Energy Strategy Reviews 54 (2024) 101434

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.elsevier.com/locate/esr

Unravelling the role of financial development in shaping renewable energy consumption patterns: Insights from BRICS countries

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A R T I C L E I N F O

Handling Editor: Mark Howells

Keywords:
BRICS economies
Carbon-reduction
FDI
Financial deepening
Inflation
Panel econometrics
Renewable energy consumption

A B S T R A C T

In line with the pursuit of clean and affordable energy, our study contributes to the United Nations Sustainable Development Goals (UNSDGs-7 and -13) and the global fight against climate change by offering evidence-based insights. We conducted a panel analysis of BRICS (Brazil, the Russian Federation, India, China, and South Africa) economies to investigate the relationship between financial development and renewable energy utilization. Our empirical findings highlight a positive statistical association between economic growth and renewable energy consumption, indicating that higher economic growth correlates with increased renewable energy adoption. Similarly, significant positive relationships are observed between the consumer price index and domestic credit with renewable energy consumption. Moreover, our study also uncovers a counterintuitive relationship between foreign direct investment and renewable energy consumption. These results provide valuable insights into the determinants of renewable energy consumption in BRICS countries. From a policy perspective, we advocate for robust strategies to promote the adoption and utilization of renewable energy sources alongside the implementation of policies encouraging the uptake of clean technologies. Such measures can spur economic growth and contribute to achieving low-carbon targets and sustainability goals within the BRICS economies. Practical steps, including incentives like feed-in tariffs and subsidies, can further enhance the cost-effectiveness of renewable energy adoption in the investigated bloc.

1. Introduction

Climate change has emerged as a critical and widely acknowledged issue of our time, transcending its theoretical origins. Its profound impact has reshaped the socio–economic landscapes of nations worldwide. The concerning aspect of climate change and global warming lies in their significant spillover effects, impacting societies and economies. This situation was strikingly exemplified by the unprecedented and devastating flood that devastated Pakistan last year, inflicting not only economic hardships but also profound psychological trauma on the affected population. The recovery process from such a calamity may span years or even prove insurmountable.

Moreover, the flood's repercussions extended beyond human beings, threatening animals and livestock, thereby exacerbating the challenge of

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https://doi.org/10.1016/j.esr.2024.101434
Received 28 February 2024; Received in revised form 15 May 2024; Accepted 31 May 2024
Available online 3 June 2024

ensuring sufficient nutrition. The complex issue of climate change is influenced by various factors, with one prominent driver being the extensive utilization of fossil fuels [1] to meet energy demands. The combustion of these fuels releases numerous greenhouse gases into the atmosphere, which are primary contributors to global warming [2]. Consequently, this not only leads to rising temperatures but also gives rise to a range of health issues.

The escalating energy demands nations face have further compounded the challenges climate change poses. A notable case is India's energy demand surge following its Liberalization, Privatization, and Globalization (LPG) reforms, which resulted in a staggering increase in carbon emissions from 611 million metric tons in 1991 to approximately 2571 million metric tons in2022.[1] Reducing dependence on fossil fuels for energy needs represents one of the most effective strategies for addressing the climate change crisis [3]. Renewable energy sources have demonstrated their potential as cleaner alternatives by harnessing solar and wind power to produce energy without emitting carbon dioxide into the environment [4]. However, the initial high costs associated with implementing renewable resources pose a barrier for potential investors in renewable energy projects. Therefore, governments must intervene and implement measures that bridge the financing gap, ensuring the viability and attractiveness of renewable energy investments [5].

Establishing a connection between renewable energy and economic growth is essential for sustainable development. By emitting greenhouse gases, fossil fuels cause environmental pollution [6]. However, renewable energy sources provide an alternative that is less environmentally harmful. Evidence indicates that using renewable energy sources does not impede the economy's expansion, regardless of whether the countries in question are developing or developed. However, the relevance of the consumption of renewable energy sources for economic expansion may differ. This situation demonstrates the importance of striking a compromise between reducing pollution and contributing to economic development, particularly in the face of obstacles like the COVID-19 pandemic. As a result of the good influence that renewable energy has on economic growth, developing countries are strongly encouraged to prioritize investments in renewable energy. More specifically, the economies that comprise the BRICS group have demonstrated a good association between the growth of the economy and the consumption of renewable energy. This observation highlights how important it is to migrate towards renewable energy sources while simultaneously encouraging economic development.

While renewable energy projects may initially incur high costs, scalability is pivotal in reducing expenses [7]. Governments should also consider providing tax rebates and subsidies to foster the growth of the renewable energy sector. Several studies highlight the influence of financial sector growth on renewable energy employment [3]. However, high inflation acts as an inhibitor to renewable energy consumption (REC), as it brings economic uncertainty that makes investors hesitant to invest in a country, consequently impacting foreign direct investments (FDI) in the renewable sector [8]. Renewable energy is expected to play a critical role in the future energy landscape as the need for energy continues to grow, and there is a strong commitment to addressing global warming, facilitated by technological advancements and policy support that make renewable energy more affordable and accessible [9].

