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Research Article

The Influences of Financial Development, Economic Growth, Energy Price, and Foreign Direct Investment on Renewable Energy Consumption in The BRICS

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Abstract

This study seeks to look into the effects of financial development, economic growth, consumer price index (CPI), and foreign direct investment (FDI) on renewable energy utilization. The investigation applied the panel dynamic ordinary least squares (DOLS) methodology by using yearly time-series data from 1990 to 2022 for the BRICS nations (Brazil, Russia, India, China, and South Africa). The empirical results show an upward trend involving financial development and the use of renewable energy, suggesting that financial development precedes the uptake of renewable energy. In a similar vein, there are noteworthy positive associations found between the CPI and economic growth when renewable energy is used. Furthermore, a surprising link between direct investment and the use of renewable energy is also revealed by our research. These findings offer insightful information about the factors influencing the use of renewable energy in the BRICS nations. From a policy standpoint, the results support the implementation of policies that encourage the uptake of clean technology in conjunction with strong efforts to promote the adoption and exploitation of renewable energy sources. Such actions can promote economic expansion and help the BRICS economies meet their sustainability and low-carbon commitments. The adoption of renewable energy in the examined bloc can be made even more cost-effective by taking practical measures, such as feed-in tariffs and subsidies. By providing evidence-based insights, this study advances the worldwide fight against climate change and the quest for affordable and sustainable energy.

Keywords: Renewable energy; financial development; domestic credit; economic growth; foreign direct investment; sustainable development

Introduction

Beyond its theoretical roots, one of the most significant and well-known challenges of our day is warming temperatures [1]. The socioeconomic environments of many countries have changed as a result of its substantial influence [2]. The alarming thing about global warming and climate change is how much of an influence they have on economies and communities. The unprecedented and destructive extreme events, such as the flood and drought, which resulted in significant psychological harm in addition to financial hardships for the impacted population, served as a conspicuous example of this predicament [3]. After a disaster like this, recovery can take years or perhaps prove to be unachievable. The consequences of the catastrophic occurrences also threatened

animals and livestock in addition to humans, making it more difficult to ensure enough nutrition. The extensive reliance on fossil fuels to fulfill energy needs is a primary factor impacting the intricate topic of climate change [4]. Burning fossil fuels releases a large amount of greenhouse gases into the atmosphere, which is the primary driver of global warming. As a result, in addition to rising temperatures, this has other negative health effects [5].

The increasing energy requirements that nations confront have exacerbated the difficulties posed by climate change [6]. The Liberalization, Privatization, and Globalization (LPG) reforms in India increased energy demand significantly. From 611 million metric tons in 1991 to over 2571 million in 2022, carbon emissions skyrocketed. Limiting fossil fuel use to fulfill energy needs is an effective climate change strategy [7]. Renewable energies like solar and wind energy generate electricity sans releasing any carbon into the atmosphere, making them greener and environment friendly [8]. However, the high initial costs of renewable resources deter energy-efficient project investors. Hence, it is imperative for governments to intervene and enact policies that close the funding shortfall, thereby guaranteeing the feasibility and desirability of investments in green power [9].

Sustainability needs to link renewable energy with financial growth [10]. Fossil fuels contribute to environmental pollution by releasing greenhouse gases. Nevertheless, renewable energy sources offer a less ecologically detrimental option [11]. Empirical data suggests that clean energy does not slow economic growth, irrespective of whether the nations involved are in the process of development or already developed [12]. The importance of using green energy sources for revenue growth could differ, though. This scenario highlights the significance of finding a middle ground between mitigating pollution and fostering economic growth [13]. Emerging countries should prioritize investments in renewable energy due to the good impact of clean electricity on economic development [14]. The use of clean energy and economic growth have been strongly correlated in the economies of the BRICS countries. This insight emphasizes the significance of transitioning to reusable energy sources while concurrently promoting economic growth.

Despite the hefty upfront expenses linked with green power initiatives, the capacity to scale them up is crucial for reducing prices. To encourage the expansion of the green electricity industry, policymakers may think about offering subsidies and tax breaks [15]. The expansion of the banking sector and its impact on the use of renewable energy sources have been the subject of multiple studies [16]. Nevertheless, elevated inflation serves as a deterrent to the adoption of clean energy sources and can lead to economic instability, which in turn discourages investors from committing cash to a country, thus impacting FDI in the renewable industry [17]. The increasing need for energy and the strong resolve to combat climate change indicate that solar power will be an integral component of the energy landscape in the years to come [18]. Technological advancements have made this possible as well as policies that enhance the affordability and accessibility of clean energy [19].

The correlation between monetary growth and green power is of utmost importance, especially for the BRICS nations, where there is a combination of fast economic growth and increasing energy demands, in order to achieve sustainable growth. Financial development provides the necessary funds, risk reduction, and investment motivations that can stimulate acceptance as well as the advancement of green power technology [20]. The recognition of financial markets' depth, efficiency, and accessibility as key drivers of renewable energy projects is growing. These markets offer the financial infrastructure required to support this energy shift. Thus, for economists and policymakers hoping to leverage finance to realize environmental sustainability, comprehending the processes by which financial development affects renewable energy consumption (REC) becomes crucial.

