption on economic growth.

When examined specifically in the context of the BRICS countries, the relationship between energy consumption and economic growth exhibits a more complex structure. While these countries have high growth rates, they are also among the economies with rapidly increasing energy demand. While rapid industrialization in countries like China and India drives up energy consumption, the abundance of energy resources in countries such as Russia and Brazil provides a significant advantage that supports economic growth. However, this heterogeneous structure leads to variations in the effects of energy consumption on economic growth across countries.

Methodological approaches are also of great importance in analyzing the relationship between energy consumption and economic growth. In particular, with the increasing use of panel data analysis, more comprehensive results can be obtained for different groups of countries. However, since factors such as global economic shocks, fluctuations in energy prices, and financial crises can affect countries simultaneously, the issue of cross-sectional dependence arises in panel data analyses. This situation renders traditional analytical methods inadequate and necessitates the use of more advanced econometric methods [5].

In conclusion, the relationship between energy consumption and economic growth is dynamic and multidimensional, varying according to country-specific conditions, rather than being a one-way, static relationship. While the role of energy consumption in supporting economic growth is particularly pronounced in developing countries, the direction and strength of this relationship vary depending on factors such as energy policies, economic structure, technological level, and external dependence. Therefore, a comprehensive analysis of the relationship between energy consumption and economic growth is of great importance for the formulation of sustainable development policies.

2.2 Renewable Energy and Economic Growth

The relationship between renewable energy and economic growth has been a subject of intense scrutiny in the economic literature, particularly as sustainable development goals have come to the forefront over the past two decades. The environmental costs of fossil fuels, carbon emissions, and energy supply security issues have driven countries toward alternative energy sources, making the study of renewable energy's impact on economic growth even more critical.

From a theoretical perspective, there are various channels through which the use of renewable energy can support economic growth. First, investments in renewable energy promote economic growth by increasing physical capital accumulation. In particular, solar, wind, and hydroelectric energy projects contribute directly to the economy through infrastructure investments and technology development activities. In this context, previous studies have demonstrated that the impact of renewable energy consumption on growth is particularly pronounced in developing countries [1]. Furthermore, empirical evidence suggests that investments in renewable energy technologies stimulate economic activity through job creation, technological innovation, and infrastructure development. In this regard, renewable energy has become a strategic component of long-term growth policies in developing countries [8].

Second, the renewable energy sector supports economic growth through its capacity to create jobs. The construction, operation, and maintenance of energy production facilities increase labor demand and raise income levels. Furthermore, as this sector requires high technology and innovation, it contributes to the development of the knowledge economy. This helps increase total factor productivity in the long term and ensures sustainable growth.

Thirdly, the use of renewable energy strengthens macroeconomic stability by reducing dependence on energy imports. Particularly in energy-importing countries, indirect effects on economic growth emerge through the reduction of the trade deficit, the stabilization of exchange rates, and the improvement of the current account balance. Previous research emphasizes that the use of renewable energy is closely associated with income dynamics and energy demand in emerging economies [2].

However, the literature frequently emphasizes that the relationship between renewable energy and economic growth is not always linear or strong. In particular, in the short term, the high initial costs of renewable energy investments, financing requirements, and infrastructure deficiencies can have a constraining effect on economic growth. This situation stems from the long payback periods of renewable energy projects and their initially low levels of efficiency. In this context, some studies indicate that renewable energy consumption may have neutral or weak effects on growth in the short term.

Additionally, the intermittent nature of renewable energy sources (such as the variability of solar and wind energy) can lead to fluctuations in energy supply, which may affect production processes. Therefore, the development of energy storage technologies and the strengthening of grid infrastructure are among the key factors determining the impact of renewable energy on economic growth.

A review of the empirical literature reveals that there is generally a long-term positive relationship between renewable energy consumption and economic growth. The empirical literature demonstrates that renewable energy consumption supports economic growth and that this relationship may become stronger in the long term [1,4]. However, some studies indicate that country-specific differences are pronounced, and the impact of renewable energy on growth varies depending on economic structure, energy policies, and the level of technological advancement.

Particularly when evaluated in the context of BRICS countries, the impact of renewable energy investments on economic growth exhibits a heterogeneous pattern. While the rapid increase in renewable energy investments supports growth in countries such as China and India, this effect is observed to be more limited in some countries. This situation stems from differences in countries' energy policies, financial capacity, and technological infrastructure.