In pursuing sustainable growth, the nexus between financial development and renewable energy becomes paramount, particularly for economies of the BRICS nations, where rapid economic expansion meets escalating energy needs. Financial development offers the requisite capital, risk mitigation, and investment incentives that can spur the adoption and innovation of renewable energy technologies [10]. The depth, efficiency, and accessibility of financial markets are increasingly recognized as fundamental drivers for renewable energy projects, providing the financial infrastructure necessary to facilitate this energy transition. Consequently, understanding the mechanisms through which financial development impacts REC becomes essential for economic theorists and policymakers seeking to harness the potential of finance to achieve environmental sustainability.

As previously emphasized, global warming and climate change are no longer mere theories but are recognized as pressing problems, affecting nations worldwide, including the BRICS nations. The BRICS countries, comprising Brazil, Russia, India, China, and South Africa, are renowned for their significant economic growth and emerging market status. Among them, China ranks second on the list of the world's largest economies, with India at fifth [11]. Collectively, the BRICS countries contribute approximately 32 % to the world's Gross Domestic Product (GDP). This growth is projected to continue, causing an annual surge in energy demand of 2.5 %.[2]

Moreover, the proportion of renewable energy in the overall energy mix varies widely among the BRICS nations, with China having the lowest share at 4.5 % and Brazil leading with the highest share at 17.7 %.[3] This disparity can be attributed to various factors, including different levels of economic development, energy policies, and resource endowments. The consequences of global warming on the socio–economic landscape of the BRICS nations is of grave concern. These countries possess large populations, high levels of industrialization, and growing energy needs, rendering them particularly vulnerable to the effects of global warming.

This study aims to explore the relationship between financial development and renewable energy utilization in the BRICS countries, an area that has received limited attention in previous research. The study examines this relationship over 27 years, from 1995 to 2022. The BRICS nations are notable for being the largest emerging economies, characterized by rapid growth and substantial variations in REC and GDP growth rates. By delving into this unexplored area of research, the study aims to bridge existing knowledge gaps and offer fresh perspectives on the interplay between the effectiveness and efficiency of the financial sector and the transition toward sustainable energy systems in the BRICS nations. This research sets itself apart by focusing on REC in the influential BRICS economies and extending the analysis period by capturing the pertinent role of Consumer Price Index (CPI) dynamics in the renewable energy mix. Thus, the nexus between CPI and REC in BRICS nations is worth studying. First, the CPI illuminates these nations' economies. The CPI measures urban consumers' average price changes for a basket of goods and services.

OECD data shows inflation rates fluctuating, including a reduction in March 2023 due to energy inflation falling after a jump in March 2022. This situation highlights the complex relationship between energy prices and consumer spending patterns and how they affect inflation. In parallel, BRICS renewable energy usage poses problems and opportunities. BRICS nations use 16 % of global renewable energy, but their use is steadily increasing, helping low-carbon development. Member states vary, with South Africa needing to increase renewable energy use and reduce coal mining. This observation emphasizes the need for country-specific energy strategies addressing geographical, economic, social, and environmental aspects. The CPI–REC relationship has wider implications for global energy transitions and financial stability. As BRICS countries move to cleaner energy, their efforts shape global energy policies and promote sustainable development. Discussions on renewable energy cooperation within the BRICS framework show that collaboration and knowledge-sharing can accelerate this transition and mitigate climate change. While the CPI and REC may not be directly related, their interconnected dynamics highlight energy's importance in economic stability, environmental sustainability, and global progress. As BRICS countries design their energy trajectories, informed policy decisions and collaboration will help create a robust and sustainable

[1] https://www.statista.com/.

[2] International Energy Agency (IEA), World Energy Outlook 2022, p.16.

[3] REN21, Renewables 2022 Global Status Report, p.10.

energy future. The results of this study carry substantial implications for policymakers, investors, and stakeholders actively promoting the energy transition agenda in these influential economies.

Based on our current understanding, this study represents one of the first quantitative examinations of the impact of financial development on REC, specifically within the BRICS nations. Our study employs a robust panel econometrics framework to systematically examine the relationship between financial development and REC. We utilize annual time-series data from 1995 to 2022 for the BRICS nations, employing fixed effect and time-stamped panel models to account for unobserved heterogeneity and time-varying influences. This methodological approach allows us to rigorously test the impact of various economic indicators on REC, including domestic credit provided by financial institutions, GDP per capita, consumer price indices, and FDI. In BRICS economies, renewable energy use depends on domestic credit. Credit lets firms and individuals invest in solar panels, wind turbines, and biofuel projects. Due to lower funding constraints, renewable energy projects are more popular in economies with freely available domestic credit. This scenario helps install renewable energy technology, lowering fossil fuel use and boosting sustainable development.

Conversely, limiting credit can delay renewable energy investment and the move to cleaner energy. Thus, strategies to increase domestic credit availability and promote renewable energy finance channels are necessary to accelerate BRICS renewable energy adoption and achieve long-term environmental and economic advantages. Meanwhile, for FDI influx dynamics, BRICS economies' REC is heavily influenced by FDI. Capital, technology, and knowledge from FDI can promote renewable energy project development and deployment. FDI in BRICS countries targets renewable energy sectors due to their development potential and sustainability goals. FDI boosts renewable energy infrastructure, production, and access. FDI also boosts renewable energy demand and investment by promoting innovation and competition. FDI drives renewable energy demand in BRICS economies, helping them achieve energy transition and sustainable development goals. The same can also be said for financial development and its implications for the BRICS blocs, where financial development's impact on BRICS countries' green energy use is enormous. Financial development, especially lending and investment options, can accelerate renewable energy adoption.