As was previously said, climate change and global warming are acknowledged as urgent issues that impact all countries [21], including the BRICS countries. They are no longer just hypotheses. The BRICS nations—Brazil, Russia, India, China, and South Africa—are well-known for their notable economic expansion and status as emerging markets. China and India are the two countries with two of the world's most populous economies, ranking second and fifth, simultaneously [22]. When combined, the BRICS nations account for about 32% of the global GDP. It is anticipated that this expansion will continue, leading to a 2.5% yearly increase in energy demand. Furthermore, Among the BRICS nations, the proportion of energy from renewable sources varies substantially; China's proportion is the lowest at 4.5 %, while Brazil's proportion is the highest at 17.7 % [22]. Numerous reasons, such as varying degrees of economic growth, energy policy, and resource endowments, might be blamed for this discrepancy. There is serious concern about how global warming will affect the socioeconomic conditions of the BRICS countries. Due to their high industrialization levels, sizable populations, and expanding

energy requirements, these nations are especially susceptible in relation to the consequences of the warming planet.

The purpose of this study is to investigate the correlation—which has not gotten much attention in prior research—between the utilization of sources of clean energy and the advancement of the BRICS nations' financial systems. The research looks at this correlation from 1990 to 2022, a span of 32 years. Being the greatest rising economies, the BRICS countries stand out for their quick growth and wide variances in GDP and REC. The study intends to close current knowledge gaps provide new insights into the relationship between the BRICS countries' transition to sustainable energy systems and investigate an unknown field to improve banking efficiency. This study distinguishes itself by examining REC in major BRICS economies and extending the analysis time frame to account for CPI dynamics in the green energy mix. Studying the BRICS CPI-REC correlation is worthwhile. Start with the CPI to understand these nations' economies. The consumer price index (CPI) analyzes median price changes for goods and services purchased by urban consumers. After rising in March 2022, energy inflation fell in March 2023, lowering OECD inflation rates. This illustrates the intricate connection between expenses for electricity, consumer expenditure, and price hikes. The BRICS countries' use of renewable energy has pros and cons. BRICS nations use 16% of global renewable energy, which helps low-carbon development. South Africa must reduce coal mining and use renewable energy. This emphasizes the need for a national energy strategy that considers social, economic, ecological, and geographic aspects. CPI-REC interactions affect global economic stability and energy transitions. BRICS countries' green energy strategies are affecting global energy policies and sustainable development. BRICS renewable energy negotiations demonstrate how sharing knowledge and working together can fight climate change and accelerate this transformation. Though unrelated, the CPI and REC show how energy affects world growth, conservation of the environment, and profitability. Through educated policy decisions and teamwork, the BRICS can create sustainable energy routes. The research conducted about the energy transition these big economies are promoting may help politicians, investors, and others.

This investigation is among the first to take a quantitative look at how financial development affects REC, particularly in the BRICS countries. Our study carefully investigates the link between economic progress and REC using a solid panel econometrics framework. We applied the panel DOLS model to yearly time-series data for the BRICS countries from 1990 to 2022. The investigation thoroughly examined the effects of numerous economic indicators on REC thanks to this methodological technique. These indicators include FDI, GDP per capita, consumer price indices, and domestic lending to the private sector. Utilizing renewable energy is dependent on domestic credit in the BRICS economies. Credit enables businesses and individuals to engage in projects involving solar panels, wind turbines, and biofuels. There are fewer financial barriers to energy efficiency initiatives in countries where domestic credit is easily accessible. By implementing renewable energy technology, this scenario reduces the need for fossil fuels and promotes sustainable development [23].

Credit restrictions might put off investing in alternative energy sources as well as cleaner energy [24]. To accelerate green power adoption in BRICS nations and achieve sustained environmental and economic benefits, local credit and channels for solar power finance must be increased. FDI influx patterns affect BRICS economies' REC. Renewable power plants can be built and operated utilizing FDI funding, technologies, and skills. BRICS FDI targets renewable energy sectors for their sustainability and growth potential. Renewable energy infrastructure, production, and accessibility benefit from FDI. FDI's pro-innovation and pro-competition policies increase green power investment and demand. BRICS economies use FDI to increase clean energy demand for energy transition and sustainable development. BRICS nations use green power based on economic growth. Finance, especially investment and money, can speed green energy adoption.

By switching to clean energy sources, fossil fuel usage is decreased, and sustainability is encouraged. Renewable energy projects can be funded, and the industry can grow with robust financial infrastructure. The results emphasize how crucial financial development is to the BRICS countries' transition to cleaner energy, which has an impact on environmental sustainability, economic growth, and global energy security. In order to achieve this, these factors are examined in an econometric framework in the current study. The findings will guide policymakers in supporting REC in nations that contribute significantly to global GDP but are using fossil fuels. BRICS economies can employ public-private partnerships (PPPs) and other government agencies to develop policies to foster green energy demand and consumption. They can thus attract greater direct and indirect FDI in

renewable energy capacity. The study's findings would provide valuable insights for the effective implementation of policies aimed at attaining sustainable development goals (SDGs) in the BRICS economies.

Literature review

Both low- and high-income countries agree that a stable monetary system drives economic growth [25]. Furthermore, three possible connections between financial expansion and energy usage have been found by Çoban and Topcu [26]: indirect impact, wealth effect, and direct corporate influence. By making credit more widely available and inexpensive, a healthy financial sector does double duty: it helps people buy long-lasting goods and services and it boosts economic demand [27]. It also allocates money to raising energy consumption, capitalizing on people's faith in reliable financial systems. By using a panel dataset from 38 nations covering the years 2002 to 2020, Li et al. [28] observed that financially advanced markets tend to have greater liquidity and a wider range of financial products. This can help alleviate the funding limitations that renewable energy technologies often face. Institutional and private investors alike can be enticed to back clean energy initiatives using green bonds and specialized funds for this purpose. [29].

