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Financial and Technological Drivers of Sustainable Development: The Role of Communication Technology, Financial Efficiency and Education in BRICS

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Abstract: A clean environment enhances well-being and drives economic growth. BRICS nations aim to cut emissions while sustaining growth, aligning with global sustainability goals. Their strong economic progress underscores the need to explore the links between communication technology, financial efficiency, education, and renewable energy consumption (RENC). Therefore, to analyze these dynamics, this study examines data spanning from 1990 to 2020 using a rigorous methodological framework. Initially, model selection was guided by AIC and BIC criteria by ensuring optimal model fit. Furthermore, multicollinearity was assessed using the Variance Inflation Factor (VIF), while heteroscedasticity and autocorrelation issues were tested through the Breusch–Pagan Test and the Ljung–Box Test, respectively. Additionally, cross-sectional dependence (CSD) was checked, followed by stationarity analysis using the second-generation CIPS. The Westerlund Cointegration Test was employed to confirm long-run relationships. As a final preliminary test, the study uses the Hausman test for selection of the appropriate model specification. Subsequently, the PMG-ARDL approach was utilized to examine both short- and long-term dynamics. The findings reveal a significant negative relationship between RENC, Gross Domestic Product (GDP), and CO_2 emissions. Conversely, RENC exhibits a strong positive association with education (EDUC), information and communication technology (IACT), the financial markets efficiency index (FMEI), and the financial institutions efficiency index (FIEI). Finally, the robustness of the PMG-ARDL results was validated through advanced techniques, including Fully Modified OLS (FMOLS) and the Generalized Method of Moments (GMM), reinforcing the reliability of the findings. The study offers valuable policy recommendations to support sustainable development in BRICS nations.

Keywords: digitalization; financial efficiency; education; renewable energy consumption; PMG-ARDL

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1. Introduction

The BRICS nations—Brazil, Russia, India, China, and South Africa—represent a coalition of rapidly emerging economies with significant contributions to global trade, natural resource utilization, and economic resilience. In recent decades, China and India have demonstrated remarkable economic progress, notably in their respective economies. The BRICS countries are among the top 10 global energy consumers [1]. These countries collectively house 40% of the world's population [2]. The BRICS countries are currently experiencing significant transformation, with their economies steadily growing and thriving. China's economy has undergone substantial expansion and development over the course of the previous few decades [3]. Currently, China is widely recognized as the second-largest economy worldwide. The impact of China is quite substantial in several areas, encompassing exports, carbon dioxide emissions, foreign direct investment, global sustainable development, and the transfer of skills among other nations [4]. Rapid and significant growth of the economy is often seen as a positive phenomenon; nonetheless, it is not without its limitations and drawbacks. For example, the BRICS nations are presently focused on the task of mitigating emissions while simultaneously ensuring economic development remains unaffected. China now has the distinction of being the foremost worldwide emitter of carbon dioxide. India has recently had the most significant increase in emissions. However, it is worth noting that the BRICS countries continue to spearhead global economic growth [5]. The phenomenon of economic empowerment has seen a transition away from established economies, mostly as a result of the growing strength and influence of developing markets. It is anticipated that the BRICS countries would contribute to over 50% of the global economic development until the conclusion of 2030 [6]. Over the course of many decades, the proportion of global commerce accounted for by the BRICS nations has experienced a roughly threefold increase. Emerging economies have made substantial contributions to global economic growth and have concurrently stimulated international commerce. The BRICS nation has the capacity to promote enduring and comprehensive economic expansion through the implementation of carefully planned and strategic actions. In the forthcoming decades, it is anticipated that the primary focus of international development would revolve on the collaboration within BRICS nations, as well as between BRICS and other countries, in order to attain shared objectives. The BRICS countries have demonstrated strong economic performance over the previous few decades. Nevertheless, substantial economic expansion has resulted in environmental issues and a rise in carbon emissions [7].

The prioritization of renewable energies has emerged as a key focus for advanced nations' governments, driven by several compelling factors such as environmental sustainability, energy security, economic development, technical breakthroughs, and global leadership [8]. During the 1990s, renewable energy garnered recognition for its significant contribution to the advancement of ecological stability and were included into worldwide endeavors focused on minimizing the consequences of global warming [9]. Many countries maintain the perspective that renewable energy is of significant importance in the effort to alleviate the impacts of greenhouse gas (GHG) emissions [10]. According to the 2010 report by the International Energy Agency (IEA), there was a significant increase of 165.4% in power output derived from renewable energy sources between 2000 and 2010 [11]. Despite the numerous commitments and pledges, the transition to renewable energies is progressing at a sluggish pace, and the objective of significantly increasing renewable energy consumption remains a distant goal [12,13]. This gradual transition underscores the complex challenges and barriers that must be overcome to accelerate the adoption of clean and sustainable energy sources on a global scale [14]. Nevertheless, the advancement towards adopting renewable energy sources is being hindered by a range of challenges, such as institutional limits and financial constraints [15]. The most significant hurdle in the implementation of alternative energy sources is financing [16]. Consequently, private investors must step forward, as public sector investments alone will be insufficient to provide the necessary capital for the execution of renewable energy projects [17]. Renewable energy is often classified as a normal good, and there is a growing trend among private enterprises to focus their attention and allocate money towards renewable energy initiatives [18]. Hence, via the establishment of partnerships with other financial markets, the efficiency of the financial sector may significantly contribute to reducing the financial obstacles that impede the widespread adoption of renewable energy. This collaboration has the potential to improve the accessibility and affordability of renewable energy solutions, thereby stimulating increased demand for environmentally friendly and sustainable energy sources [19]. Furthermore, Ref. [20] have emphasized the enduring advantages of economic development in relation to the use of renewable energy, hence emphasizing the mutually beneficial connection between economic growth and sustainable energy practices. Ref. [21] provides a more nuanced perspective on this issue, highlighting the need of a synergistic relationship between economic development and renewable energy sources in order to effectively improve renewable energy consumption.

On the other hand, empirical investigations, shown by the study undertaken by [22], have revealed captivating dynamics. A number of studies have concluded a positive association between the use of renewable energy and carbon intensity, while other perspectives have also been presented that challenge this notion. Nevertheless, within the context of these deliberations, there is a discernibly restricted corpus of literature that is specifically focused on investigating the impact of IACT on the use of renewable energy. IACT, which includes various devices such as radio, television, the Internet, mobile phones, and tablets, play a crucial role in facilitating the wider adoption of renewable energy sources. However, their impact is sometimes undervalued. The incorporation of these technologies into sustainable energy practices holds the potential to make a substantial contribution towards the collecting, dissemination, and usage of information. The integration in question not only provides immediate advantages, but also has significant importance in attaining enduring sustainability, a critical aspect for the overall welfare of our planet [13]. The use of IACT facilitates the efficient and prompt acquisition of information by individuals and organizations, as shown by the empirical investigation performed by [23]. Moreover, IACT also involves the economic sphere. Ref. [24] proposes that the use of IACT might play a pivotal role in shifting our economic paradigm away from an excessive focus on materialism. This transformation represents a notable progression towards the realization of a modernized, efficient, digitalized, and ecologically conscious economy. Nevertheless, it is essential to consider the counter viewpoint presented by [25]. This analysis highlights a complex situation in which the production and use of IACT commodities may lead to a substantial rise in global energy demand. Moreover, Ref. [25] argues that the interdependent relationship between the IACT is of paramount importance in promoting the extensive integration of renewable and sustainable energy sources. Moreover, education plays a crucial role in promoting renewable energy adoption and addressing environmental pollution. It equips individuals with the knowledge to make informed decisions about sustainable energy practices, fostering a greener future [21]. By raising awareness and enhancing commitment to sustainability, education encourages proactive adoption of renewable energy and reduces environmental impact [21]. Additionally, environmental degradation stems from energy-intensive activities and polluting technologies, necessitating education as a key strategy for mitigating these effects [26]. Education fosters innovation, improves accessibility to sustainable energy solutions, and drives societal engagement in cleaner energy transitions [27]. Moreover, heightened environmental awareness through education influences families to adopt renewable energy, embrace eco-friendly technologies, and contribute to a more sustainable lifestyle [28].