The move to renewable energy sources reduces the consumption of fossil fuels and promotes sustainability. Strong financial systems can fund renewable energy projects and boost the industry. The findings highlight the importance of financial development in BRICS nations' shift to cleaner energy, which affects economic growth, environmental sustainability, and global energy security. To this end, the present study examines theses variables in an econometric framework. The used econometrics setting will aid in addressing potential endogeneity issues and ensure the reliability of our findings, providing a solid foundation for policy implications. The research outcomes are expected to provide valuable insights for policymakers, guiding them in formulating effective strategies to promote REC in countries that substantially contribute to the world's GDP but still heavily rely on fossil fuels for their energy demands. These action steps can be achieved via the involvement of government apparatus and public–private partnership (PPP) in policy crating chat the course for the promotion of increased demand and increased consumption of renewable energy in BRICS economies as it engenders attraction of more FDI investment in REC via direct and indirect channels.

This study provides a comprehensive 27-year analysis (1995–2022) of the relationship between financial development and renewable energy consumption (REC) in BRICS nations. By employing fixed effect and time-stamped panel models, it rigorously examines the impact of financial variables like domestic credit, GDP per capita, CPI, and FDI on REC. Additionally, it uniquely explores the role of CPI dynamics in the renewable energy mix, highlighting the interplay between economic stability and energy transitions. Our findings offer actionable policy recommendations to guide BRICS policymakers in promoting sustainable economic growth through enhanced financial development.

The subsequent sections of this paper are structured as follows: Section 2 provides a brief overview of the relevant theoretical background, Section 3 describes the data and methodology employed in the study, Section 4 presents the empirical findings, Section 5 and Section 6 conclude the paper with a conclusion and policy implications derived from the findings, respectively.

2. Literature review

The influence of a well-established financial system on economic progress is widely acknowledged in both low- and high-income countries [12]. In a comprehensive study by Guru and Yadav [13], the spillover effects of financial development indicators, including banking, credit supply by non-banking finance companies, and FDIs, were demonstrated in the growth of BRICS nations. This observation raises an interesting question regarding the potential impact of a developed financial sector on REC. Three potential pathways linking financial development and energy consumption have been identified by Çoban and Topcu [14]: direct influence, corporate influence, and the wealth effect. A well-functioning financial sector not only enables individuals to access and acquire durable goods and services but also stimulates demand in the economy through accessible and affordable credit [15]. Additionally, it directs funds toward increasing energy demand, leveraging the trust individuals place in well-established financial markets [16].

As [17] pointed out, financially developed markets typically exhibit higher liquidity and offer diverse financial products, which can mitigate the funding constraints often encountered by renewable energy technologies. The introduction of green bonds and dedicated renewable energy funds are prime examples of how financial instruments can mobilize individual and institutional investors towards sustainable energy projects [18].

The financial sector's evolution has paved the way for specialized financial instruments that cater specifically to the needs of renewable energy projects. These instruments may include preferential interest rates on green loans and government grants for developing renewable technologies. Employing a nonlinear autoregression distributed lag model [19], critically analyzed the impact of financial development on REC across China's 30 provinces from 2000 to 2020. The findings indicate that financial development significantly bolsters renewable energy usage, with a 1 % increase in financial development translating to a 0.24 % rise in REC. This study offers a viable framework for boosting socially and economically sustainable renewable energy investments in China and sets a precedent for other energy-importing nations aiming to meet post-pandemic sustainability targets. Additionally, financial mechanisms such as risk-sharing facilities and credit enhancements can significantly lower the perceived risks associated with investments in renewable energy, thereby attracting a broader base of financiers [20–22].

The study by Ref. [23] shed light on the impact of financial development on renewable energy across 103 economies, highlighting the positive influence of well-developed financial institutions, particularly banks, on REC. Using a dynamic panel model, it reveals that while financial institutions in developed economies robustly support renewable energy initiatives, in developing economies, the effect is restricted to the institutional level only, suggesting a disparity in financial infrastructure's effectiveness. However, the study overlooks the specific financial needs of SMEs engaged in renewable technologies, which benefit significantly from a well-established financial system that improves market efficiency and facilitates quicker and easier access to capital. This gap suggests that further exploration is needed to enhance policy relevance and practical financial support mechanisms in the renewable energy sector, particularly for SMEs lacking sufficient collateral or operating on a small scale.

Numerous studies have investigated the relationship between financial development and the demand for cleaner energy sources, but their findings have been inconsistent. These studies can be categorized into three groups based on their findings. First, some studies show a positive relationship between financial development and the demand for cleaner energy. For instance, employing the fully modified OLS approach found a positive relationship between financial sector growth and the demand for environmentally friendly energy. Expanding on this research [3], incorporated the inflation variable and employed autoregressive distributed lag and vector error correction models to examine the impact of financial sector development on the demand for cleaner energy sources in Turkey. Similarly [24], utilized the quantile autoregressive distributed lag (QARDL) technique and revealed a significant positive relationship between financial sector efficiency and the demand for renewable energy. Other studies [4] have explored the impact of stock market parameters, such as the value of stocks traded and stock turnover, on the demand for cleaner energy sources and have also found a positive and significant relationship.