Modernization in the banking industry has allowed for the introduction of renewable energy project-specific financial products. Financial aid and loans with favorable interest rates for the environment could be part of these instruments, from the government for the advancement of renewable technologies. Using a nonlinear and highly aggressive distributed lag model for all 30 Chinese provinces, Chang et al. [30] examined the impact of economic expansion on GDP growth from 2000 to 2020. The findings point to a robust There is an advantageous link with the growth of the economy and the use of clean energy. Renewable energy use is increased at a rate of 0.24 percent for every 1 percent rise in economic development. Investments in green power in China can be more socially and economically sustainable, according to this paper's practical paradigm. It also establishes a model for other countries that rely on energy imports and have goals of achieving sustainability after the epidemic. Furthermore, Lessening the alleged dangers of green energy adoption can be achieved through the employment of financial mechanisms like risk-sharing facilities and credit upgrades. This, in turn, can attract a wider range of funders [31].

The study by Sun et al. [32] shed light on how financial growth affects renewable energy in 103 economies from 1991 to 2014, emphasizing the benefit that developed financial institutions—especially banks—have for renewable energy sources. The discrepancy in the efficacy of financial infrastructure is indicated by the fact that, whereas lenders in industrialized economies vigorously support renewable energy initiatives, the impact in emerging economies is confined to the institutional level. This is demonstrated through the use of a dynamic panel model. The study, however, ignores the particular financial requirements of SMEs working in the renewable technology sector, it would greatly benefit from a well-established financial system that streamlines transactions, boosts market efficiency, and shortens the time it takes to get a loan. Because of this knowledge gap, additional study is required to develop green energy initiatives that are relevant and to provide practical financial assistance mechanisms, particularly for SMEs without sufficient collateral.

Despite numerous attempts, researchers have failed to find a link between rising incomes and a preference for greener energy. The findings of these investigations can be classified into three distinct groups. Several studies indicate a direct correlation between the advancement of financial systems and the increased demand for sustainable energy sources. Using the fully modified OLS technique, it has been found that the expansion of the financial sector is positively correlated with the demand for environmentally conscious energy. Mukhtarov et al. [16] used inflation as a variable and models for auto-regressive distributed lag and vector-error correction. The research examined how Turkey's booming financial sector affected the demand for renewable energy between 1980 and 2019. The results indicate that there is a direct and significant relationship between the level of financial development and the amount of renewable energy consumed. Similarly, Raza et al. [33] employed the quantile (ARDL) technique and discovered a substantial positive correlation between the efficiency of the banking sector and the demand for renewable energy in Pakistan from 1960 to 2019. Anton and Nucu [34] have looked at how stock market characteristics like stock turnover and stock valuation affect the demand for renewable energy in the EU nations from 1990 to 2015. A positive association of considerable strength and significance has been found.

Nevertheless, the results of not all investigations have been consistent. For instance, Destek [35] asserted that the demand for green energy is not necessarily augmented by efficient and effective monetary development in 17

emerging nations from 1991 to 2015. Shahbaz et al. [36] found that the growth of the financial industry reduced the demand for electricity in India from 1960 to 2015. Rather, they highlighted how urbanization significantly and favorably influences the demand for energy. Given the contradictory results of earlier studies, more investigation is required to fully comprehend the connection between REC and economic expansion, especially in the context of the BRICS nations. This study's goal is to close this gap by examining the intricate connection between the growth of the financial industry in the BRICS nations and REC.

Financial institutions' efficacy and efficiency are essential for promoting economic growth. An efficient, effective, transparent, and easily accessible financial system contributes to the economies' overall growth and development [20]. Numerous metrics, including FDI, the banking industry's performance, income levels, and economic growth, can be used to monitor this scenario. These four parameters are represented in this study by proxy variables. Furthermore, a robust financial sector's capacity to offer credit at reasonable rates is crucial for drawing in more capital and stimulating the economy. Consequently, there is a following spike in the demand for energy [16]. Çoban and Topcu [26] provide a comprehensive explanation of the indirect effects of economic growth on power usage via their three channels of influence: direct, business, and wealth.

In conclusion, research has provided a basic grasp of the financial factors influencing REC, but there are still gaps, especially in developing nations like the BRICS. According to our analysis, certain facets of financial expansion are invariably linked to higher REC, whereas other components exhibit a more nuanced and occasionally opposite association. These complex observations underpin our theories, which predict that BRICS financial development may have a complex impact on REC that merits a thorough empirical study. Therefore, the hypothesis to be examined in the current research is that economic progress favorably improves REC based on the theoretical underpinning indicated above.

Methodology

Data

The research draws on yearly time-series data from 1990–2022, covering the five member nations of the BRICS group. The availability and trustworthiness of the data were the deciding factors in selecting this time frame for the investigation. In this analysis, REC—a measure of sustainable energy consumption—acts as the dependent variable. A metric of income that is adjusted for constant purchasing power parity prices in 2017 US dollars is GDP per capita, which is used to examine the economic backdrop. One indicator of the health of the banking system is the amount of money that households and businesses in the country lend to one another. As a proximate indicator, the CPI has been employed in past studies since particular energy price data is not available [34]. The Consumer Price Index tracks the general trend of prices paid by consumers over a specified period of time for a set of goods and services. A set schedule may dictate how often the basket of goods and services is modified or remains constant. The Consumer Price Index tracks how much a typical consumer's basket of goods and services has cost over time. Furthermore, each country's foreign investment level is shown by the net FDI inflows as a proportion of GDP. An in-depth examination of the connections between REC and several economic aspects within the BRICS nations was made possible by using data for all variables obtained from the World Development Indicators (WDI) [22]. The variables' descriptions are presented in Table 1.

Table 1. Description of the variables.