This research makes a significant contribution to energy economics by addressing critical gaps in the literature and providing new insights into the financial and technological drivers of renewable energy transitions in BRICS countries. Specifically, (i) to the best of our knowledge, this study is the first empirical investigation to comprehensively examine the interplay between renewable energy investments and financial development within BRICS economies. Unlike prior studies that focus on individual countries or broader regions, our analysis provides a comparative perspective, highlighting the distinct roles of financial markets, financial institutions, education, and IACT in shaping renewable energy consumption. (ii) A key contribution of this study is the exploration of whether financial efficiency exerts a symmetric or asymmetric effect on renewable energy investments. Given that human behavior is inherently nonlinear, as suggested by [29], and that asymmetric models are considered more robust than linear approaches [30], this investigation enhances the understanding of financial-market-driven energy transitions. (iii) Methodologically, the study employs ARDL-PMG models [31], which allow for a nuanced analysis of short- and long-term effects while accommodating variables with different integration orders (I(0) and I(1)). (iv) Furthermore, by incorporating education and IACT as key enablers of renewable energy adoption, the study extends prior research that has predominantly focused on economic and policy factors, offering a more holistic perspective on energy transitions. (v) Given BRICS' influence in global decision-making and their significant strides toward environmental sustainability, our findings provide valuable policy implications for fostering green investments and accelerating the shift toward clean energy. Ultimately, this research not only supports but also refines and extends the existing literature by demonstrating how financial market efficiency, institutional strength, education, and IACT collectively drive renewable energy consumption in emerging economies. Building on the study discussions, this research explores the following key questions.

1. What is the impact of CO_2 emissions on renewable energy consumption in BRICS countries?
2. How does financial market efficiency influence renewable energy consumption in BRICS countries?
3. What is the relationship between economic growth and renewable energy consumption in BRICS countries?
4. How does the efficiency of financial institutions affect renewable energy consumption in BRICS countries?
5. What role does education play in promoting renewable energy consumption in BRICS countries?
6. How does information and communication technology influence renewable energy consumption in BRICS countries?

The remainder of this study is structured as follows: Section 2 presents a comprehensive literature review, examining the existing research on financial development, education, IACT, and their roles in renewable energy transitions within BRICS countries. Section 3 outlines the methodology, detailing the data sources, econometric approach, and justification for using PM73G-ARDL models. Section 4 discusses the empirical results, providing an in-depth analysis of the short- and long-term effects of financial market efficiency, education, and IACT on renewable energy consumption. Section 5 concludes the study by summarizing key findings and offering policy recommendations to enhance renewable energy investments in BRICS economies.

2. Literature Review

2.1. CO_2 and RENC

The role of renewable energy consumption (RENC) in achieving environmental sustainability is well documented, yet its long-term viability depends on substantial CO_2 emission reductions [32]. While governments promote RENC through policies and incentives, persistent high emissions pose challenges to its effectiveness [33]. Research on knowledge-based economies (KBEs) from 1990 to 2020 suggests that contractionary monetary policies and RENC contribute to emission reductions, but expansionary policies and resource dependence undermine these efforts [34]. This underscores the necessity of stringent emission control measures to sustain renewable energy transitions. Regulatory frameworks, such as the European Union's incentive-driven policies, accelerate RENC adoption [35]. However, without parallel reductions in emissions, such efforts risk losing effectiveness over time [36]. Similarly, technological advancements—such as ocean energy innovation—have shown significant potential in reducing CO_2 emissions, reinforcing the need for continuous investment in low-carbon solutions [36]. Financial mechanisms are also essential, given the high initial costs of renewable energy projects, yet their impact is often constrained by persistent emissions and economic instability [37]. For instance, foreign direct investment (FDI) has been identified as a key driver of CO_2 emissions, highlighting how unregulated economic growth can dilute the effectiveness of renewable energy policies [38]. Beyond financial barriers, non-economic factors also hinder RENC. In South Africa, increasing aggregate domestic consumption spending (ADCSP) has been linked to rising CO_2 emissions, further complicating efforts to achieve sustainable energy transitions [39]. Empirical evidence across 116 countries reveals that economic expansion and industrialization are directly correlated with emissions growth, emphasizing the environmental burden of development [40]. A fixed-effects model on 61 nations similarly finds that GDP per capita growth, while reducing poverty and improving income equality, contributes to rising CO_2 emissions [41]. Overall, the literature highlights that while RENC is crucial for sustainability, it cannot independently counteract the environmental impact of economic expansion and emissions growth. Clean energy adoption and technological innovation mitigate environmental degradation, but their effectiveness is shaped by economic and financial dynamics [32]. This study builds on these findings to explore the impact of CO_2 emissions on RENC in BRICS countries, leading to the following hypothesis:

H1. *CO_2 emissions negatively impact renewable energy consumption in BRICS countries.*

2.2. FMEI and RENC

The banking sector plays a crucial role in financing renewable energy, but its impact depends on ensuring that investments drive sustainability rather than reinforcing carbon-intensive growth. A well-structured financial system can provide cost-effective financing for renewable projects, yet without strict emissions control, such efforts risk being undermined [42]. Capital markets can ease liquidity constraints for green investments, but their true impact depends on channeling financial resources toward emissions reduction alongside energy transition [43]. Financial intermediation improvements have reduced renewable energy project costs while promoting sustainability [44], but this support must align with emissions reduction strategies. Similarly, stock market expansion can enhance renewable energy demand and productivity [45–47], but prioritizing long-term sustainability over short-term financial gains is essential.

Furthermore, institutional quality also matters. Therefore, according to the literature, improved governance in European countries strengthened the link between renewable energy investments and economic growth [48], yet economic progress must not come at the cost of higher CO_2 emissions. A study in Tunisia (1980–2016) found that industrialization, GDP, and even renewable energy consumption (RENC) contributed to environmental degradation, highlighting the need for emissions-focused policies [49]. Similar findings were reported for EU nations [50], emphasizing that renewable investments alone are insufficient without carbon mitigation strategies. The link between financial development and renewable energy remains mixed—neutral in Russia and China [51], positive in Germany [52], but negative where financial efficiency fails to support clean energy transitions [53].

Research on financial investment in renewable energy remains fragmented, with limited studies comparing developed and developing nations [54]. While most findings suggest financial development supports renewable adoption, some warn of drawbacks if emissions reductions are not prioritized. This study addresses these gaps by examining the role of financial efficiency in renewable energy expansion within BRICS, emphasizing the need to balance investment growth with emissions control to secure the sector's future. Based on the study discussion, the work proposes the following research hypothesis.

H2. *Financial market efficiency positively influences renewable energy consumption in BRICS countries.*

2.3. GDP and RENC

The relationship between traditional energy and economic development has been extensively studied, but research on renewable energy's role in economic growth remains limited. Several studies highlight a positive association between financial sector development and renewable energy investments, particularly in non-OECD economies [48]. For instance, research covering 22 emerging economies from 1990 to 2014 supports the idea that the development of the financial sector fosters investments in renewable energy [55]. Moreover, granger causality tests have been pivotal in understanding the direction of these relationships. Studies by [7,56–60] explore the link between carbon emissions and GDP, with mixed results—some showing bidirectional relationships, while others point to a neutral or unidirectional connection. Notably, research on Chile [61], Nigeria [62], and India [63] suggests a consistent pattern of economic growth driving carbon emissions, although this impact varies across countries.