However, not all studies have yielded similar results. For example [25], reported that efficient and effective financial development does not necessarily increase the demand for cleaner energy [26,27]. specifically focused on advanced economies with high per capita income, analyzing data from 1990 to 2014. They examined the bond market as a component of the financial sector and found no evidence of it stimulating a rise in REC.

Interestingly [27], conducted a study that produced contrasting findings. They discovered that the development of the financial sector attenuated energy demand. Instead, they emphasized urbanization's significant and positive role in driving energy demand. Consistent with this [25,26], obtained similar results, highlighting that financial development contributes to a decline in REC.

Considering the varied findings from previous studies, further research is necessary to understand the relationship between REC and financial development, particularly within the context of the BRICS countries. Thus, the objective of this study is to fill this gap and investigate the complex relationship between REC and financial sector development in the BRICS countries.

The efficiency and effectiveness of financial institutions play a critical role in stimulating economic progress. A well-developed financial system, characterized by efficiency, effectiveness, transparency, and accessibility, adds to the overall growth and development of the economy [10,28]. This situation can be observed through various indicators such as FDI, the performance of the banking sector, income levels, and economic growth. In this study, proxy variables are utilized to represent these four parameters.

A significant aspect of a developed financial sector is its ability to provide affordable credit, attracting more capital and fostering increased economic activities. As a result, there is a subsequent surge in energy demand [29]. The spillover impact of financial development on energy consumption is comprehensively explained by Ref. [14] through their three-effect channel: direct effect, business effect, and wealth effect.

In summary, while existing studies have laid a foundational understanding of the financial determinants of REC, inconsistencies remain, particularly in emerging economies like the BRICS. Our review reveals that while some aspects of financial development are consistently associated with increased REC, others show a more complex and sometimes inverse relationship. These nuanced insights form the bedrock of our hypotheses, anticipating that financial development within BRICS might exhibit a multifaceted influence on REC that warrants a detailed empirical investigation. Therefore, based on the aforementioned theoretical foundation, the hypothesis to be tested in the present study is that financial development positively impacts REC.

Table 1
Definition of variables.

Variables	Definition	Source
REC	Percentage of renewable energy consumption in total energy consumption	World Development Indicators
DCPS	Domestic credit provided by the financial sector	World Development Indicators
GDPPC	Percentage change in GDP per capita based on the purchasing power parity (Constant 2017 International)	World Development Indicators
CPI	Consumer price index (2010 = 100) is a measure of the average change in prices paid by consumers for a basket of goods and services. The basket of goods and services may be fixed or changed at specified intervals. The CPI reflects the changes in the cost of the basket of goods and services to the average consumer.	World Development Indicators
FDI	Foreign direct investment, net inflows (% of GDP)	International Monetary Fund
GDPG	GDP growth (annual %)	World Bank

3. Data and methodology

3.1. Data

The study utilizes annual time–series data from five prominent nations comprising BRICS from 1995 to2022.[4] This time frame was selected based on data availability and reliability to ensure a comprehensive analysis. The dependent variable in the study is REC, which serves as an indicator of sustainable energy usage. To assess the economic context, GDP per capita is employed as a measure of income, adjusted for constant purchasing power parity prices in 2017 US dollars. Due to the unavailability of specific energy price data, the CPI is used as a proximate indicator following previous studies [4]. Domestic lending by financial institutions (DCPS) is a representative variable used to estimate the development of the financial sector. Additionally, net FDI inflows are considered as a percentage of GDP, reflecting each country's foreign investment level. The World Bank, the International Monetary Fund, and other reputable sources provide country-specific variables such as REC, GDP per person, and GDP growth, facilitating an extensive analysis of the relationships between REC and various economic factors within the BRICS countries. Table 1 outlines variables, unit of measurement and data sources.

3.2. Methodology

In the present study, after conducting a Hausman test, we decided to select the entity-specific effects panel model over the time-variant effects panel model (see Fig. 1). This decision was influenced by the inherent assumption in the time-variant effects model that unobserved heterogeneity between entities is uncorrelated with the independent variables. Should the period covered by the study not be extensive enough, a potential correlation between unobserved heterogeneity and the independent variables could render the time-variant effects model inappropriate. Consequently, the entity-specific effects panel model was

[4] However, it should be noted that complete data availability was limited for the renewable energy consumption (REC) variable up to 2019, for foreign direct investment (FDI) up to 2021, and for gross domestic product (GDP) up to 2021. To address this data limitation, ARIMA-based predictions were employed to estimate values for REC, GDP, and FDI beyond their available data points. The ARIMA model was utilized to generate predicted values, enabling a more comprehensive analysis of the relationships between these variables and other factors within the specified time frame. These predicted values were integrated into the dataset to ensure a more complete representation of the variables of interest throughout the study period.

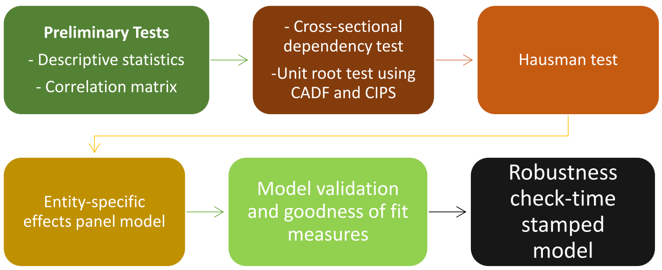

Fig. 1. Empirical analysis flow.

deemed the most suitable for our analysis, aligning with the methodologies used in the studies by Ref. [4].