Variables	Data description
REC	Renewable energy consumption (% of total final energy consumption)
DC	Domestic credit to private sector (% of GDP)
GDP	GDP per capita (current US$)
CPI	Consumer price index (2010 = 100)
FDI	Foreign direct investment, net inflows (% of GDP)

Source: World Development Indicators [22]

Analysis methods

A number of independent factors, such as GDP, DC, CPI, and FDI, are analyzed in this research in relation to the dependent variable, REC. The selection of these variables is grounded in prior research that investigated the elements impacting REC [34]. Here is the model's equation:

$$REC_t = \tau_0 + \tau_1 DC_t + \tau_2 GDP_t + \tau_3 CPI_t + \tau_4 FDI_t + \varepsilon_t \quad (1)$$

Preventing regression that isn't correct requires using a unit root check. This technique guarantees that the parameters in a regression are stationary by differentiating them, and it uses only stationary processes to estimate the equation of interest. It is necessary to employ numerous unit root tests when evaluating the sequence's assimilation order, according to some studies, because the unit root evaluations' different abilities change on sample sizes. To pinpoint the auto-regressive unit root, several tests were employed, including the Augmented Dickey-Fuller (ADF) test [37], the Dickey-Fuller generalized least squares (DF-GLS) test [38], and the Phillips-Perron (P-P) test [39].

The time series statistics were analyzed using the panel DOLS method [40]. The panel DOLS co-integration approach uses the covariance matrix of errors to synchronize endogeneity and standard deviation calculation. The matrix incorporates descriptive parameters as well as the leads and lags of the preliminary variance phrases. To demonstrate that the error component is orthogonalized, we provide both the leading and following terms of the individual estimates. As a reliable test of statistical significance, the panel DOLS estimator's standard deviations follow a typical asymptotic distribution. The main advantage of the panel DOLS assessment is that it allows for the integration of specific parameters in the co-integrated framework by approximating the contingent parameter on illustrative variables in levels, leads, and lags when a combined arrangement of integration occurs. In the regression, some of the other parameters were I(1) parameters with leads (p) and lags (-p) of the initial variance, while some variables stayed constant at I(0). The evaluation eliminates issues of tiny-sample bias, endogeneity, and auto-correlation by adding the leads and lags among the illustrative pieces. After making sure the data was stationary, the study used the panel DOLS technique and Equation (2) to get the long-run coefficients.

$$\Delta REC_t = \tau_0 + \tau_1 REC_{t-1} + \tau_2 DC_{t-1} + \tau_3 GDP_{t-1} + \tau_5 CPI_{t-1} + \tau_6 FDI_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta REC_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta DC_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta GDP_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta CPI_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta FDI_{t-i} + \varepsilon_t \quad (2)$$

Results and discussion

The summary statistics for the whole panel dataset including all BRICS nations are shown in Table 2. Our sample shows substantial cross-national heterogeneity in REC, as shown by the descriptive statistics. With 52.65% of the total, Brazil has the highest REC percentage among the five BRICS countries (Figure 1). In contrast, from 1990 to 2022, Russia's REC level was the lowest at a meager 3.18%. Russia is clearly not meeting expectations when it comes to REC. In addition, DC shows large differences across countries and throughout time. Russia ranks last among the countries studied, in comparison to China, which has the greatest values of credit granted by financial institutions. Variation levels are similar for other variables including GDP, CPI, and FDI.

We utilized the unit root test to back up the panel DOLS estimator and make sure that no variables had a greater order of integration than the rest. We isolated the auto-regressive unit root using trend-and-constants-based ADF, DF-GLS, and P-P techniques. We ran a few unit root tests and the results are presented in Table 2.

Table 2. Summary statistics.

Variables	REC	DC	GDP	CPI	FDI
Mean	25.47	72.09	4901.87	88.29	2.10
Standard error	1.38	3.36	307.67	4.02	0.13
Median	18.56	58.08	3494.06	81.84	1.81
Std. Dev.	17.68	43.18	3952.12	51.60	1.68
Minimum	3.18	11.54	301.50	0.00	-0.06
Maximum	52.65	190.69	15974.62	204.48	9.95