In addition to economic growth, renewable energy consumption (RENC) has been shown to influence sustainability. Research by [60] in 15 countries found a bidirectional relationship between RENC and economic growth. Similarly, ref. [64] observed a negative correlation between environmental technologies and ecological footprints in East Asia, including China. Ref. [65] investigated the relationship between RENC, GDP, CO_2 emissions and financial development in China, revealing a negative correlation between CO_2 and both RENC and financial development, while GDP showed a positive correlation with CO_2 emissions. Other studies focus on how RENC contributes to economic progress. For example, ref. [66] used panel data from 42 developed countries (2002–2011) and found a favorable long-term impact of RENC on economic growth. Ref. [67] explored the role of renewable energy and marine-based energy generation technologies in ecological sustainability, showing that RENC and marine technologies positively impact sustainability, while natural resource consumption has a negative effect.

Despite the positive findings, comparing the dynamics of financial development and renewable energy investments across developed and emerging economies, particularly within BRICS, presents challenge. The existing literature highlights the need for further analysis on the relationship between financial sector efficiency and renewable energy adoption, with a growing body of empirical evidence [68]. Research methods like Granger causality and ARDL have provided valuable insights, but a deeper understanding of these interactions is still required, especially in emerging economies like those in BRICS [7,69–71]. As a result, economic growth in BRICS countries tends to increase carbon emissions and resource consumption, hindering renewable energy adoption. The positive correlation between GDP and CO_2 emissions suggests that as economies grow, their reliance on non-renewable energy may rise, limiting the shift to renewables despite technological advancements. Based on the literature discussion, the current study proposes the following research hypothesis.

H3. *Economic growth negatively impacts renewable energy consumption in BRICS.*

2.4. FIEI and RENC

The relationship between financial sector efficiency and renewable energy production has been widely studied in various contexts. Research by [72] highlights the importance of financial sector development in supporting renewable energy production in the GCC states. The IPCC reports indicate the direct impact of renewable energy systems on business credit, which reflects the financial sector's strength. In Saudi Arabia, ref. [73] found a positive contribution of technological innovation to sustainability, including renewable energy. Similarly, ref. [51] examined Russia and concluded that renewable energy did not significantly contribute to economic growth despite financial sector improvements. Furthermore, ref. [74] emphasized that governance regulations in Saudi Arabia were effective in reducing emissions, while [75] found that foreign direct investment (FDI) and stock market development positively impacted renewable energy in BRICS countries. Other studies, such as [76,77], show a correlation between financial instruments and renewable energy growth in various regions, including OPEC and CIS countries. Additionally, ref. [78] suggested that the relationship between economic growth and renewable energy adoption varies across income groups, while [79] found a time-varying relationship between globalization and renewable energy. Research in India by [80] concluded that improved financial and economic conditions positively influenced renewable energy use. Studies of Granger Causality, including [81,82], confirm that an efficient financial sector is crucial for long-term renewable energy development. Lastly, refs. [83,84] found that stock market performance and oil price shocks, respectively, also play significant roles in renewable energy adoption, with positive effects on financial and economic growth. Overall, the literature indicates that financial sector efficiency, governance, and market development are critical for promoting renewable energy, though the effects vary across regions and contexts. Therefore, according to the literature discussion, the current study proposes the following hypothesis:

H4. *The efficiency of financial institutions positively influences renewable energy consumption in BRICS countries.*

2.5. EDUC and RENC

Education affects the environment through both direct and indirect control of energy use. It can influence individuals' environmental attitudes and behaviors, potentially contributing to environmental degradation through increased energy-intensive practices such as transportation and industrial activities [85,86]. While education can promote cleaner technologies and energy efficiency, its impact varies based on a country's development level [87]. For instance, in high-income countries, education may exacerbate environmental issues, while in lower-income countries, it could contribute to improvements [88–90]. Several studies explore this relationship. For example, refs. [89,91] found that education can both positively and negatively affect energy consumption and environmental quality. While some research shows education's positive influence on reducing CO_2 emissions, especially in more developed economies [86], other studies show mixed results, with education in specific countries like Brazil, India, China, and South Africa linked to both increases and decreases in CO_2 emissions depending on the level of education; ref. [92] noted that education alone may not reduce environmental degradation without an environmentally conscious curriculum. Similarly, ref. [93] found an inverted U-shaped relationship between education and carbon emissions in some Asian countries, where education first increased emissions but later helped reduce them. Despite these mixed results, the literature highlights that education's role in shaping environmental outcomes is multifaceted. The discrepancies in findings likely stem from differences in methodology, data, and sample characteristics. Based on the literature discussion, this study proposes the following hypothesis:

H5. *Education positively influences renewable energy consumption in BRICS.*

2.6. IACT and RENC

The combination of renewable energy and digitalization can significantly improve environmental outcomes. Digital technologies enhance the efficiency of renewable energy generation and distribution, reducing reliance on fossil fuels and mitigating environmental harm. Smart grids enable a seamless integration of renewable energy into existing infrastructure, improving energy efficiency and resilience. While the limited body of literature has explored the correlation between renewable energy consumption (RENC) and information and communication technology (IACT), some studies show promising results. For instance, research using Gaussian Mixture Models across 60 countries finds that IACT in urban areas contributes to reducing CO_2 emissions [94]. Similarly, a study using the panel Vector Autoregressive Model in 18 African nations finds that IACT contributes to lower CO_2 emissions by improving resource access and enabling effective carbon monitoring [95]. In China, the extensive use of IACT has led to reduced carbon intensity in cities [96], while the use of the CUP-FM estimator in 17 Asian nations shows a decrease in CO_2 emissions. Research in Saudi Arabia indicates that IACT reduces ecological footprints (EF), confirmed by the Johansen co-integration method and VECM [97]. Other studies, such as those in the G7 nations using AMG estimators, have found a negative association between IACT and EF. However, the results vary across regions. In N11 countries, the Feasible General Least Squares (FGLS) method suggests that IACT increases EF, while a study using PMG methodology for BRICS countries found no significant impact on EF [98]. Research in Sub-Saharan Africa [94] and 19 developing nations [99] further confirms these mixed findings. Based on the literature, the study proposes the following research hypothesis:

H6. *Information and communication technology positively influence renewable energy consumptions in BRICS countries.*

2.7. Literature Gap

While the existing literature has explored various aspects of renewable energy consumption (RENC), there remains a significant gap in understanding the collective influence of GDP, CO_2, EDUC, FIEI, FMEI, and IACT on RENC. Most of the prior studies have primarily examined RENC in connection with environmental outcomes, whereas our study shifts the focus to identifying the key determinants of RENC. This novel perspective helps bridge the knowledge gap by highlighting the economic, financial, technological, and educational drivers of renewable energy adoption. Furthermore, no prior research has comprehensively investigated these relationships in the context of BRICS economies using the PMG-ARDL approach. Our study enhances methodological rigor by conducting a detailed preliminary analysis before applying PMG-ARDL and validating results through robust techniques such as FMOLS and GMM, effectively addressing endogeneity and serial correlation concerns. Additionally, the study offers in-depth discussions, policy-relevant insights, and visual representations to enhance clarity and impact. Given the growing importance of renewable energy in BRICS nations, our findings provide timely and actionable recommendations for policymakers to drive sustainable energy transitions.

3. Methodology

The objective of this study is to examine the link between the dependent variable RENC and a set of independent variables, including information and communication technology (IACT), financial institution efficiency index (FIEI), financial market efficiency index (FMEI), economic growth (GDP), carbon emissions (CO_2), and education (EDUC).