The research examines the relationship between REC, which is our dependent variable, and various independent variables, including economic growth (GDPG), income (GDPPC), domestic credit from the financial institutions (DCPS), CPIs, and FDIs. These variables are chosen based on previous studies [4] that explored the factors influencing REC.

The equation of the model is as follows:

$$REC_{it} = \beta_0 + \beta_1 DCPS + \beta_2 GDPPC + \beta_3 CPI + \beta_4 FDI + \beta_5 GDPG + c_i + \varepsilon_t \tag{1}$$

where: REC_{it} represents REC for entity i at time t, and DCPS, GDPPC, CPI, FDI, and GDPG represent the exogenous variables. β_0, β_1, β_2, β_3, β_4 and β_5 are the coefficients of the respective variables, c_i in the model equation represents an unknown country-specific constant and ε_t represent the error term, which accounts for the heteroskedasticity in the model.

The general specification for the fixed effect can be represented as follows:

$$Y_{i,t} = \alpha_i + X_{i,t} \times \beta + \varepsilon_{i,t} \tag{2}$$

Robust standard errors were used in the model estimation to address heteroskedasticity and provide more reliable inferences.

To enhance the reliability and credibility of our analysis, we integrate a robustness check utilizing fixed effects within the model, commonly known as a time-stamped model. This methodological choice enables us to delve deeper into the intricate relationship between REC and the independent variables by effectively controlling for unobserved time-varying factors that might otherwise confound our findings [30].

These factors encompass a broad spectrum of dynamic phenomena, ranging from shifts in governmental policies to fluctuations in the global economic landscape and natural disasters. By incorporating the time-stamped model into our analytical framework, we ensure a more comprehensive understanding of the determinants of REC within the BRICS nations, thus enhancing the robustness of our conclusions. Moreover, the time-stamped model offers several distinct advantages. Firstly, it facilitates comprehensive control over unobserved time-varying factors, thereby minimizing the risk of omitted variable bias and bolstering the validity of our results [31]. Secondly, by incorporating lagged variables and time-specific effects, this model provides valuable insights into the persistence of the effects of independent variables on REC over time, enriching our analysis with a dynamic perspective [32].

The justification for employing the time-stamped model is grounded in established methodological principles and supported by seminal works in the field of panel data analysis. For instance, the pioneering work of [33] laid the foundation for applying fixed effects within models to control for time-varying factors in empirical research. Similarly, the seminal contributions by Ref. [34] underscore the importance of accounting for time-specific effects in panel data analysis, further validating the appropriateness of the time-stamped model for our study. The following equation shows a time-stamped model for the study:

$$\begin{aligned} REC_{it} = {} & \alpha_i + \beta_1 Lag(REC_{it-1}) + \beta_2 DCPS_{it} + \beta_3 GDPPC_{it} + \beta_4 CPI_{it} + \beta_5 FDI_{it} \\ & + \beta_6 GDPG_{it} + \gamma_t + \varepsilon_t \end{aligned} \tag{3}$$

where: REC_{it} represents REC for entity i at time t and Lag (REC_{it-1}) represents the lagged value of REC for entity i at time $t-1$. Further, $DCPS_{it}$, $GDPPC_{it}$, CPI_{it}, FDI_{it}, and $GDPG_{it}$ in the equation represents exogenous variables for entity i at time t. α_i represents the individual fixed effect for entity I, whereas, β_1, β_2, β_3, β_4, β_5, and β_6 represent the coefficients of the respective variables. γ_t represents the country-specific fixed effect. And ε_t represents the error term.

4. Empirical results and discussion

4.1. Empirical results

Table 2 presents the summary statistics for the complete panel dataset encompassing the countries that constitute BRICS. The descriptive statistics reveal a significant cross-country variation in REC within our sample, as evidenced by the standard deviation of 17.68. Among the five BRICS nations, Brazil exhibits the highest proportion of REC, accounting for 45.87 %. Conversely, Russia has the lowest level of REC at a mere 3.58 %, from 1995 to 2022. Thus, it is evident that Russia is performing inadequately in terms of REC.

The financial development variable (DCPS) exhibits substantial inter-country and temporal variations. Among the countries examined, China records the highest values of credit provided by financial institutions, while Russia lags behind the rest. Similarly, other variables such as economic development (GDPG), CPI, and FDI also display comparable levels of variation.

The study evaluates the presence of correlation and multicollinearity using correlation matrices and eigenvalues as presented in Table 3. REC negatively correlates with domestic lending from (DCPS, a proxy for financial development. Additionally, the correlation matrix between the variables of interest shows that CPI is highly correlated with GDPG.

Based on these findings, we conclude that REC can be represented as a function of DCPS, GDPPC, CPI, FDI, and GDPG. We also employ a test for multicollinearity using extracted eigenvalues. The results of this test suggest that multicollinearity is not a problem, as the average eigenvalue of the variables was 1.56.

Moreover, we analyzed cross-sectional dependency (CSD) to verify the presence of interdependencies among sections. The results of the CSD analysis are detailed in Table 4. Following this, we apply second-generation unit root tests, particularly the cross-sectional augmented lm-Pesaran (CIPS) and covariate augmented Dickey–Fuller (CADF), as developed by Ref. [35], to evaluate stationarity levels. The findings from these panel unit root tests are displayed in Table 5. The results indicate that the variables achieve stationarity at level (I–0) or after the first difference (I–1).