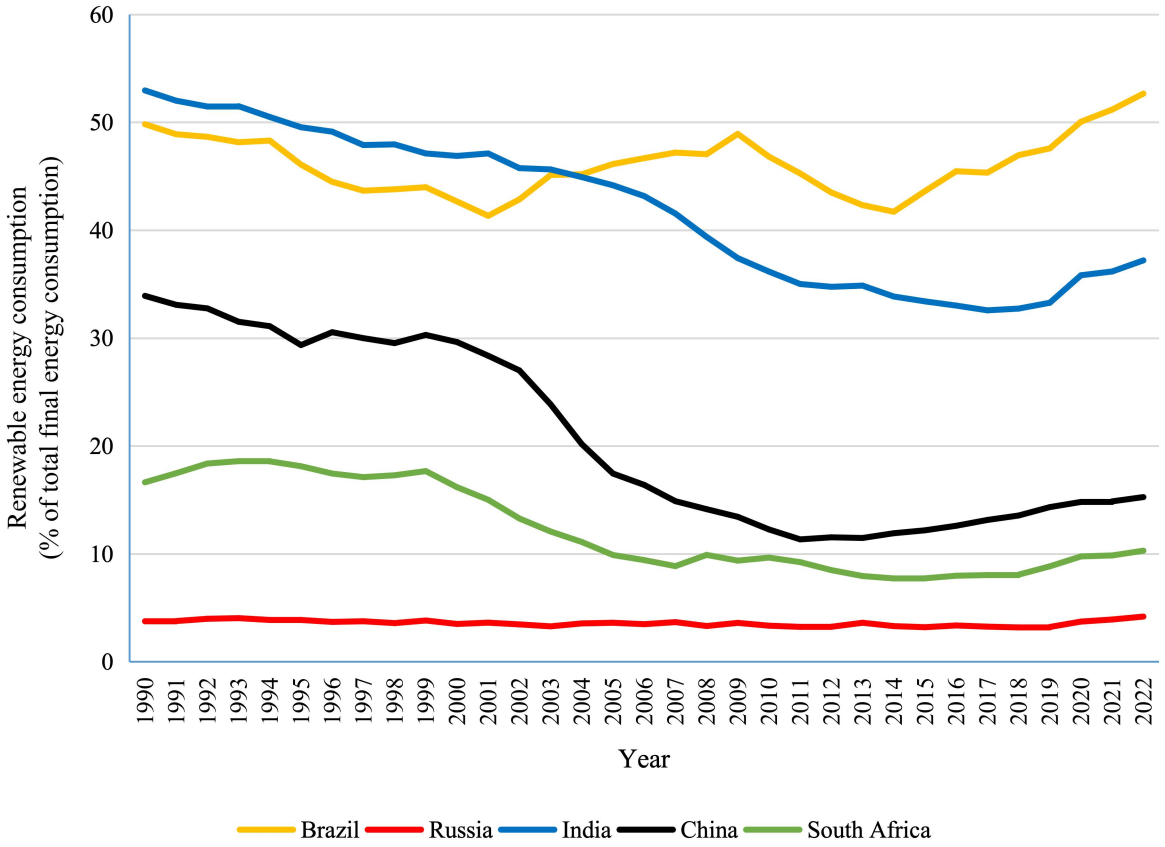

Figure 1. Renewable energy consumption in BRICS.
Source: World Development Indicators [22]

Table 2. Results of unit root tests.

Variables	ADF		DF-GLS		P-P	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
REC	-0.56	-5.68***	-1.49	-4.38***	-0.46	-5.93***
DC	-0.96	-3.84***	-1.30	-3.48***	-0.88	-3.86***
GDP	-1.14	-4.64***	-1.08	-4.02***	-1.09	-5.13***
CPI	-0.59	-6.54***	-0.87	-5.33***	-0.59	-6.54***
FDI	-1.23	-3.64***	-1.02	-3.09***	-0.45	-3.73***

Note: ***p<0.01

Despite not being level-stationary, the variables did become stationary once the first difference was measured, according to all three unit root tests. Hence, the variables are integrated in the same first-difference order, according to the unit root results. Since all of the variables included in the empirical studies are moving closer to their actual values, a misleading regression analysis is completely out of the question.

The panel DOLS estimation results are displayed in Table 3. The analysis evaluates the impact of FDI, GDP, CPI, and domestic lending from the DC on REC. The findings provide striking new information about the factors that influence REC. Research indicates that GDP and REC have a positive correlation. A favorable correlation between GDP growth and REC is suggested by the positive (0.61) and statistically significant ($p<0.01$) coefficient estimate for GDP. In a similar vein, the DC coefficient estimate is statistically significant ($p<0.01$) and positive (0.29). These findings imply that, even after adjusting for other variables, variations in the domestic loans made by financial institutions have a significant impact on the usage of renewable energy. The coefficient estimate for

CPI is positive (0.07) and statistically significant ($p<0.01$) in this regard. According to this research, increased consumer prices—which the CPI suggests—encourage a wider uptake of sustainable energy sources. It is noteworthy that FDI showed a negative coefficient estimate (-0.32) and was statistically significant ($p<0.01$), suggesting a negative correlation between greater FDI levels and lower REC.

Table 3. Results of panel DOLS estimation

Variables	Coefficient	Standard error	t-statistic	p-value
GDP	0.61***	0.16	3.84	0.00
DC	0.29***	0.09	3.28	0.00
CPI	0.07***	0.02	3.53	0.00
FDI	-0.32***	0.07	-4.67	0.00
C	13.32	9.65	1.38	0.14
R^2	0.94			
Adjusted R^2	0.93			
F-statistic	31.29			0.00
Root mean square error (RMSE)	0.02			
Mean Absolute Error (MAE)	0.01			

Note: ***p<0.01

In order to determine how well the calculated simulation suited the data, multiple diagnostic tests were employed. To begin, we find that $R^2 = 0.94$ and 0.92. Based on these numbers, it's possible that the independent factors can account for over 90% of the dependent variable's volatility. Additionally, the F-statistic is quite significant ($p<0.01$), which strongly suggests that the regression model as a whole is relevant and that the independent variables, taken together, greatly explain the variation in REC. Thirdly, the model's predictions are accurate because the RMSE and MAE values are close to zero and not negative. Table 4 also shows the results of tests for normality, serial correlation, and heteroscedasticity, which were done to make sure the test was strong. The model reveals that the data are normally distributed and do not exhibit serial correlation or heteroscedasticity. Figure 2 also displays the cumulative sum of squares of recursive residuals (CUSUMQ) and cumulative sum of recursive residuals (CUSUM), both at a significance level of 5%. The blue lines depict the residual values, while the red lines denote the confidence intervals. Findings show that the examined residuals' values stay within the 95% confidence interval, which is a good sign that the model is stable.

This research's empirical analysis offers insightful information about the connections involving REC and other economic aspects in the BRICS countries. Our research clarifies a number of important issues that help to comprehend the dynamics of renewable energy adoption and its contributing factors in these nations. Above all, our findings support earlier studies by showing a substantial positive correlation between GDP and REC [34,36,41,42,43]. It appears that strong economic growth increases the demand for energy from green sources, as indicated by the positive coefficient estimate for GDP. This discovery highlights how sustainable energy practices can be propelled by economic prosperity.