In conclusion, the relationship between renewable energy and economic growth is multifaceted and dynamic. While the short-term effects may be limited due to cost and infrastructure constraints, in the long term, investments in renewable energy become a key driver of sustainable growth. Therefore, it is of great importance that renewable energy policies be designed in alignment with economic growth objectives.

2.3 Empirical Studies on BRICS Countries

The BRICS countries (Brazil, Russia, India, China, and South Africa) have been at the center of empirical studies examining the relationship between energy consumption and economic growth in recent years. These countries hold a special position in the energy-growth literature due to their rapid economic growth, rising energy demand, and pivotal roles in global energy markets. At the same time, these countries attract attention as developing economies striving to strike a balance between sustainable growth and environmental goals.

An examination of empirical studies on BRICS countries reveals that there is generally a long-term relationship between renewable energy consumption and economic growth. For example, one study on BRICS countries used ARDL and VECM methods to identify a long-term cointegration relationship among the variables [3]. Furthermore, the study demonstrates the existence of bidirectional causality (the feedback hypothesis) between renewable energy consumption and economic growth. Similarly, other empirical studies on BRICS countries also demonstrate strong links between energy consumption and economic growth. While studies based on panel data analysis reveal that energy consumption is a significant determinant of economic growth, some studies argue that economic growth increases energy demand. This suggests that both the growth hypothesis and the feedback hypothesis may hold true in the literature.

In this context, the growing interest in renewable energy in developing economies is noteworthy in terms of both economic growth and environmental sustainability. However, it is noteworthy that the impact of renewable energy consumption on economic growth is not homogeneous across BRICS countries. Differences in economic structures, energy supply diversity, levels of technological advancement, and energy policies among these countries are among the key factors determining the direction and strength of this relationship. For example, while renewable energy investments emerge as a key factor supporting economic growth in countries such as China and India, this effect appears to be more limited in some other BRICS countries. Recent studies have shown that renewable energy consumption affects not only economic growth but also environmental sustainability. In particular, models that take carbon emissions into account conclude that the use of renewable energy both supports economic growth and reduces environmental degradation. Indeed, empirical analyses show that an increase in renewable energy use has positive effects on GDP and facilitates a more efficient growth process compared to fossil fuels.

Furthermore, the literature emphasizes that multivariate models, which consider variables such as energy consumption, economic growth, trade openness, financial development, and capital, yield stronger results [11,12]. These studies reveal that there are not only direct but also indirect relationships between economic growth and energy consumption. For further recent BRICS-focused evidence on renewable energy consumption, economic risk, technological innovation, carbon emissions, and the broader energy-growth nexus, we refer to [13–17].

However, a significant limitation in the literature is noteworthy. A substantial portion of studies on BRICS countries rely on limited datasets or cover specific time periods. Furthermore, many studies do not sufficiently account for important methodological issues such as cross-sectional dependence and country heterogeneity. This limits the generalizability of the findings. Indeed, some studies emphasize that research on the relationship between renewable energy and economic growth in BRICS countries remains limited and that more comprehensive analyses are needed. In conclusion, empirical studies on BRICS countries generally reveal a significant relationship between renewable energy consumption and economic growth. However, the direction, strength, and dynamics of this relationship vary across countries. Therefore, it is of great importance to take into account both country heterogeneity and the impact of global shocks in analyses of BRICS countries. This study aims to contribute to the literature by addressing these gaps through the use of an up-to-date dataset and panel methods that account for cross-sectional dependence.

2.4 Gaps in the Literature

A review of the existing literature reveals that although significant findings have been obtained regarding the relationship between energy consumption, renewable energy, and economic growth, several gaps remain, particularly in the context of BRICS countries. First, many empirical studies on BRICS economies cover relatively short time periods and therefore do not fully reflect the recent expansion of renewable energy investments or the impact of global shocks, including the post-COVID-19 period. Second, a considerable part of the literature focuses either on total energy consumption or on renewable energy use separately, while studies that examine both variables together within a comprehensive framework remain limited. Third, although BRICS countries differ substantially in terms of energy supply structure, energy dependence, and economic development levels, some studies rely on homogeneous panel assumptions and do not sufficiently account for country heterogeneity. Fourth, common shocks such as global energy prices, financial crises, and climate-related policies may affect BRICS countries simultaneously; nevertheless, many studies do not adequately test or account for cross-sectional dependence. Finally, the distinction between short-run and long-run dynamics is not always clearly emphasized, despite the fact that renewable energy investments may generate cost pressures in the short run while supporting efficiency and growth in the longer run.