Table 6 shows the main results. The study investigates the relationship between REC and several key explanatory variables using a fixed effects panel data analysis. The analysis assesses the influence of domestic lending from the DCPS, GDPPC, CPI, FDI, and GDPG on REC. The

Table 2
Summary statistics.

Variable	Mean	Std. Error	Median	Std. Deviation	Minimum	Maximum
REC	25.47	1.38	18.56	17.68	3.18	58.65
DCPS	72.09	3.36	58.08	43.18	11.54	190.69
GDPPC	2.79	0.83	3.24	10.61	−92.82	53.15
CPI	88.29	4.02	81.84	51.60	0.00	204.48
FDI	2.10	0.13	1.81	1.68	−0.06	9.95
GDPG	4.04	0.37	4.50	4.74	−14.53	14.23

Source: Author's calculation

Table 3
Correlation matrix analysis.

	REC	DCPS	GDPPC	CPI	FDI	GDPG
REC	1					
DCPS	−0.30306	1				
GDPPC	−0.13569	0.148176238	1			
CPI	−0.11818	0.300943881	0.062359	1		
FDI	0.006108	0.152627296	0.198201	0.328368	1	
GDPG	0.165031	0.251914025	0.390915	0.083087	0.340973	1

Source: Author's calculation

Table 4
Cross-sectional dependency test.

Variables	REC	DCPS	GDPPC	CPI	FDI	GDPG
Pesaran CD	8.146	4.914	−1.273	3.817	7.947	4.245
p-value	0.000	0.002	0.000	0.000	0.000	0.004

Authors' calculation

Table 5
Unit root testing using CADF and CIPS methods.

Variables	Covariate Augmented Dickey–Fuller (CADF)		Cross-sectional augmented lm-Pesaran (CIPS)	
	I (0)	I (1)	I (0)	I (1)
REC	1.927[b]	−6.967[b]	−1.914	−6.115[b]
DCPS	6.237	−6.753[b]	−2.425	−5.017[b]
GDPPC	−3.147[b]	−21.117[a]	−3.917[b]	−6.217[b]
CPI	−8.417[b]	−17.023[a]	−5.467[b]	−7.201[a]
FDI	−2.946[b]	−6.923[b]	−2.992[b]	6.127[b]
GDPG	−1.993	−10.237[b]	−2.119	−3.517[b]

[a] ' indicates moderate significance at the 0.001 level.
[b] ' indicates lower significance at the 0.05 level.
Authors' calculation.

Table 6
Main regression results.

Variables	Parameter	Std. Error	T-stat	p-Value
CPI	0.0811	0.0294	2.7578	0.0065**
DCPS	0.2492	0.3502	2.9803	0.1308
FDI	−0.6629	1.0216	2.9003	0.0013**
GDPG	0.8642	4.3723	1.7986	0.0540**
GDPPC	0.5823	0.5925	1.5075	0.1337
Observations	165	165	165	165
No. of Countries	5	5	5	5
Year FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes

Authors' calculation.
'***' indicates moderate significance at the 0.001 level.
**' indicates lower significance at the 0.05 level.

results unveil compelling insights into the determinants of REC. Empirical findings suggest a positive relationship between GDPG and REC, consistent with previous research [4,27]. The coefficient estimate for GDPG is positive (0.8642) and statistically significant (p-value = 0.0540). The coefficient estimate for DCPS is also positive (0.2492) but not statistically significant (p-value = 0.1308). These results suggest that changes in domestic lending provided by financial institutions do not substantially influence the demand of renewable energy when controlling for other factors.

Regarding GDPPC, the coefficient estimate is positive (0.5823), implying that greater GDP per capita is indicative of higher REC levels. However, the statistical significance of this relationship was not established (p-value = 0.1337). Hence, the effect of GDPPC on REC requires further investigation or consideration of additional factors that might influence the relationship. In terms of CPI, the coefficient estimate is positive and statistically significant (0.0811, p-value = 0.0065*), which is in line with the findings of [36]. This finding suggests that higher consumer prices, as the CPI indicates, encourage greater adoption of clean energy sources.

Interestingly, FDI exhibited a negative coefficient estimate (−0.6629) and was statistically significant (p-value = 0.0013**), indicating that higher levels of FDI as a percentage of GDP are associated with lower REC. The result is in line with the findings of [4]. There could be two possible explanations behind this counterintuitive relationship. First, it may suggest that FDI may divert attention and resources away from renewable energy initiatives, leading to a decrease in their adoption or utilization; and second, FDI may lead to technological enhancement that may lead to a reduction in energy demand. Additionally, the coefficient estimate for GDPG was positive (0.8642), suggesting a positive association between GDP growth and REC. However, the statistical significance of this relationship was marginally insignificant (p-value = 0.0540**), warranting further investigation or the inclusion of additional explanatory variables.

The goodness-of-fit statistics and robustness of the model were assessed to evaluate the reliability and validity of the fixed effects panel data analysis (Table 7). The R-squared (Between) value was calculated to be 0.7212. This value represents the proportion of variation in REC attributed to differences between countries rather than within-country variation. The higher R-squared (Between) value indicates that country-specific characteristics can explain a significant portion of the total variation in REC. This finding suggests that country-level factors not captured by the included independent variables may play a substantial role in shaping REC.