Table 4. Results of diagnostic tests

Diagnostic tests	Coefficient	p-value	Decision
Lagrange Multiplier test	1.86	0.47	No serial correlation
Breusch-Pagan-Godfrey test	1.81	0.19	No heteroscedasticity
Jarque-Bera test	1.39	0.23	Residuals are normally distributed

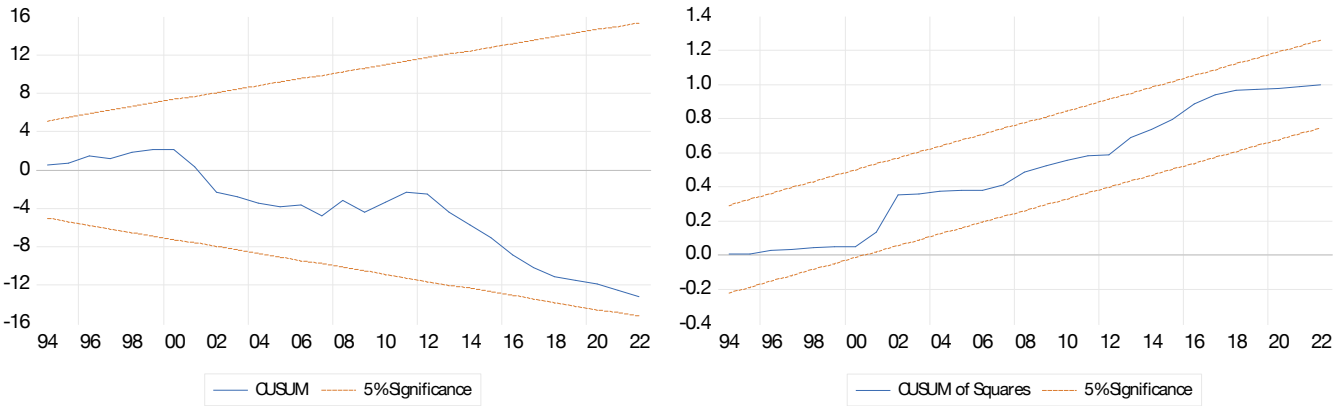

Figure 2. Results of CUSUM and CUSUMQ tests.

We found a favorable and statistically significant connection between DC and REC. Renewable energy initiatives can be funded by venture capital, private equity, and project financing in robust financial markets. This capital flow lowers renewable energy deployment costs, enabling the development of infrastructure and technology for solar, wind, and hydroelectric power. Financial institutions can also offer sustainable bonds and renewable energy funds to attract domestic and global investors seeking sustainable investments in the clean power sector. A strong financial sector promotes competition and efficiency, lowering renewable energy project financing costs and boosting their economic feasibility. BRICS economies' financial development provides the financial resources, expertise, and market incentives to fuel sustainable energy initiatives, accelerating the shift to renewable energy. The substantial positive link between financial expansion and sustainable energy use is consistent with previous studies [34,41,42,43].

Additionally, our research shows an encouraging association between REC and CPI, and this agrees with Sadiq et al. [44]. The increase in consumer prices, as indicated by the CPI, seems to encourage a higher rate of adoption of renewable energy sources. One potential explanation is that the increased cost of conventional power sources, such as petroleum and coal, makes renewable energy options comparatively more economically viable and appealing. Consumers can transition to renewable energy sources as a means of reducing their energy costs. Our study reveals a surprising link between FDI and REC. The inverse correlation between FDI and REC indicates that an increase in FDI as a proportion of GDP is linked to a decrease in REC. The outcome aligns with the discoveries of Anton and Nucu [34]. There are two potential explanations for this surprising association. Firstly, it is possible that Renewable energy programs may see a decrease in uptake or utilization if FDI diverts attention and resources from them. Secondly, FDI has the potential to spur technical progress, which could lead to a potential decrease in energy usage.

Overall, the financial development reforms of the BRICS economies have made significant progress. Brazil's financial development has been significantly enhanced by the implementation of banking sector reforms and the promotion of financial inclusion. Brazil is actively engaged in the development of renewable energy sources, with a specific focus on biofuels such as sugarcane ethanol. This type of fuel plays a significant role in Brazil's transportation sector. South Africa's credit availability and entrepreneurial programs have significantly contributed to the country's financial progress. South Africa has constructed a solar power facility of considerable size, ranking among the largest in the world. Additionally, Renewable energy schemes involving wind and solar power have been completed by the nation. The government's efforts to prevent climate change and reduce carbon emissions have been greatly assisted by the exploitation of renewable energy sources. In order to facilitate the collaborative development and shaping of new energy and environmental policies, the South African government and lawmakers set up the Consultative National Environmental Policy Process (CONNEPP), a thorough participatory framework. The expansion of China's banking industry and the liberalization of its financial markets are indicative of a pattern of financial development comparable to that of Russia. As for wind and solar electricity, China is unrivaled. Amid a global green energy transformation, the nation is at the forefront thanks to its massive expenditures in renewable energy infrastructure. A sustainable, low-carbon future can be achieved through the implementation of suitable policies by governments and institutions, which will propel the broad adoption of cleaner energy sources, boost economic growth, and more.

Conclusions and policy implications

This study examines the impact of financial development, GDP, CPI, and FDI on the utilization of renewable energy. The analysis utilized the panel DOLS methodology, employing yearly time-series data from 1990 to 2022 for the BRICS states. The data series' stationarity was verified by the ADF, DF-GLS, and P-P unit root tests. The panel DOLS estimation results reveal that a 1% rise in GDP, financial development, and CPI would result in a corresponding increase in renewable energy consumption by 0.61%, 0.29%, and 0.07% respectively, over the long term. Conversely, a 1% increase in FDI would lead to a reduction in renewable energy consumption by 0.32%.