2.5 Original Contributions of the Study

This study aims to address the gaps in the literature identified above and offers several original contributions to the energy-growth literature. First, it uses a current and relatively long dataset covering the period from 2000 to 2023, thereby allowing the analysis to reflect recent developments in energy consumption and renewable energy use in BRICS countries. Second, the study adopts a holistic approach by examining total energy consumption and renewable energy consumption within the same empirical framework. Third, it accounts for cross-sectional dependence by explicitly testing for it and by reporting fixed-effects estimates with robust standard errors, which improves the reliability of statistical inference. Fourth, the study distinguishes between short-run and long-run dynamics by first testing for cointegration and then interpreting the final estimates within a first-difference short-run framework. Finally, the findings provide policy-relevant implications for BRICS countries by emphasizing the need to combine renewable energy expansion with energy efficiency, grid modernization, and demand-side management strategies.

3 Data and Variables

The dataset consists of a balanced panel covering Brazil, Russia, India, China, and South Africa. Annual observations from 2000 to 2023 were used for each country; thus, the panel comprises $N = 5$ countries and $T = 24$ years (a total of 120 observations). Since the BRICS group consists of five countries, the cross-sectional dimension of the panel is limited by design. Therefore, the empirical findings should be interpreted as average BRICS-level evidence rather than as country-specific estimates. The analysis includes three key variables obtained from the World Bank database. The first is the cons variable, representing total energy consumption measured in terawatt-hours (TWh). The second is the ren variable, representing renewable energy consumption. The third is the gdp variable, representing real gross domestic product measured in constant US dollars. The variables are used in their annual level values before the stationarity analysis, and no logarithmic transformation is applied. All series have been converted into a country-specific panel data format, and econometric tests were conducted using this structure.

In this study, the dependent variable is the annual change in energy consumption, defined as Δcons. The independent variables are modeled as the annual change in renewable energy supply (Δren) and the annual change in gross domestic product (Δgdp). These first differences are calculated as absolute annual changes, not as logarithmic differences. The use of absolute first differences is not merely an econometric choice; it also determines the interpretation of the analysis. For this reason, the study does not measure a long-term cointegrated equilibrium relationship but rather identifies which factors trigger increases in energy consumption in the short term. In other words, the coefficients obtained here capture the short-term dynamics of the energy transition. Accordingly, the estimated coefficients should be interpreted as short-run marginal changes rather than elasticities.

4 Stationarity and Cointegration

In econometric analysis, the risk of spurious regression is one of the most fundamental methodological issues [18]. If two or more variables increase together but there is no true causal or equilibrium relationship between them, ordinary level regressions can produce relationships that appear meaningful but are actually misleading. For this reason, the stationarity properties of the variables were tested in the first step. For this purpose, the Im, Pesaran, and Shin (IPS) panel unit root test was applied. The test results are reported in Table 1.

As shown in Table 1, the *p*-values for the level values of the energy consumption (cons), renewable energy (ren), and economic growth (gdp) variables were calculated as 0.4807, 1.0000, and 0.9160, respectively.

In the IPS test, the null hypothesis (the null hypothesis of the study) is that the series contains a unit root, meaning it is non-stationary. In the level series, these p-values are well above 0.05, and therefore, it is concluded that the level values are non-stationary. In contrast, the IPS test p-values for the first differences are 1.897×10^{-5} for the energy consumption difference, 0.08537 for the renewable energy difference, and 4.163×10^{-8} for the GDP difference. This result confirms that the first differences of the series have become stationary, meaning that all series are integrated of order I(1).

Table 1: Panel Unit Root Test Results (IPS).