The obtained F-statistic of 54.029 suggests that the model is statistically significant, indicating that the independent variables jointly explain a significant portion of the variation in REC. The Adjusted R-squared of 0.6137 indicates that the included independent variables can explain approximately 61.37 % of the variation in REC, adjusted for the number of variables in the model.

Overall, the robustness analysis indicates that the model adequately explains a significant portion of the variation in REC. The inclusion of robust estimation techniques and the assessment of model fit statistics provide confidence in the reliability and validity of the findings, enhancing the robustness of the research conclusions.

We employed the time-stamped model to assess whether the relationship (as found in the fixed effect model) between the variables remains stable and consistent. On the other hand, this cross-verification of the results through a time-stamped model will further strengthen the validity and reliability of the research findings (Table 8). It is evident from the findings that the time-stamped model strengthens our findings

Table 7
Model validation and goodness of fit measures.

Parameter	Values
R-squared	0.6354
R-squared (Between)	0.7212
F-statistic (Robust)	54.029
Adjusted R-squared	0.6137
Covariance Estimator	Robust

Source: Authors' calculation

and makes it more reliable. Additionally, it indicates that the lagged REC variable [lag (rec, 1)] has a highly significant positive effect on current REC, with an estimated coefficient of 0.504 ($p < 0.001$). This result indicates that past REC has had a substantial influence on current levels of consumption.

The overall model demonstrates a good fit to the data, explaining a substantial portion of the variation in REC as rendered in Table 9. The R-squared value of 0.651 indicates that the included variables can account for about 65.1 % of the variation in REC. The adjusted R-squared value of 0.633, which considers the number of predictors in the model, suggests that 63.3 % of the variation is explained while penalizing for model complexity.

The F-statistic of 37.677 is highly significant ($p < 0.001$), providing strong evidence that the overall regression model is meaningful and that, collectively, the independent variables contribute significantly to explaining the variation in REC.

4.2. Discussion

The empirical analysis conducted in this study provides valuable insights into the relationship between REC and various economic factors within the BRICS nations. Our findings shed light on several key aspects that contribute to understanding the dynamics of renewable energy adoption and its determinants in these countries.

First and foremost, our results reveal a significant positive relationship between GDPG and REC, which aligns with previous research by Ref. [37]. The positive coefficient estimate for GDPG suggests that robust economic growth stimulates the demand for renewable energy sources. This finding underscores the importance of economic development in driving the transition toward sustainable energy practices.

Furthermore, our analysis indicates a positive association between CPI and REC, consistent with the findings of [38]. Higher consumer prices, as reflected by CPI, appear to incentivize greater adoption of renewable energy sources. This trend reflects a growing recognition of clean energy technologies' environmental and economic benefits.

Interestingly, our study also uncovers a counterintuitive relationship between FDI and REC. The negative coefficient estimate for FDI suggests that higher levels of FDI as a percentage of GDP are associated with lower REC. Two potential explanations for this relationship are posited: (a) FDI may divert attention and resources away from renewable energy initiatives, leading to decreased adoption or utilization, and (b) FDI may drive technological enhancements that reduce overall energy demand.

Moreover, our analysis indicates a positive but statistically insignificant relationship between DCPS and REC. While the coefficient estimate for DCPS is positive, its lack of statistical significance suggests that changes in domestic lending do not substantially influence the demand for renewable energy when controlling for other factors [23]. This finding highlights the need for further investigation into the role of financial mechanisms in promoting renewable energy adoption.

Regarding GDPPC, our results suggest a positive but statistically insignificant relationship with REC. While the coefficient estimate for GDPPC is positive, its lack of statistical significance indicates that the effect of GDP per capita on REC requires additional exploration or consideration of other influencing factors.

The robustness analysis confirms the reliability and validity of our model, with the fixed effects panel data analysis explaining a significant portion of the variation in REC. The inclusion of robust estimation techniques and assessment of model fit statistics provide confidence in the robustness of our findings. Additionally, the validation of results through the time-stamped model strengthens the reliability of our findings, further supporting the stability of the relationship between the variables over time.

Table 8
Time-stamped results.

Variables	Parameter	Std. Error	T-stat	P-value
lag (REC, 1)	0.504	0.046	11.082	0.000***
CPI	0.058	0.018	3.285	0.001***
DCPS	0.124	0.156	2.124	0.761
FDI	−0.117	0.194	−0.599	0.006***
GDPG	0.321	0.084	3.826	0.0002***
GDPPC	0.219	0.327	1.132	0.182
Observations	165	165	165	165
No. of Countries	5	5	5	5
Year FE	Yes	Yes	Yes	Yes

'**' indicates lower significance at the 0.05 level.
**' indicates moderate significance at the 0.001 level.
Authors' calculation.

Table 9
Goodness of fit measures of the time-stamped model.

Test	Value
R-squared	0.691
Adjusted R-squared	0.633
F-statistics	37.677 (p-value = 0.001)

Authors' calculation

5. Conclusion

This study explored how financial development impacts the demand or consumption of greener energy sources. According to empirical findings, there is a positive relationship between economic growth and REC, which is consistent with earlier studies. Additionally, empirical results suggest that changes in domestic lending provided by financial institutions do not substantially influence REC when controlling for other factors. However, the findings indicate that FDIs have an inverse effect on the demand for renewable energy. There are two plausible rationales for this paradoxical association: (a) FDI might divert attention and resources from renewable energy initiatives, resulting in a decline in their uptake or utilization, and (b) FDI could engender technological advancements that contribute to a reduction in energy demand.