The outcomes of the research recommend policies to increase renewable energy use. To make renewable energy cheaper for customers, feed-in tariffs and subsidies are needed. These steps can reduce the cost of greener energy and encourage businesses and individuals to convert. Second, research, development, and infrastructure should be adequately funded to help integrate sustainable energy advances. This includes improving renewable energy systems, grid infrastructure, and storage technologies for reliability and scalability. Thirdly, FDIs should be monitored and managed to avoid draining resources from renewable energy projects. Policies can align FDI with sustainable energy goals and promote domestic renewable energy growth by properly overseeing it. In addition, it is imperative to advocate for the dissemination of knowledge and understanding of the advantages of renewable energy. Public campaigns and educational initiatives can provide information to citizens regarding the economic and environmental benefits of clean energy, they will be encouraged to make informed choices and adopt energy-saving habits. Last but not least, lawmakers should regularly evaluate and change renewable energy rules to make sure they work. To make renewable energy initiatives as effective as possible, it is important to regularly evaluate policy outcomes and gather stakeholder input. This will help influence any revisions and additions. The research also provides a thorough analysis of BRICS from 1990–2022, however, it might miss some of the nuanced aspects of BRICS+'s growing dynamics or recent policy changes. The extended BRICS+ framework and its impact on REC in recent years might be the subject of future research. In addition, policymakers might benefit greatly from detailed information gleaned from studies examining the effects of different financial mechanisms on various renewable energy sources. In several economic contexts, this would enhance the strategic planning for a transition to sustainable energy.

While the current study has yielded significant empirical results about BRICS, our analysis has shown numerous limits that should be explored in future research. Due to the lack of data, the analysis was limited to a duration of only 33 years, specifically from 1990 to 2022. Further investigation can be carried out with a more extensive dataset. Additional research could be conducted on other groupings of countries, employing various econometric modeling techniques or utilizing micro-disaggregated data. These findings could offer valuable insights into the relevant literature, allowing for useful comparisons with the results of our investigation. Furthermore, future research can consider additional factors that contribute to renewable energy development but were not examined in this study, such as globalization and technological innovation.

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References

[1] Voumik, L. C., Mimi, M. B., & Raihan, A. (2023). Nexus between urbanization, industrialization, natural resources rent, and anthropogenic carbon emissions in South Asia: CS-ARDL approach. Anthropocene Science, 2(1), 48-61.

[2] Begum, R. A., Raihan, A., & Said, M. N. M. (2020). Dynamic impacts of economic growth and forested area on carbon dioxide emissions in Malaysia. Sustainability, 12(22), 9375.
[3] Spiegel, S. J., Kachena, L., & Gudhlanga, J. (2023). Climate disasters, altered migration and pandemic shocks:(im) mobilities and interrelated struggles in a border region. Mobilities, 18(2), 328-347.
[4] Johnsson, F., Kjärstad, J., & Rootzén, J. (2019). The threat to climate change mitigation posed by the abundance of fossil fuels. Climate Policy, 19(2), 258-274.
[5] Perera, F. (2018). Pollution from fossil-fuel combustion is the leading environmental threat to global pediatric health and equity: Solutions exist. International journal of environmental research and public health, 15(1), 16.
[6] Patz, J. A., Gibbs, H. K., Foley, J. A., Rogers, J. V., & Smith, K. R. (2007). Climate change and global health: quantifying a growing ethical crisis. EcoHealth, 4, 397-405.
[7] Ridwan, M., Raihan, A., Ahmad, S., Karmakar, S., & Paul, P. (2023). Environmental Sustainability in France: The Role of Alternative and Nuclear Energy, Natural Resources, and Government Spending. Journal of Environmental and Energy Economics, 2(2), 1-16.
[8] Aliyu, A. K., Modu, B., & Tan, C. W. (2018). A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. Renewable and Sustainable Energy Reviews, 81, 2502-2518.
[9] Raihan, A., & Tuspekova, A. (2022). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. Resources, Conservation & Recycling Advances, 15, 200096.
[10] Raihan, A., Pavel, M. I., Muhtasim, D. A., Farhana, S., Faruk, O., & Paul, A. (2023). The role of renewable energy use, technological innovation, and forest cover toward green development: Evidence from Indonesia. Innovation and Green Development, 2(1), 100035.
[11] Ghosh, S., Hossain, M. S., Voumik, L. C., Raihan, A., Ridzuan, A. R., & Esquivias, M. A. (2023). Unveiling the Spillover Effects of Democracy and Renewable Energy Consumption on the Environmental Quality of BRICS Countries: A New Insight from Different Quantile Regression Approaches. Renewable Energy Focus, 46, 222-235.
[12] Riti, J. S., Song, D., Shu, Y., Kamah, M., & Atabani, A. A. (2018). Does renewable energy ensure environmental quality in favour of economic growth? Empirical evidence from China's renewable development. Quality & Quantity, 52, 2007-2030.
[13] Fang, W., Liu, Z., & Putra, A. R. S. (2022). Role of research and development in green economic growth through renewable energy development: empirical evidence from South Asia. Renewable Energy, 194, 1142-1152.
[14] Raihan, A., Muhtasim, D. A., Farhana, S., Pavel, M. I., Faruk, O., & Mahmood, A. (2022). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. Energy and Climate Change, 3, 100080.
[15] Gan, L., Eskeland, G. S., & Kolshus, H. H. (2007). Green electricity market development: Lessons from Europe and the US. Energy policy, 35(1), 144-155.
[16] Mukhtarov, S., Yüksel, S., & Dinçer, H. (2022). The impact of financial development on renewable energy consumption: Evidence from Turkey. Renewable Energy, 187, 169-176.
[17] Li, R., Li, L., & Wang, Q. (2022). The impact of energy efficiency on carbon emissions: evidence from the transportation sector in Chinese 30 provinces. Sustainable Cities and Society, 82, 103880.
[18] Voumik, L. C., Ridwan, M., Rahman, M. H., & Raihan, A. (2023). An Investigation into the Primary Causes of Carbon Dioxide Releases in Kenya: Does Renewable Energy Matter to Reduce Carbon Emission?. Renewable Energy Focus, 47, 100491.
[19] Jayachandran, M., Gatla, R. K., Rao, K. P., Rao, G. S., Mohammed, S., Milyani, A. H., ... & Geetha, S. (2022). Challenges in achieving sustainable development goal 7: Affordable and clean energy in light of nascent technologies. Sustainable Energy Technologies and Assessments, 53, 102692.
[20] Prempeh, K. B. (2023). The impact of financial development on renewable energy consumption: new insights from Ghana. Future Business Journal, 9(1), 6.
[21] Sultana, T., Hossain, M. S., Voumik, L. C., & Raihan, A. (2023). Does globalization escalate the carbon emissions? Empirical evidence from selected next-11 countries. Energy Reports, 10, 86-98.
[22] World Bank. (2023). World Development Indicators (WDI), Data series by The World Bank Group. The World Bank: Washington, DC, USA. Retrieved from https://databank.worldbank.org/source/world-development-indicators
[23] Sultana, T., Hossain, M. S., Voumik, L. C., & Raihan, A. (2023). Democracy, green energy, trade, and environmental progress in South Asia: Advanced quantile regression perspective. Heliyon, 9(10), e20488.
[24] Ridwan, M., Raihan, A., Ahmad, S., Karmakar, S., & Paul, P. (2023). Environmental Sustainability in France: The Role of Alternative and Nuclear Energy, Natural Resources, and Government Spending. Journal of Environmental and Energy Economics, 2(2), 1-16.