The transition to renewable energy consumption (RENC) in BRICS countries (Brazil, Russia, India, China, and South Africa) is influenced by factors like economic growth, technological innovation, financial systems, and education [100]. While GDP increases energy demand, potentially raising fossil fuel consumption and CO_2 emissions, it also creates opportunities for investment in renewable energy [101]. As these nations industrialize, their economic growth drives the expansion of renewable energy solutions, although achieving this requires integrating technologies and financial systems capable of supporting the transition. Reducing CO_2 emissions is critical, especially in countries like China and India, where industrialization has significantly increased energy consumption and emissions [102]. As a result, promoting cleaner technologies and investing in renewables can help reduce carbon footprints, supporting global climate goals.

Furthermore, IACT plays a pivotal role in improving energy efficiency and supporting the shift to renewable energy. IACT enables the development of smart grids and energy-efficient systems, crucial for integrating renewable sources [103]. It can also enhance energy access, particularly in remote areas, by improving electricity distribution and reducing operational costs. While IACT alone cannot drive the entire transition, it plays a crucial enabling role in enhancing the efficiency and accessibility of energy systems, thereby supporting the large-scale adoption of renewable energy across BRICS countries [104]. Additionally, education, particularly in STEM fields, is essential for fostering innovation and developing new renewable energy technologies. A skilled workforce is necessary to drive the growth of clean energy solutions, while higher education levels also help raise awareness of the environmental and economic benefits of renewable energy [105]. Therefore, educated populations are more likely to embrace sustainable technologies, support energy policies, and demand clean energy, thus aiding the transition to renewable sources. Hence, a well-educated workforce can also optimize energy systems, enhancing the efficiency of renewable energy deployment in BRICS nations.

Moreover, the efficiency of financial markets and institutions is crucial for attracting investments in renewable energy. Efficient markets facilitate the creation of financial instruments, such as green bonds, which raise capital for renewable energy projects [106]. Hence, by improving financial market efficiency, BRICS countries can channel funds into large-scale renewable energy projects, encouraging private sector involvement. Furthermore, efficient financial institutions are also necessary to ensure capital flows toward sustainable development, reducing transaction costs and enhancing the scalability of renewable energy projects. With better financial systems, BRICS nations can accelerate the transition to renewable energy, balancing rapid economic growth with environmental sustainability [107]. As a result, leveraging these factors—GDP, CO_2 emissions, IACT, financial efficiency, and education—can enable BRICS countries to achieve renewable energy goals and contribute to global climate objectives.

Prior studies have examined various interrelationships, such as the linkages between energy consumption, economic advancement, and carbon emissions [37,108] energy consumption, carbon emissions, and urbanization [69] and carbon emissions, economic growth, urbanization, and energy consumption [109]. Furthermore, a study was undertaken by [110] with the aim of examining the relationship between environmental sustainability and agro-economic performance. Furthermore, to ensure the appropriate selection of variables, we utilized the Variance Inflation Factor (VIF) test. VIF is a statistical tool used to detect multicollinearity among explanatory variables in a regression model [111]. It measures how much the variance of a regression coefficient is inflated due to correlations with other independent variables. A high VIF indicates that a variable is highly correlated with one or more other variables, which can lead to unreliable estimates and biased results. By calculating VIF values, we can identify and address multicollinearity, ensuring the accuracy and robustness of the model's estimates. The VIF test is essential for enhancing model reliability, as it ensures that each independent variable contributes uniquely to explaining the dependent variable, without redundancy or overlap [112].

To address heteroscedasticity and autocorrelation in the model, the study utilized the Breusch–Pagan Test and the Ljung–Box Test. The Breusch–Pagan Test is used to detect heteroscedasticity, which occurs when the variance of the error terms is not constant across observations [113]. The literature shows that heteroscedasticity can lead to inefficient estimates and invalid inferences. The Breusch–Pagan Test examines whether the variance of the residuals is related to the independent variables, helping identify potential issues with non-constant variance. If detected, corrective measures, such as weighted least squares, can be applied to ensure the validity of the regression results. The Ljung–Box Test, on the other hand, is employed to test for autocorrelation in the residuals. Autocorrelation refers to the correlation of a variable with its own past values, which can violate the assumption of independent errors in regression models. The Ljung–Box Test assesses whether there is significant autocorrelation at multiple lags [114]. Identifying and addressing autocorrelation ensures that the model's error terms are independent, improving the accuracy and reliability of the estimates. As a result, both tests are essential for ensuring the robustness of the regression model. By detecting and addressing heteroscedasticity and autocorrelation, the study ensures that the model provides unbiased and efficient estimates, leading to more reliable conclusions.

Furthermore, to ensure the robustness of the panel data analysis, the study utilized the cross-sectional dependence (CSD), CIPS unit root test, and the Westerlund Cointegration Test. CSD tests the presence of correlations between cross-sectional units in a panel, which can lead to biased and inconsistent results if ignored [115]. This is particularly important in panel data, where cross-sectional dependence may arise due to common shocks or interconnectedness between units, and must be accounted for to avoid misleading inferences. Whereas, the CIPS (Cross-sectionally Augmented IPS) unit root test is then used to examine the stationarity of the panel data, extending the IPS test by addressing the potential cross-sectional dependence, which is crucial when dealing with large panels where unit-specific shocks might lead to non-stationary data [116]. Finally, the Westerlund Cointegration Test is employed to check for long-term relationships among variables in the panel, ensuring that the variables move together over time despite short-term fluctuations [117]. Therefore, this test is vital for understanding whether a stable equilibrium relationship exists between the variables, which is a key assumption in many econometric models. These three tests collectively ensure that the panel data analysis is robust, addressing potential issues of cross-sectional dependence, non-stationarity, and cointegration, thereby providing reliable estimates and accurate policy implications [118].

Furthermore, the study employs the Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) approach to analyze the long- and short-term relationships between the variables of interest. The PMG-ARDL model allows for the estimation of both short-term dynamics and long-term equilibrium relationships in a panel setting [119]. This method is particularly useful for situations where the data exhibits different slopes across cross-sectional units while assuming a common long-run relationship, which is typical in the context of panel data analysis [120]. Hence, the PMG-ARDL model captures both the short-term dynamics and the long-term effects, providing a comprehensive view of the interrelationships among the variables under study.

Furthermore, the rationale for selecting the PMG-ARDL approach lies in its flexibility and ability to handle heterogeneous panels, where the assumption of a single common slope across countries may not hold. Given the diverse economic, political, and social environments of BRICS countries, the PMG-ARDL model allows us to accommodate these differences while focusing on the shared long-run relationship between the variables. Additionally, this approach is well suited for non-stationary time series data that are integrated of order one (I(1)) or mutually cointegrated, which is a frequent characteristic of macroeconomic and environmental variables [121]. One of the significant strengths of the PMG-ARDL model is its robustness to non-normal data. Panel data often exhibits non-normal distributions due to various country-specific factors. To account for this potential non-normality and heteroscedasticity in the error terms, we employed the robust standard error option. This adjustment ensures that the estimates remain unbiased and efficient, even in the presence of non-normal error distributions. Therefore, by using robust standard errors, the model provides more reliable results despite the challenges posed by the non-normality of the data. As a result, for the PMG-ARDL model, we used the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) to determine the optimal lag order. AIC and BIC balance model fit with complexity, where lower values indicate better models. AIC penalizes parameters, while BIC imposes a stricter penalty, especially for larger samples. This ensures the selection of a lag length that captures the necessary dynamics without overfitting, improving the reliability of the PMG-ARDL estimates.