Variable	Level p-Value	First-Difference p-Value	Interpretation
Energy Consumption (cons)	0.4807	$1.897 \times 10^{-5***}$	Not stationary in levels; stationary after first differencing
Renewable Energy (ren)	1.0000	0.08537^{*}	Not stationary in levels; stationary after first differencing
GDP	0.9160	$4.163 \times 10^{-8***}$	Not stationary in levels; stationary after first differencing

Note: In the IPS test, H0: "There is a unit root in the series", meaning that the series is not stationary. $^{***}p < 0.01$, $^{*}p < 0.10$.

The fact that the series are I(1), that is, they are not stationary at the level but become stationary at the difference, leads us to the next critical question: Is there a long-run equilibrium relationship among these variables? The answer to this question lies in cointegration analysis. If the variables move in tandem, that is, if there is a common long-run equilibrium mechanism among them, a model operating at the level can be economically interpreted. If no such equilibrium exists, the level regressions are likely to be spurious.

In this study, cointegration was tested by adapting the classical Engle-Granger approach to a panel context. First, a level equation was estimated for total energy consumption, renewable energy, and GDP.

Subsequently, the residuals from this regression were obtained, and their stationarity was tested using the IPS method. If these residuals are stationary (I(0)), the variables are cointegrated; that is, there is a long-run equilibrium relationship between them. The results of the IPS test applied to the residuals are reported in Table 2. The p-value obtained is 0.7531, which is well above the 0.05 threshold. This indicates that the null hypothesis of no cointegration cannot be rejected, and therefore, there is no long-run common equilibrium relationship between the variables. Accordingly, the subsequent empirical analysis is conducted using first-differenced variables, and the findings are interpreted as short-run dynamics rather than long-run equilibrium effects.

Table 2: Panel Cointegration Test (Engle-Granger-type residual IPS).

Test	Statistic (Wtbar)	p-Value
IPS residual test	0.68443	0.7531

H0: "The residuals are not stationary" ⇒ there is no cointegration.

This result is methodologically significant. For the BRICS countries, no statistically significant long-run co-integration mechanism can be observed between energy consumption, renewable energy, and economic growth. Therefore, interpreting "long-run coefficients" using level regression is unreliable and carries the risk of spurious regression. From this point onward, the analysis proceeds exclusively with first-difference data, that is, the short-term dynamic components of the variables. This also determines the policy implications of the findings: The relationships measured here represent short-term marginal effects.

5 Short-Run Causality: Panel Granger Causality Results

Since no long-run cointegration was found, the causality analysis was conducted using the stationary first differences. Directional causality relationships between the variables were estimated using the Dumitrescu-Hurlin panel Granger causality test. The null hypothesis of the test is that one variable does not predict the other; for example, "Δren is not a Granger cause of Δcons". Rejection of this hypothesis indicates the presence of the relevant Granger causality.

The causality test was applied separately for different lag lengths. First, a one-period lag structure (lag = 1) was tested, followed by a two-period lag structure (lag = 2). The lagged structure of the Dumitrescu-Hurlin test is used to examine predictive causality, that is, whether past values of one variable help explain another variable. In contrast, the fixed-effects regression reported later estimates contemporaneous short-run associations among first-differenced variables. Therefore, the causality test and the regression model serve complementary purposes rather than identical ones.

In the lag = 1 model, the relationship where changes in renewable energy supply predict changes in energy consumption was found to be statistically significant at the 5% level; however, the effect from energy consumption to economic growth remained significant only at a weak level. In the lag = 2 model, the statistical strength of the main causal relationships increased. Therefore, the causality results reported in Table 3 are based on the two-lag (lag = 2) model.

The results are presented in Table 3. A strong and statistically significant causal relationship was found from changes in renewable energy supply to changes in energy consumption. This result supports a one-way short-term effect in the direction of Δren → Δcons. In contrast, no causality was detected from energy consumption to renewable energy supply; this asymmetry suggests that renewable energy functions as a supply component that feeds the system, but that energy consumption shocks do not trigger renewable supply at the same rate.

Furthermore, a strong causal relationship was found from changes in energy consumption to changes in economic growth. According to the results presented in Table 3, Δcons is a statistically significant Granger cause of Δgdp (p-value at the 0.0001171 level). In contrast, no significant causality was detected from Δgdp to Δcons. This finding confirms that, in the short term, energy consumption acts as an input to economic growth.

Table 3: Results of the Panel Granger Causality Test (First Differences, lag = 2).