Conversely, the CPI shows a significant positive relationship with REC, while per capita income does not significantly impact REC. The findings underscore a positive relationship between higher consumer prices, as reflected in the CPI, economic growth, and increased adoption of clean energy sources. One possible reason could be that higher consumer prices for traditional energy sources (such as fossil fuels) make clean energy sources relatively more cost-effective and attractive. Consumers may switch to clean energy sources to save on their energy expenses. A schematic summary of key findings is displayed in Fig. 2.

6. Policy suggestions and limitations

According to the results obtained from this study, policy suggestions can be made to promote the adoption and utilization of renewable energy sources. Firstly, it is important to implement targeted incentives such as feed-in tariffs and subsidies to make renewable energy more cost-effective for consumers. These measures can help bridge the affordability gap and encourage individuals and businesses to switch to cleaner energy alternatives. Secondly, there should be a focus on allocating adequate resources for research, development, and infrastructure to assist the integration of clean energy advancements. Examples include investing in enhancing renewable energy systems, grid infrastructure, and storage technologies, ensuring their reliability and scalability. Thirdly, regulatory measures should be in place to monitor and manage FDIs to prevent them from diverting attention and resources away from renewable energy initiatives. By carefully overseeing FDI, policies can be designed to align them with sustainable energy goals and prioritize the growth of domestic renewable energy sectors.

Additionally, promoting awareness and education about renewable energy's benefits is crucial. Public campaigns and educational programs

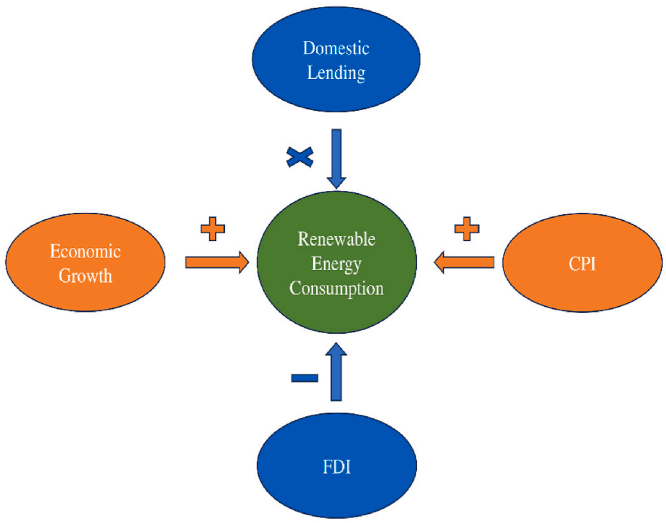

Figure-2. Schematic summary of major results.

can inform individuals about clean energy's economic and environmental advantages, encouraging them to make informed choices and adopt sustainable energy practices. Lastly, policymakers should continuously evaluate and adapt renewable energy policies to ensure their effectiveness. Regular assessment of policy outcomes and stakeholder feedback can guide necessary adjustments and improvements to optimize the impact of renewable energy initiatives.

In summary, the BRICS economies' financial development reforms have advanced. In particular, banking sector reforms and financial inclusion have advanced Brazil's financial development. Brazil is also working on renewable energy, particularly biofuels like sugarcane ethanol, which makes up a large share of its transportation fuel. Interestingly, South Africa's credit availability and entrepreneurial programs have advanced financial growth. South Africa has built one of the world's largest solar power facilities and completed wind and solar energy projects. Renewable energy has helped the government cut carbon emissions and fight climate change. The South African government and policymakers created an all-inclusive participatory framework called the Consultative National Environmental Policy Process (CONNEPP) to allow stakeholders to design and formulate new energy and environmental policies. China and Russia have similar financial development patterns, with China's banking sector growing and its financial markets liberalizing. China also leads the world in solar and wind power. The country leads the worldwide green energy transition due to its ambitious renewable energy infrastructure investments. By implementing these policy suggestions, governments and institutions can drive the widespread adoption of cleaner energy, stimulate economic growth, and contribute to a sustainable, low-carbon future.

Furthermore, this study's focus on BRICS from 1995 to 2022 provides a robust analysis, yet it may not fully capture the intricacies of recent policy changes or the newer BRICS + dynamics. In this sense, future research could explore the extended BRICS + framework, analyzing the fresher impacts on REC. Additionally, further exploration into how different types of renewable energy options are affected by varied financial instruments could offer policymakers targeted insights, thus enhancing the strategic planning for a sustainable energy transition in diverse economic conditions.

CRediT authorship contribution statement

Ashutosh Yadav: Conceptualization, Methodology, Validation, Visualization. **Festus Victor Bekun:** Writing – original draft, Writing, Supervision, and Corresponding. **Ilhan Ozturk:** Validation, Visualization. **Paulo Jorge Silveira Ferreira:** Data curation, Writing – original draft. **Turgay Karalinc:** Formal analysis, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

Paulo Ferreira acknowledges the funding support from Fundação para a Ciência e a Tecnologia (grant UIDB/05064/2020).

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