To further strengthen the robustness of the findings, we incorporated the Fully Modified Ordinary Least Squares (FMOLS) and Generalized Method of Moments (GMM) as robustness checks. The FMOLS estimator corrects for endogeneity and serial correlation, making it particularly useful when dealing with non-stationary time series data [122]. The GMM, on the other hand, helps to account for potential endogeneity issues and provides more efficient and consistent estimates by using internal instruments to control for endogenous variables [123]. The use of both FMOLS and GMM reinforces the validity and reliability of the PMG-ARDL estimates by providing alternative techniques to cross-verify the results, especially in the presence of non-normal data. These robustness checks serve as a safeguard, ensuring that the results are not driven by model specification or data issues. The combined use of PMG-ARDL, FMOLS, and GMM significantly enhances the credibility of the study's conclusions, providing a more comprehensive and reliable analysis of the relationships among the variables in question. The model and equations under consideration are as follows:

$$\text{RENC} = \text{f}(\text{IACT, FIEI, FMEI, EDU, GDP, CO}_2) \tag{1}$$

$$lRENC_{i,t} = \alpha + \beta_1 lIACT_{i,t} + \beta_2 lFIEI_{i,t} + \beta_3 lFMEI_{i,t} + \beta_4 lEDU_{i,t} + \beta_4 lGDP_{i,t} + \beta_4 lCO2_{i,t} + \varepsilon_{i,t} \tag{2}$$

The logarithmic form of the variables has been utilized to achieve constant variance in the data series. Thus, we use lIACTi,t, lFIEIi,t, lFMEIi,t, lEDUi,t, lGDPi,t, and lCO2i, respectively, and for our independent variables, we use FIEI, FMEI, EDU, and GDP and CO$_2$. β represents the intercept term and the partial slope coefficient, also referred to as the stochastic term. The PMG-ARDL methodology is designed to mitigate the bias resulting from the association between the white noise term and the mean-differenced independent variables. This bias poses a challenge for the ARDL estimation method when attempting to assess bias in panel dataset models that incorporate individual effects. The ARDL model and PMG estimator [31] are combined in this method proposed by [124].

$$\begin{gathered}\Delta y_{it} = A + \varnothing y_{it-1} + \alpha_i \sum_{i=1}^{p} \Delta y_{it-i} + \pi_i \sum_{i=1}^{p} \Delta lIACT_{it-i} + \omega_i \sum_{i=1}^{p} \Delta lFIEI_{it-i} \\ + \psi_i \sum_{i=1}^{p} \Delta lFMEI_{it-i} + \Omega_i \sum_{i=1}^{p} \Delta lEDU_{it-i} + {}_i \sum_{i=1}^{p} \Delta lGDP_{it-i} + \theta_i \sum_{i=1}^{p} \Delta lGDP_{it-i} + \beta_1 y_{it-1} + \beta_2 lIACT_{it-1} \\ + \beta_3 lFIEI_{it-1} + \beta_4 lFMEI_{it-1} + \beta_5 lEDU_{it-1} + \beta_6 lGDP_{it-1} + \beta_7 lCO2_{it-1} + \eta_i + \varepsilon_{it}\end{gathered} \tag{3}$$

From the above model, ∅ is the coefficient of dependent variable; α_i, π_i, ω_i, ψ_i, Ω_i, $_i$, and θ_i are the short-run coefficients, while β_1 to β_7 denote the long-run coefficients. Meanwhile, the MG estimator is presented as follows:

$$MG = N^{-1} \sum_{i=1}^{N} \overline{\beta}_i \tag{4}$$

The study utilizes publicly available secondary data from the sources listed in Table 1.

Table 1. Data sources and units.

Variables	Short Forms	Definition	Source
Renewable energy consumption	RENC	% of total final energy consumption	https://shorturl.at/oryGY (WDI) (10 December 2024)
Information and communication technologies	IACT	Individuals using the Internet (% of population	https://shorturl.at/oryGY (WDI) (10 December 2024)
Financial institutions efficiency index	FIEI	Relative index comparing the efficiency of financial institutions	https://shorturl.at/LNQRS (IMF) (10 December 2024)
Financial markets efficiency index	FMEI	Relative index represents a comparative measure of efficiency across financial markets	https://shorturl.at/LNQRS (IMF) (10 December 2024)
Education	EDUC	Government expenditure on education, total (% of GDP)	https://shorturl.at/oryGY (WDI) (10 December 2024)
Gross domestic product	GDP	GDP per capita (constant 2015 US$)	https://shorturl.at/oryGY (WDI) (10 December 2024)
Carbon emissions	CO_2	CO_2 emissions (metric tons per capita)	https://shorturl.at/oryGY (WDI) (10 December 2024)

4. Results and Discussion

Descriptive statistics, as shown in Table 2, provide insights into the distribution of key variables. The mean values for RENC, IACT, GDP, FMEI, EDUC, FIEI, and CO_2 are 25.56817, 21.54729, 5206.925, 0.599893, 3.995050, 0.564956, and 5.289443, respectively. Skewness values range from 0.2007 to 0.9477, and kurtosis values are all below 3, indicating platykurtic distributions. None of the variables exhibit a normal distribution, as seen from the skewness and kurtosis values. Non-normality can affect the validity of certain statistical tests, like OLS regression, which assumes normality of the residuals. To address this, we employed robust estimation techniques, including PMG-ARDL and FMOLS, which are less sensitive to non-normality, ensuring the reliability of our results despite deviations from normal distribution.

Figure 1 clearly illustrates that each BRICS country exhibits unique trends in renewable energy use between 1990 and 2020. Brazil displays a moderate increase, Russia maintains a generally stable situation, India provides consistent growth, and China showcases extraordinary expansion. Nevertheless, South Africa is falling behind, suggesting the possibility of greater investment. Collectively, these patterns highlight the many strategies and advancements made by the BRICS nations in their pursuit of a sustainable energy transition.

Next the study checked for multicollinearity among the independent variables using the Variance Inflation Factor (VIF) test and results are reported in Table 3. The results show that all VIF values are below the critical threshold of 5, indicating that multicollinearity is not a significant concern among the variables. This supports the proper selection of model variables and ensures the stability and reliability of the regression analysis. Specifically, the VIF values range from 1.89 (IACT) to 4.15 (EDUC), with corresponding Tolerance values ranging from 0.241 (EDUC) to 0.529 (IACT). These findings confirm that the independent variables in the model exhibit relatively low correlation, ensuring the reliability of the regression analysis.

Table 2. Descriptive statistics.

	RENC	**IACT**	**GDP**	**FMEI**	**EDUC**	**FIEI**	**CO_2**
Mean	25.56817	21.54729	5206.925	0.599893	3.995050	0.564956	5.289443
Median	18.58595	8.065375	5798.910	0.538954	3.948930	0.579991	4.467700
Maximum	58.65286	84.99467	10358.26	1.009965	6.348910	0.806828	14.62147
Minimum	3.180000	6.00×10^{-5}	527.5145	0.045000	1.654470	0.221098	0.645362
Std. Dev.	17.72300	25.68604	2933.780	0.310642	1.195421	0.142454	3.963930
Skewness	0.200685	0.947676	−0.186748	0.098326	−0.097293	−0.497035	0.478115
Kurtosis	1.549447	2.467121	1.829503	1.525934	2.397461	2.714923	1.872604
Jarque–Bera	14.62943	25.03456	9.749254	14.28287	2.589258	6.906818	14.11403
Probability	0.000666	0.000004	0.007638	0.000792	0.274000	0.031638	0.000861