Hypothesis (H_0)	Z-Value	p-Value	Conclusion
Δren $\nrightarrow$ Δcons	2.6037	0.009223	H_0 is rejected; causality exists
Δcons $\nrightarrow$ Δren	0.7737	0.4391	H_0 cannot be rejected; there is no causality
Δgdp $\nrightarrow$ Δcons	−0.8417	0.4000	H_0 cannot be rejected; there is no causality
Δcons $\nrightarrow$ Δgdp	3.8522	0.0001171	H_0 is rejected; causality exists

H0: "There is no Granger causality." The symbol $\nrightarrow$ means "is not a Granger cause".

When these results are considered together, the short-term energy-growth mechanism for BRICS countries can be interpreted as follows: An increase in renewable energy supply is driving up total energy consumption; this rise in energy consumption, in turn, is supporting economic growth. This structure is consistent with the "growth hypothesis", which views energy consumption as the engine of growth. This finding yields a critical policy implication: Countries that view energy consumption as the fuel for economic activity may face growth-suppressing effects if they artificially curb energy demand in the short term.

6 Assumption Tests, Model Selection, and Analysis of Error Structure

This section accomplishes two tasks simultaneously: (i) it clearly identifies which panel model has been deemed reliable, and (ii) it tests whether the error structure of this model satisfies the classical assumptions. All panel estimations and diagnostic tests were conducted in R using the plm, lmtest, sandwich, and car packages. Panel unit root tests were implemented using the *purtest* function, panel Granger causality was tested using *pgrangertest*, cross-sectional dependence was examined using *pcdtest*, and Driscoll-Kraay standard errors were obtained using *vcovSCC*.

First, the model selection was conducted. In the panel regression based on the first difference, the dependent variable was Δcons, and the independent variables were Δren and Δgdp. Three standard comparisons were made regarding this model: (i) the Fixed Effects (FE) model versus Pooled OLS, (ii) the Random Effects (RE) model versus Pooled OLS, (iii) the RE model versus the FE model. The F-test clearly found the FE model to be superior to Pooled OLS (p-value = 3.583×10^{-14}). A Breusch-Pagan-type LM test also showed that the RE model is superior to pooled OLS (p-value 7.65×10^{-6}). Therefore, panel effects (country-specific fixed components) cannot be ignored.

The critical point is the Hausman test. The Hausman test directly compares the FE and RE estimators and answers the question, "Is the RE model consistent?" The output of the Hausman test was $\chi^2 = 92.479$, degrees of freedom 2, and a p-value $< 2.2 \times 10^{-16}$. This result indicates that the RE model is not consistent and should be rejected; conversely, the FE model is consistent. Therefore, the Fixed Effects (FE) model has been selected as the final estimator. This also necessitates that policy interpretations of the results be based on the FE model.

First, we examined whether there was excessive correlation among the explanatory variables. The correlation matrix created using first-difference data indicates a positive and strong relationship of 0.890 between the change in energy consumption (Δcons) and the change in renewable energy use (Δren). However, the variance inflation factor (VIF) values were found to be around 1.748. The fact that the VIF values are well below high thresholds such as 10 indicates that there is no serious multicollinearity problem. This confirms that the model coefficients are statistically significant and that the Δren and Δgdp variables do not overshadow one another.

Second, we tested for the presence of heteroskedasticity (varying variance) in the error terms. In the Breusch-Pagan test applied to the Fixed Effects model, the p-value of the statistic was calculated as 3.16×10^{-8}. This value is well below the 0.05 threshold and clearly indicates the presence of a non-constant variance structure in the error terms. In other words, the standard errors based on the classical (homoscedastic) assumption are unreliable.

Third, the panel error terms were tested for serial correlation (autocorrelation). In the Breusch-Godfrey/Wooldridge-type panel serial correlation test, the p-value was found to be 0.0002883. This indicates that the error terms are not independent over time; past errors are related to current errors. The correlation of residuals over time further reduces the reliability of standard OLS-based standard errors.

Finally, cross-sectional dependence was tested. The results of the Pesaran CD test (z-statistic 3.4614, p-value 0.0005374) indicate that the error terms of the BRICS countries are not independent of one another, meaning that common shocks or spillover effects were found among the countries. This result is also economically meaningful: major energy price shocks, global energy supply conditions, or geopolitical developments typically affect these countries collectively. Therefore, it is clear that they do not behave like independent economies. All of these tests are summarized in Table 4.