[25] Rahman, A., Khan, M. A., & Charfeddine, L. (2020). Financial development–economic growth nexus in Pakistan: new evidence from the Markov switching model. Cogent Economics & Finance, 8(1), 1716446.
[26] Çoban, S., & Topcu, M. (2013). The nexus between financial development and energy consumption in the EU: A dynamic panel data analysis. Energy economics, 39, 81-88.
[27] Wang, Q., Zhang, F., & Li, R. (2023). Revisiting the environmental kuznets curve hypothesis in 208 counties: The roles of trade openness, human capital, renewable energy and natural resource rent. Environmental Research, 216, 114637.
[28] Li, R., Wang, Q., & Guo, J. (2024). Revisiting the environmental Kuznets curve (EKC) hypothesis of carbon emissions: exploring the impact of geopolitical risks, natural resource rents, corrupt governance, and energy intensity. Journal of Environmental Management, 351, 119663.
[29] Amin, S. B., Khan, F., & Rahman, M. A. (2022). The relationship between financial development and renewable energy consumption in South Asian countries. Environmental Science and Pollution Research, 29(38), 58022-58036.
[30] Chang, L., Qian, C., & Dilanchiev, A. (2022). Nexus between financial development and renewable energy: empirical evidence from nonlinear autoregression distributed lag. Renewable Energy, 193, 475-483.
[31] Mukhtarov, S., & Mikayilov, J. I. (2023). Could financial development eliminate energy poverty through renewable energy in Poland? Energy Policy, 182, 113747.
[32] Sun, Z., Zhang, X., & Gao, Y. (2023). The impact of financial development on renewable energy consumption: A multidimensional analysis based on global panel data. International journal of environmental research and public health, 20(4), 3124.
[33] Raza, S. A., Qamar, S., & Ahmed, M. (2023). Asymmetric role of non-renewable energy consumption, ICT, and financial development on ecological footprints: evidence from QARDL approach. Environmental Science and Pollution Research, 30(8), 20746-20764.
[34] Anton, S. G., & Nucu, A. E. A. (2020). The effect of financial development on renewable energy consumption. A panel data approach. Renewable Energy, 147, 330-338.
[35] Destek, M. A. (2018). Financial development and energy consumption nexus in emerging economies. Energy Sources, Part B: Economics, Planning, and Policy, 13(1), 76-81.
[36] Shahbaz, M., Van Hoang, T. H., Mahalik, M. K., & Roubaud, D. (2017). Energy consumption, financial development and economic growth in India: New evidence from a nonlinear and asymmetric analysis. Energy Economics, 63, 199-212.
[37] Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. Journal of the American Statistical Association, 74(366a), 427-431.
[38] Elliott, G., Rothenberg, T. J., & Stock, J. H. (1996). Efficient tests for an autoregressive unit root. Econometrica, 64(4), 813-836.
[39] Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. Biometrika, 75(2), 335-346.
[40] Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica: Journal of the Econometric Society, 61(4), 783-820.
[41] Dimnwobi, S. K., Madichie, C. V., Ekesiobi, C., & Asongu, S. A. (2022). Financial development and renewable energy consumption in Nigeria. Renewable Energy, 192, 668-677.
[42] Yi, S., Raghutla, C., Chittedi, K. R., & Fareed, Z. (2023). How do economic policy uncertainty and financial development contribute to renewable energy consumption? The importance of economic globalization. Renewable Energy, 202, 1357-1367.
[43] Deka, A., Özdeşer, H., & Seraj, M. (2024). The impact of oil prices, financial development, and economic growth on renewable energy use. International Journal of Energy Sector Management, 18(2), 351-368.
[44] Sadiq, M., Ou, J. P., Duong, K. D., Van, L., & Xuan Bui, T. (2023). The influence of economic factors on sustainable energy consumption: evidence from China. Economic research-Ekonomska istraživanja, 36(1), 1751-1773.