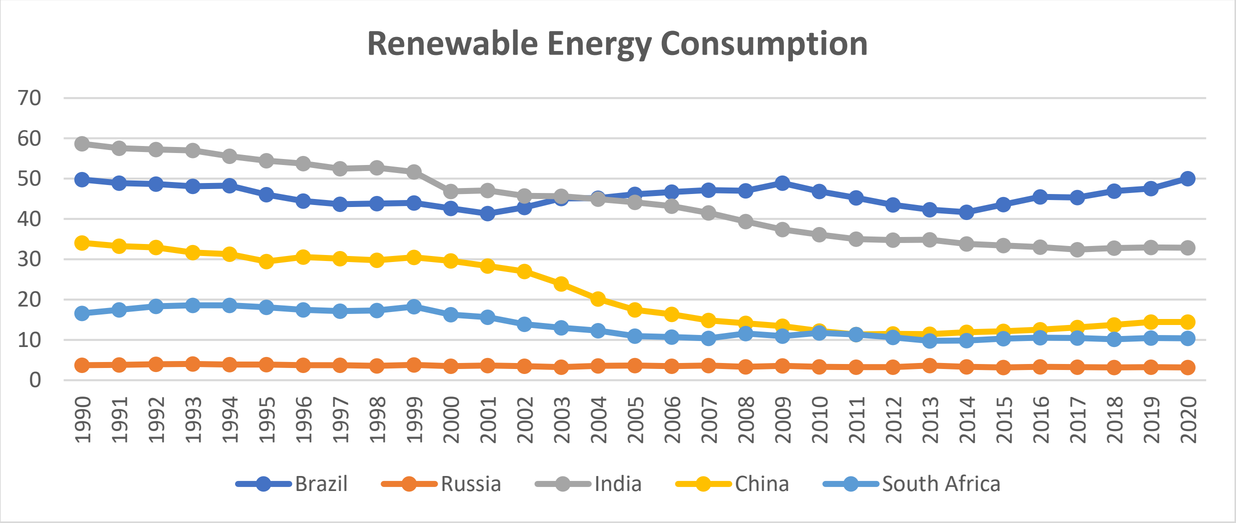

Figure 1. Consumption of RENC in BRICS countries.

Table 3. Variance Inflation Factor test.

Variable	**VIF**	**Tolerance**
IACT	1.89	0.529
FIEI	3.47	0.288
FMEI	1.92	0.521
EDUC	4.15	0.241
GDP	3.04	0.328
CO_2	2.58	0.387

After checking for multicollinearity using the VIF test, the study next examined heteroscedasticity using the Breusch–Pagan Test. The results, reported in Table 4, show a Breusch–Pagan Test statistic of 1.25 with a *p*-value of 0.305. Since the *p*-value is greater than the conventional significance level of 0.05, we conclude that there is no evidence of heteroscedasticity, suggesting that the model's error variance is constant across observations.

Table 4. Breusch–Pagan Test for heteroscedasticity.

Test Statistic	*p*-Value	Result
Breusch–Pagan	1.25	0.305

In continuation with the heteroscedasticity check from Table 4, the study also examined autocorrelation using the Ljung–Box Test, as shown in Table 5. The test results reveal that for both lags 1 and 2, the Q-statistic values were 0.45 and 1.60, respectively, with corresponding *p*-values of 0.50 and 0.44. Since the *p*-values are greater than the 0.05 significance threshold, no autocorrelation is detected in the model, suggesting that the residuals are independent and not serially correlated.

Table 5. Ljung–Box Test for autocorrelation.

Lag	Q-Statistic	*p*-Value	Result
1	0.45	0.50	No autocorrelation detected, as the *p*-value > 0.05.
2	1.60	0.44	No autocorrelation detected, as the *p*-value > 0.05.

Before moving toward checking the stationarity of the data, we need to confirm the cross-sectional dependence between the units under study. For this, we applied Pesaran's CSD test (2021) to see if cross-sectional dependence between the countries exists. This implies that any change in one variable in one country can bring the corresponding change to other countries. From Table 6, it is evident that there exists cross-sectional dependence between the units, and the results are significant at the 1% level. It means that any change in the RENC of one country will affect the other country's BRICS. As the test results of CSD are confirmed, we will now proceed toward checking the stationarity of the data.

Table 6. Cross-sectional dependence.

Variables	Statistics	Probability
RENC	10.0838 ***	0.0000
IACT	17.1784 ***	0.0000
FIEI	2.7196 ***	0.0065
FMEI	3.7529 ***	0.0002
EDUC	7.3416 ***	0.0000
CO_2	7.1796 ***	0.0000
GDP	15.8156 ***	0.0000

Note: *** stands for significance level at 1%.

After analyzing the results of the CD test, we utilize the CIPS unit root test, a second-generation test that provides accurate estimations. The CIPS unit root test expands upon conventional unit root tests, such as the Augmented Dickey–Fuller (ADF) test, to accommodate panel data scenarios by considering the interdependence among individual series. It is specifically developed to tackle the problem of cross-sectional dependence, which is frequently encountered in panel data where observations are gathered across various entities (cross-sections) across different time periods. Due to the significance of the results obtained from CSD, it is necessary to utilize second generation unit root tests instead of first-generation tests such as Levin–Lin–Chu (LLC). The results of the second-generation unit root test are displayed in Table 7. It is evident that all the variables exhibit stationarity at the integrated order of I(1). This result indicates that we should proceed with the co-integration test. To achieve this objective, this study utilizes the co-integration test introduced by [125]. It takes into account the potential confounding factors in the data while calculating test statistics.

Table 7. Unit root test (CIPS).

Series	I(0)	I(1)
RENC	−2.754 *	−4.516 ***
IACT	−3.977 ***	−5.179 ***
FIEI	−2.264	−5.719 ***
FMEI	−2.314	−5.391 ***
EDUC	−1.388	−4.354 ***
GDP	−1.372	−2.994 **
CO_2	−1.766	−3.527 ***
Critical values: −2.73 (10%)	−2.84 (5%)	−3.06 (1%)

Note: ***, ** and * represent significance at 1%, 5% and 10%.

Prior to utilizing PMG-ARDL, we conducted a co-integration test to assess the ongoing link between the variables under consideration. Through this test, the researchers may confirm the substantial and enduring correlation between the parameters, so enhancing the dependability and accuracy of the model. The [125] was utilized for this specific objective, and the outcomes are displayed in Table 8. The analysis of the results reveals a co-integration between the research variables, as indicated by the p values. The results indicate a substantial co-integration of the panel data. This suggests that all variables are interconnected and progress in unison in the long run. Hence, we may infer that the PMG-ARDL approach can be employed to examine the enduring and immediate correlation among the variables.

Table 8. Westerlund Cointegration Test.

Statistic	Value	Z-Value	p-Value
Gt	−4.206 ***	−3.188	0.001
Ga	−15.995	0.270	0.606
Pt	−12.348 ***	−6.118	0.000
Pa	−22.073 **	−2.175	0.015

Note: *** and ** represent significance at 1% and 5%.

Before we estimate the ARDL model using the Pool Mean Group (PMG), we test the model using Hausman. One of the most important purposes of the Hausman test in panel data analysis is the choice among the estimate methods, namely Pooled Mean Group (PMG), Augmented Mean Group (AMG), and Dynamic Fixed Effects (DFE) models. These models are often used in the framework of dynamic panel data analysis which implies the combination of time-series and cross-sectional dimensions. There are three tests for panel estimation: MG, PMG, and DFE. The Hausman test is useful in deciding which of the three panel estimations is the most appropriate. Table 9 displays the outcomes of the Hausman test, which assesses the appropriateness of the PMG test in comparison to the MG and DFE tests.

Table 9. Hausman test.