Table 4: Summary of Hypothesis Testing and Diagnostic Tests.

Test	Statistic	*p*-Value	Conclusion
Correlation (Δcons, Δren)	0.890	-	Highly correlated relationship
VIF (Δren, Δgdp)	1.748	-	No serious multicollinearity problem
Breusch-Pagan (heteroscedasticity)	34.543	3.16×10^{-8}	There is heteroscedasticity
Breusch-Godfrey/Wooldridge (serial correlation)	53.765	0.0002883	There is serial correlation
Pesaran CD (cross-sectional dependence)	3.4614	0.0005374	There is interdependence among countries

Note: All results were obtained using first differences.

In light of these findings, it is clear that interpretations based on classical standard errors cannot be relied upon. The simultaneous presence of heteroscedasticity, serial correlation, and cross-sectional dependence implies that ordinary standard errors may be systematically biased (mostly overly optimistic). Therefore, the study bases its final interpretations on results obtained using robust standard errors of the Driscoll-Kraay (SCC) type on the Fixed Effects model. The Driscoll-Kraay covariance estimator provides standard errors that are robust to heteroscedasticity, autocorrelation, and cross-sectional dependence. This correction affects the estimated standard errors and significance levels, but not the coefficient estimates themselves. Consequently, Table 5 should be considered the study's primary regression output for policy reporting purposes.

Table 5: Final Fixed Effects (FE) model. Dependent variable: Change in energy consumption (Δcons). Standard errors: driscoll-kraay (SCC).

Variable	Coefficient	Std. Errors (SCC)	t-Statistic	*p*-Value
Δren	0.989	0.475	2.082	0.0397
Δgdp	0.107	0.037	2.851	0.0052

Note: Country-specific fixed effects are included. Driscoll-Kraay (SCC) standard errors were used.

7 Final Short-Term Coefficients and Interpretation

The Fixed Effects model used Δcons as the dependent variable and Δren and Δgdp as independent variables; standard errors were corrected using the Driscoll-Kraay (SCC) method. The results of this final model are reported in Table 5. The FE model used here focuses on explaining contemporaneous (same-year) first differences; that is, Δcons_{it} is related to Δren_{it} and Δgdp_{it} at the current time. In the Granger causality test, lagged values (specifically two-period lags) were used, and the purpose of this test is to assess predictive power, not to estimate structural coefficients. Therefore, the two-period lag structure in the causality test does not require the final regression model to include the same lag length. The Granger test indicates lagged predictive relationships, while the FE + Driscoll-Kraay model reports contemporaneous short-run associations.

The results in Table 5 clearly demonstrate two key relationships. First, the coefficient for the increase in renewable energy supply is approximately 0.99 and is statistically significant at the 5% level ($p \approx 0.04$). This result indicates that short-term increases in renewable energy capacity increase total energy consumption rather than reducing it. In other words, renewable energy is not yet fully replacing fossil fuels at this stage; rather, it is expanding the total supply to support the system, particularly during periods of high demand. This finding debunks a common misconception regarding the energy transition: the addition of renewable capacity does not, at least in the short term, reduce total consumption on its own.

Second, the coefficient of change in economic growth (approximately 0.107) is positive and statistically highly significant ($p \approx 0.005$). This result indicates that, in the short term, increases in economic activity occur alongside increases in energy consumption. This situation indicates that economic growth in BRICS countries continues to proceed within an energy-intensive structure, and that energy demand remains a fundamental input for growth. When evaluated alongside the panel Granger causality results, this picture implies that increases in energy consumption trigger economic growth and that growth has not yet fully decoupled from energy demand (has not yet experienced a complete "decoupling").

Two critical policy implications emerge at this point. First, strict restrictive policies aimed at limiting energy consumption in the short term risk directly impacting growth in these countries. Second, increasing renewable energy, rather than simply reducing fossil fuel demand, serves to supply existing energy demand in a more secure and diversified manner. Therefore, renewable energy strategies cannot be considered independently of energy efficiency and demand management policies. Renewable energy expansion should be supported by energy efficiency policies, grid modernization, storage technologies, and demand-side management strategies. Not only supply-side investments but also policies that increase energy efficiency and transform the energy-intensive growth model are necessary. In addition, policy design should consider affordability, energy access, and the possible social effects of demand-side measures, especially for low-income households and energy-intensive sectors.

8 Conclusion and Policy Implications

This study examines the relationship between energy consumption, renewable energy supply, and economic growth in BRICS countries for the period 2000–2023 using panel data techniques. Since the analysis is based on five BRICS countries and annual observations, the findings should be interpreted as average short-run panel evidence rather than as identical effects for each individual country. The findings clearly reveal several key methodological points. First, all variables are not stationary at the level, but their first differences are stationary; this indicates that the series have an I(1) structure (Table 1). Second, no long-term common equilibrium relationship was found between the variables; the panel cointegration test shows that the residuals are not stationary (Table 2). This finding makes the interpretation of long-run level coefficients econometrically inappropriate and necessitates conducting the analysis through short-term dynamics. For this reason, all coefficient estimates and policy implications in the revised analysis are interpreted within a short-run first-difference framework. Third, it has been shown that in the short term, an increase in renewable energy supply triggers an increase in total energy consumption; an increase in energy consumption predicts an increase in economic growth (Table 3). This causal chain is unidirectional, beginning with renewable energy supply, followed by energy consumption, and then economic growth; no statistically significant feedback loop in the opposite direction was detected. Furthermore, the effect is not instantaneous but becomes stronger under a two-period lag structure. This finding confirms that energy consumption continues to function as a short-term input to economic growth in the BRICS context.

Fourth, the model selection process favors the Fixed Effects (FE) estimator over the Random Effects (RE) estimator. The Hausman test rejects the RE specification, indicating that the FE model is preferable for the final estimation. Therefore, the empirical interpretation is based on the FE specification. Fifth, heteroskedasticity, serial correlation, and especially cross-sectional dependence reflecting simultaneous shocks across countries are present in the error terms (Table 4). Therefore, classical standard errors are unreliable, and the final FE estimates are reported with robust Driscoll-Kraay (SCC) standard errors.

The final model (Table 5) should be interpreted within this framework. The Fixed Effects panel model, after controlling for country-specific fixed characteristics, shows that an increase in renewable energy supply increases energy consumption on a nearly one-for-one basis, and that increased economic growth positively impacts energy consumption. These results reveal that energy consumption is still the short-term fuel for growth in BRICS economies, and that renewable energy capacity currently functions more as a tool to expand total supply and support growth. From a policy perspective, these findings suggest that restrictive measures that directly suppress energy consumption may be costly in the short term for growth, and therefore efficiency-focused policies (reducing energy intensity, technological modernization, grid optimization, demand-side management, etc.) are likely to be more effective. Furthermore, the cross-sectional dependence finding shows that BRICS countries do not behave as isolated energy islands, but rather respond jointly to common shocks. Therefore, energy transition policies should be considered not only at the level of individual national strategies, but also within the framework of regional cooperation and coordination.

In conclusion, this study shows that renewable energy investments in BRICS countries act not as a short-term energy consumption reducer, but as an additional supply channel enabling growth; energy consumption, meanwhile, continues to support growth. The econometric analysis confirms why the tension between growth targets and climate targets is felt so intensely in these countries. From a sustainability perspective, simply increasing renewable energy supply is not enough; efficiency-based transformation policies that gradually decouple growth from energy consumption in the medium term must also be designed. The study also has several limitations. First, the panel is limited to five BRICS countries and annual observations for the period 2000–2023. Therefore, the results should be interpreted as average BRICS-level short-run evidence rather than as country-specific effects. In addition, although the fixed-effects model controls for time-invariant country-specific characteristics, it does not allow the slope coefficients to vary across countries. Moreover, Driscoll-Kraay standard errors improve the reliability of statistical inference, but they do not fully eliminate potential coefficient bias arising from omitted common factors. Second, the use of annual data may not fully capture shorter-term fluctuations in energy and growth dynamics. Finally, the model focuses on three core variables, and future studies may extend the analysis by including additional factors such as energy prices, trade openness, industrial structure, or policy indicators.

Acknowledgement: The authors acknowledge the use of AI-assisted tools for language editing and R coding support during the manuscript preparation process. The authors take full responsibility for the final content of the manuscript.

Funding Statement: The authors received no specific funding for this study.