Test Summary	Chi-Stat	Prob.	Decision
PMG vs. MG	2.389700	0.4956	PMG
PMG vs. DFE	2.677428	0.4441	PMG

After validating the data through preliminary tests, the study examines the long-term and short-term relationships between the studied variables. For this purpose, we employed the PMG-ARDL technique. The study utilized the AIC and BIC criteria to determine the optimal lag length for the PMG-ARDL model. The results revealed that a lag length of 2 was optimal, as it produced the lowest values for both AIC (4.85) and BIC (5.10), indicating the best model fit. While a lag length of 1 had relatively low values (AIC: 5.25, BIC: 5.60), and a lag length of 3 had slightly higher values (AIC: 4.92, BIC: 5.20), the lag of 2 demonstrated the most balanced trade-off between fit and complexity. A lag length of 4 showed increased values (AIC: 5.10, BIC: 5.30), suggesting potential overfitting. Thus, lag 2 was selected to ensure a robust and well-fitted model. The results are presented in Table 10, which indicate that renewable energy consumption (RENC) has a significant relationship with various economic and financial factors in BRICS countries. From Table 10's outcomes, we see that IACT has a positive and significant impact on RENC in both the long and short run. This shows that a 1% increase in IACT leads to a 0.0571% increase in RENC. This result aligns with previous studies [103,126] that emphasize how IACT fosters renewable energy adoption by improving energy efficiency by facilitating smart grids and promoting research in clean technologies. The possible reasons for these relationships in BRICS economies are due to digital infrastructure and smart technology that have played a crucial role in increasing the penetration of renewable energy. For instance, China and India have heavily invested in AI-driven energy management systems, while Brazil has integrated blockchain technology in renewable energy distribution [127]. As an outcome, the H6 hypothesis supports the study's results, as the findings demonstrate that IACT positively influences RENC in BRICS countries.

Additionally, our findings indicate that GDP negatively impacts RENC at a significant level. The outcome shows that if a 1% increase in GDP is made then it will give rise to RENC at the rate of 1.2217%. This negative association is consistent with the findings of [128,129], who suggest that high economic growth in developing nations often prioritizes fossil fuel consumption over clean energy due to cost efficiency and energy security concerns. The possible reasons for these relationships in BRICS are due to industrial expansion, which remains energy-intensive with a significant reliance on coal and oil-based energy sources. In support of this, we see from the literature that Brazil, Russia, and India continue to expand their industrial base with subsidized fossil fuels, which diminishes the urgency for a transition to renewable energy. Even though China is a leader in renewable energy investments, its energy mix remains coal-dominated, reflecting a trade-off between GDP growth and renewable energy consumption. As a result, this outcome highlights that if economic expansion is not accompanied by green policies, it could lead to increased carbon emissions and slow the transition toward renewable energy, ultimately hindering environmental sustainability. Furthermore, in line with this, H3 supports the study's results, demonstrating that GDP negatively impacts RENC in BRICS countries. Similarly, the analysis finds that CO_2 emissions negatively impact RENC at a significant level. This shows that a 1% increase in CO_2 emission reduces RENC by 1.0445%. This finding aligns with the work of [130,131] who argue that countries with high emissions tend to rely heavily on fossil fuels, making it more challenging to transition to renewable energy. Out of several reasons the one is that in BRICS economies, high CO_2-emitting industries such as manufacturing, mining, and transportation are heavily reliant on fossil fuels which are creating a lock-in effect that limits the adoption of renewable energy sources. Furthermore, weak environmental regulations in some BRICS countries, such as Russia, India, and South Africa, hinder the shift toward renewable alternatives. As a result, this strong dependence on fossil fuels not only undermines climate action but also contributes to increased environmental degradation. These findings emphasize the need for stricter carbon pricing policies and enhanced green financing mechanisms to accelerate the transition to cleaner energy. Moreover, in line with this, H1 supports the study's results, demonstrating that CO_2 emissions negatively impact RENC in BRICS countries.

Table 10. PMG-ARDL.

Variable	Coefficient	Std. Error	t-Statistic	Prob. *
		Long Run Equation		
IACT	0.057124 ***	0.019984694	2.858387547	0.0042
GDP	−1.22169 ***	0.471429462	−2.591458743	0.0095
FMEI	0.001357 ***	0.000462035	2.93700384	0.0033
FIEI	0.0356454 ***	0.011655213	3.058322359	0.0022
EDUC	0.3215547 **	0.150954677	2.130140688	0.0331
CO_2	−1.0444557 ***	0.325291012	−3.210834792	0.0013
		Short Run Equation		
ECT	−0.117789 ***	0.044343024	−2.656314075	0.0079
D(IACT)	0.023457 **	0.011492849	2.041008321	0.0412
D(GDP)	−0.246978 *	0.131949703	−1.87175866	0.0612
D(FMEI)	0.0045698 **	0.00222622	2.052717333	0.0401
D(FIEI)	0.0536698 *	0.030802381	1.742391284	0.0814
D(EDUC)	0.06565 **	0.032547487	2.017052834	0.0436
D(CO_2)	−0.22369 *	0.120073323	−1.862945034	0.0624

Note: ***, ** and * represent significance at 1%, 5% and 10%.

Furthermore, the results indicate that financial market efficiency (FMEI) positively influences RENC, with a 1% increase in FMEI leading to a 0.0014% increase in RENC. These findings are consistent with the work of [132,133], who argue that efficient financial markets channel more investments into renewable energy infrastructure. The possible reasons for such relationship in BRICS are mainly due to research evidence which states that stronger financial markets attract international green investments, facilitating large-scale renewable energy projects in these countries. As an example, China and India's expansion of green bonds and renewable energy subsidies has significantly improved the financial accessibility of clean energy projects. As result we can conclude that well-functioning financial markets can accelerate the adoption of renewable energy, thereby improving environmental quality. Additionally, in line with this, H2 hypothesis supports the study's results, demonstrating that FMEI positively influences RENC in BRICS countries. In a similar way, the results show that the FIEI also positively impacts RENC. This shows that a 1% increase in FIEI leads to a 0.0356% increase in RENC. This result aligns with the findings of [54,134], who emphasize that financial institutions provide crucial funding mechanisms that support the transition to clean energy. Furthermore, the literature shows that access to green finance and energy-specific loans enable private sector participation in renewable energy projects in BRICS countries which become the reason for such relationships. As it is evidenced from the literature, state-owned banks in China, Brazil, and Russia have provided low-interest financing for solar and wind energy projects, significantly enhancing the adoption of renewable energy. As a result, strong financial institutions play a vital role in bridging the funding gap for green energy projects, thereby accelerating the transition toward sustainability. This outcome of the study supports the H4 hypothesis because the result indicated that FIEI positively influences RENC in BRICS countries.

Finally, the results confirm that education (EDUC) also positively impacts RENC, showing a 1% increase in EDUC which lead to a 0.3216% increase in RENC. This finding aligns with the work of [135,136], who argue that higher education levels lead to greater environmental awareness and increased support for renewable energy policies. Furthermore, the literature evidence such results indicating that higher education fosters innovation in clean technologies, promoting research and development (R&D) in renewable energy. Additionally, public awareness campaigns and sustainability education programs in BRICS nations contribute to a societal shift toward renewable energy preferences. This result emphasizes that investing in education is essential for achieving long-term environmental sustainability. Furthermore, in line with the study outcomes, H5 supports the study's results, demonstrating that EDUC positively influences RENC in BRICS countries.

Moreover, the error correction term (ECT) quantifies the speed at which a system corrects itself from a temporary imbalance to a stable long-term state. Based on current studies, it is anticipated that the ECT parameter will have a significantly negative value. The PMG estimate indicates that the ECT is negatively valued and has statistical significance at the 1% level. The ECT coefficient, representing the rate of convergence towards equilibrium in the PMG estimate, is −0.117789. This suggests that the shift in variables from a temporary imbalance to a permanent equilibrium is a significant process, with an annual adjustment rate of 11.78% for the BRICS countries. Furthermore, the study outcomes have been shown in Figure 2.