Author Contributions: Perihan Hazel Kaya: Writing original draft, Investigation, Visualization, Writing, review, and editing. Coşkun Kuş: Writing original draft, Conceptualization, Formal analysis, Methodology, Software, Investigation, Visualization. Mustafa Çoklu: Writing original draft, Data curation, Investigation, Visualization, Writing, review, and editing. Mustafa Göktuğ Kaya: Writing original draft, Investigation, Visualization, Supervision, Editing. All authors reviewed and approved the final version of the manuscript.

Availability of Data and Materials: Available on request by corresponding author.

Ethics Approval: No ethical approval was needed, as this work does not involve any human or living organism.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Bhattacharya M, Paramati SR, Ozturk I, Bhattacharya S. The effect of renewable energy consumption on economic growth: evidence from top 38 countries. Appl Energy 2016;162:733–41. [CrossRef].
2. Sadorsky P. Renewable energy consumption and income in emerging economies. Energy Policy. 2009;37(10):4021–8. [CrossRef].

3. Sebri M, Ben-Salha O. On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: fresh evidence from BRICS countries. Renew Sustain Energy Rev. 2014;39:14–23. [CrossRef].
4. Inglesi-Lotz R. The impact of renewable energy consumption to economic growth: a panel data application. Energy Econ. 2016;53:58–63. [CrossRef].
5. Pesaran MH. General diagnostic tests for cross section dependence in panels. Bonn, Germany: Institute for the Study of Labor (IZA); 2004. IZA Discussion Paper No. 1240. [CrossRef].
6. Parab N, Naik R, Reddy YV. Renewable energy, economic growth and sustainable development: a model development in the light of empirical insights. Nat Resour Forum. 2024;48(2):572–93. [CrossRef].
7. Chou CH, Ngo SL, Tran PP. Renewable energy integration for sustainable economic growth: insights and challenges via bibliometric analysis. Sustainability. 2023;15(20):15030. [CrossRef].
8. Bhuiyan MA, Zhang Q, Khare V, Mikhaylov A, Pinter G, Huang X. Renewable energy consumption and economic growth nexus—a systematic literature review. Front Environ Sci. 2022;10:878394. [CrossRef].
9. Rahman MM. The dynamic nexus of energy consumption, international trade and economic growth in BRICS and ASEAN countries: A panel causality test. Energy. 2021;229:120679. [CrossRef].
10. Raza A, Khan MA, Bakhtyar B. Exploring the Linkage Between Energy Consumption and Economic Growth in BRICS Countries Through Disaggregated Analysis. J Knowl Econ. 2025;16:3869–91. [CrossRef].
11. Sadorsky P. Trade and energy consumption in the Middle East. Energy Econ. 2011;33(5):739–49. [CrossRef].
12. Shahbaz M, Khan S, Tahir MI. The dynamic links between energy consumption, economic growth, financial development and trade in China: fresh evidence from multivariate framework analysis. Energy Econ. 2013;40:8–21. [CrossRef].
13. Ojekemi OS, Ağa M, Magazzino C. Towards Achieving Sustainability in the BRICS Economies: The Role of Renewable Energy Consumption and Economic Risk. Energies. 2023;16(14):5287. [CrossRef].
14. Khobai H, Abel S, Le Roux P. A review of the nexus between energy consumption and economic growth in the BRICS countries. Int J Energy Econ Policy. 2021;11(3):424–31. [CrossRef].
15. Mehta D, Patel N, Abdi AH. Nexus between carbon emissions, economic growth, renewable energy, and innovation of BRICS: Kuramoto dynamic synchronization approach. Discov Sustain. 2025;6:987. [CrossRef].
16. Soyu Yıldırım E, Tuğlu Dur D. The impact of renewable energy consumption on economic growth in BRIC-T countries: panel data analysis. İşletme. 2024;5(1): 65–79. [CrossRef].
17. Nica I, Georgescu I, Kinnunen J. Economic growth, innovation, and CO_2 emissions: analyzing the Environmental Kuznets Curve and the Innovation Claudia Curve in BRICS countries. Sustainability. 2025;17(8):3507. [CrossRef].
18. Granger CWJ, Newbold P. Spurious regressions in econometrics. J Econom. 1974;2(2):111–20. [CrossRef].