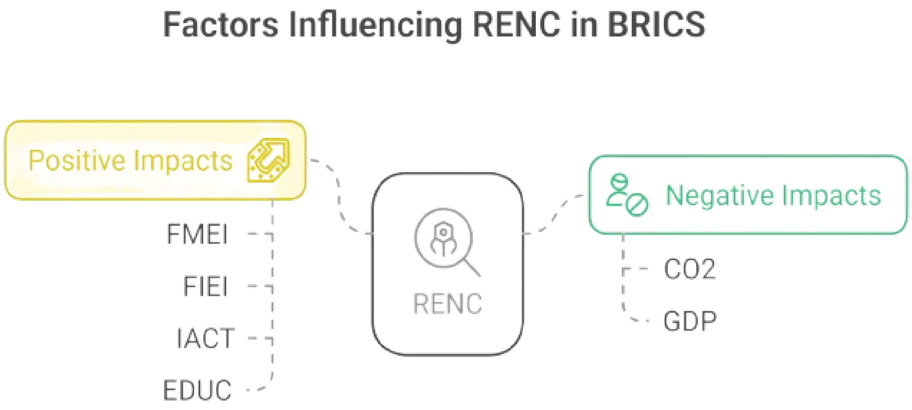

Figure 2. Study outcomes.

The study employs PMG-ARDL methodology to analyze both long-run and short-run outcomes. To ensure the robustness and reliability of the findings, we further validated the results using the FMOLS and GMM tests and results are reported in Table 11. These methods address potential issues such as endogeneity and serial correlation, ensuring the accuracy and consistency of the estimates. As demonstrated in previous studies [137], the use of FMOLS and GMM provides a non-parametric and instrumental variable approach to enhance the validity of the results. The findings from both FMOLS and GMM align with the PMG-ARDL results, supporting the robustness of the analysis.

Table 11. Robustness check through FMOLS and GMM.

Study-Variables	**FMOLS**		**GMM**	
	Coefficients	***p*-Value**	**Coefficients**	***p*-Value**
IACT	0.031250 ***	0.0046	0.025361 **	0.0131
GDP	−0.574669 ***	0.0015	−0.404191 **	0.0124
FMEI	0.136597 ***	0.0031	0.105324 **	0.0237
FIEI	1.350148 ***	0.0029	1.103951 **	0.0137
EDUC	0.176635 **	0.0307	0.125469 *	0.0594
CO_2	−1.365577 ***	0.0038	−1.102765 **	0.0237

Note: ***, ** and * show level of significance at 1%, 5% and 10%.

5. Conclusions and Policy Implications

Dealing with environmental degradation has emerged as a pivotal global issue over the past few decades. Inadequate regulations and policies in this field could potentially have profound repercussions on the economy, human welfare, and even our fundamental survival. To address ecological degradation and promote environmental sustainability, a multifaceted approach is essential led by government and non-government institutions to safeguard the environment. This paper concentrates on BRICS economies to properly address these kinds of problems and suggests some appropriate actions to address the issue. It aims to see the long term and short-term relationship between IACT, FIEI, FMEI, EDUC, GDP, and CO_2 on RENC. The PMG ARDL approach was employed to examine the impact of various variables on renewable energy consumption (RENC). The results reveal a significant negative relationship between GDP and CO_2 emissions with RENC, both in the long and short run. This suggests that as economic activity increases (represented by GDP), and as CO_2 emissions rise, the adoption of renewable energy may face challenges, potentially due to increased reliance on traditional energy sources associated with higher emissions. On the other hand, IACT (innovative energy technologies), FIEI (financial inclusion and energy investment), EDUC (education), and FMEI (financial market efficiency) exhibit a positive significant relationship with RENC in the long run. This indicates that investments in innovative technologies, improving financial access for energy-related projects, advancing education on renewable energy, and enhancing financial market efficiency can drive the transition to renewable energy sources.

The conclusion of this study provides several important policy implications for addressing environmental degradation and promoting environmental sustainability in BRICS economies. These implications can guide governments and non-government institutions in their efforts to safeguard the environment. It is clear that there is an urgent need to enhance rules and policies concerning environmental sustainability. Insufficient rules and policies may have significant consequences on the economy, human well-being, and even our basic existence. In light of the substantial influence of several variables on environmental deterioration, it is imperative for BRICS countries to give utmost importance to the establishment and implementation of strong environmental rules and policies. Emphasis should be placed on implementing strategies that target the reduction of carbon emissions (CO_2) and the advancement of sustainable environmental practices.

- As evidenced from the outcomes, GDP has a significant negative impact on RENC, suggesting that BRICS nations should focus on promoting green growth strategies within their economic planning. Policies aimed at decoupling economic growth from fossil fuel use can help increase the RENC while ensuring economic stability.

- Moreover, since CO_2 emissions have a negative relationship with RENC, it is important for BRICS nations to prioritize carbon reduction policies. These could include enforcing stricter environmental regulations, encouraging the use of carbon capture technologies and investing in renewable energy sources that are low in carbon emissions.
- As IACT shows a positive impact on RENC therefore, BRICS nations should prioritize the development and deployment of clean technologies by ensuring that IACT infrastructure is optimized to support renewable energy projects and energy efficiency initiatives.
- Furthermore, FMEI also positively impacts RENC, highlighting the need for BRICS nations to improve the efficiency of their financial markets. This could be achieved by enhancing access to capital for renewable energy projects, creating green financial products, and encouraging financial market reforms that support investments in the renewable energy sector.
- As EDUC also plays a key role in promoting RENC, therefore, investing in education and skill development programs focused on renewable energy, environmental sciences, and sustainability is essential. This will help build a workforce capable of supporting the transition to a green economy.
- Since FMEI is also positively related to RENC, hence, BRICS nations should work on improving their financial markets to facilitate investments in renewable energy projects. This can be performed by enhancing access to capital for green businesses and introducing financial products like green bonds.
- Additionally, BRICS nations should also align their renewable energy and climate change policies with global frameworks such as the Paris Agreement. This can be achieved by adopting Nationally Determined Contributions (NDCs) that prioritize renewable energy adoption, carbon reduction targets, and climate-resilient development strategies.
- Lastly, regional cooperation on renewable energy projects is key. BRICS countries should collaborate by sharing the best practices, technologies, and knowledge, which can strengthen energy security and lower costs by pooling resources for large-scale renewable energy infrastructure projects.

By adopting these strategies, BRICS nations can accelerate renewable energy adoption, promote sustainable development, and contribute to global climate change mitigation efforts.

This study provides valuable insights into the relationship between economic and financial variables and renewable energy consumption (RENC) in BRICS nations—Brazil, Russia, India, China, and South Africa. The findings highlight the significant role of economic growth, financial markets, and environmental factors in shaping RENC trends. However, certain limitations must be acknowledged. The use of the PMG-ARDL approach, while effective, may not fully account for cross-sectional dependence or endogeneity concerns. Additionally, data availability constraints and the exclusion of newer BRICS members, such as Iran, the United Arab Emirates, Egypt, and Ethiopia, may affect the generalizability of the results. Future research should consider expanding the scope to include a broader set of emerging economies to assess whether the findings hold across different regional and institutional contexts. Examining sectoral variations, such as the impact of RENC adoption in industrial, agricultural, and transportation sectors, could provide more granular insights. Furthermore, incorporating technological innovation, government policies, and regulatory frameworks into the analysis would deepen the understanding of how policy-driven initiatives influence RENC, particularly in light of global climate goals. To enhance methodological rigor, future studies could address potential endogeneity issues and employ advanced econometric techniques, such as CS-ARDL or MMQR, to capture heterogeneous effects across different economies. Additionally, utilizing updated datasets extending beyond 2020 would allow for a more comprehensive and policy-relevant analysis. Investigating the role of financial efficiency, green finance, and regional cooperation in scaling renewable energy projects could also yield valuable insights for policymakers and investors. Furthermore, as our study does not specifically use the Hansen J-test and Arellano–Bond test, future research could consider employing these methods to confirm instrument validity and check for autocorrelation, further enhancing the robustness of econometric models in addressing potential endogeneity concerns. By addressing these future research avenues, subsequent studies can build upon this work, offering a more robust understanding of the economic, financial, and policy-driven determinants of renewable energy consumption in emerging economies.

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