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The Dynamic Impact of Financial Globalization, Environmental Innovations and Energy Productivity on Renewable Energy Consumption: Evidence From Advanced Panel Techniques

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Attaining cleaner production is a major challenge for BRICS economies. In this context, this study explores the effect of financial globalization on renewable energy consumption in BRICS economies from 1990 to 2018. It is probably the first research to study the linkage between financial globalization and renewable energy consumption. Therefore, this research adds to the current literature by presenting new empiric evidence on how financial globalization, in conjunction with environmental innovations, energy productivity, energy prices, and economic growth, affect renewable energy consumption in BRICS economies. In doing so, this research utilized novel econometric methods such as continuously updated fully modified (CUP-FM) and continuously updated bias-corrected (CUP-BC) techniques to evaluate the long-run results. The empirical findings show that financial globalization, environmental innovation, energy productivity, and energy prices promote renewable energy consumption. In contrast, economic growth impedes renewable energy consumption. This study suggests that governments and policymakers in BRICS countries should consider financial globalization and the increasing role of environmental innovations to increase the renewable energy share, which can be the appropriate solutions to the environmental challenges and achieve the Paris Climate Agreement's goals. BRICS economies require speeding up permits for renewable energy projects, raising tax credits, including substantially more grants and loans, extending timelines for pandemic-affected projects, and investing directly in emerging clean energy sources.

Keywords: financial globalization, environmental innovation, CUP-FM, CUP-BC, renewable energy consumption (REC)

1 INTRODUCTION

The most critical challenges are climate change and environmental deterioration to accomplish environmental sustainability in the 21st century (Zhenmin and Espinosa, 2019). Rapid economic expansion, industrialization, and higher energy consumption have made climate change more disastrous (Zaman and Moemen, 2017; Mesagan and Chidi, 2020). To cope with the rising energy consumption and environmental problems, countries worldwide are formulating policies considering the Paris Agreement (COP21) to curb global warming to less than 2°C (United Nations, 2020). Researchers have found different strategies and policies to combat environmental deterioration and increase energy consumption. Among others, the development and usage of renewable energy have ecological and economic benefits. Renewable energy is critical in achieving energy security and independence from fossil fuel markets (Anton and Afloarei Nucu, 2020). Therefore, higher renewable energy consumption (hereafter REC) is an essential component of the national planning agenda for smart, sustainable, and inclusive growth (Binz et al., 2017; Liu et al., 2019).

The energy sector is one of the most capital intensives compared to other industries. Renewable energy projects require a high initial investment relative to fossil fuel energy. Despite the increasing role of energy from renewable sources in sustainable economic growth, there is little about how globalization affects REC. It is argued that globalization is considered a valuable tool to mitigate environmental degradation (Wang et al., 2020) because globalization promotes REC (Padhan et al., 2020). Globalization is a part of financial liberalization and openness that increases renewable energy research and development (Gozgor et al., 2020). A well-developed and sound financial system offer more funds for renewable production at a lower cost, giving rise to improved financing, which sequentially increases renewable energy production and consumption. Thus, improvements in the financial sector through financial globalization are likely to benefit the renewable energy sector, particularly for raising external funds for renewable energy projects.

Moreover, financial globalization and liberalization of capital markets enhance the interaction between financial channels and international firms, which may have ample technological power transfer for renewable energy and research and development to the host country (Eren et al., 2019; Fan and Hao, 2020; Sabishchenko et al., 2020). Therefore, governments have options for environmentally friendly and cost-effective solutions because of increased demand for energy consumption and environmental degradation. Likewise, environmental innovations are considered efficient ways to lessen carbon emissions and promote REC (Alvarez-Herranz et al., 2017; Li et al., 2020). Geissdoerfer et al. (2017) also pointed out that the circular economy (sustainable) may not be possible without environmental innovations (Shpak, 2021).

The BRICS (Brazil, Russia, India, China, and South Africa) economies are among the top 10 largest and fastest-growing energy producers and consumers globally (BP Statistical Review of World Energy, 2020). REC in BRICS economies has also grown steadily in the last few decades. However, considerable disparities exist in the usage of renewable energy among BRICS economies (Zeng et al., 2017). Brazil has achieved a high share in renewable energy in its final gross energy use (43.79%), after that India (36.02%), South Africa (17.15%), China (12.41%), Russia (3.30%) (see **Figure 1**) in the year of 2018 (World Bank, 2019). Anton and Afloarei Nucu (2020) believed that REC and its development depend on countries' financial conditions. However, other factors may affect discrepancies, such as geography and other domestic factors, despite financial and economic aspects. For Instance, Brazil has the highest forested area in BRICS, and hydroelectric power generation is being the most vital source of renewable energy with a share of 63.8%, followed by biomass, biogas (8.9%), wind (9.3%), and solar centralized (1.4%). In contrast, Russia is categorized with vast land area, low population, and rich in minerals. India has the world's fifth-largest wind energy industry, with a volume of 22. GW. China's renewable energy is growing faster in the hydroelectric and wind power sectors than in other countries. That seems to be evident as a circular economy is an economic model which is the reasonable use and recovery of natural resources based on reducing, reusing and recycling (Ślusarczyk, 2012; Pathak and Shah, 2019).

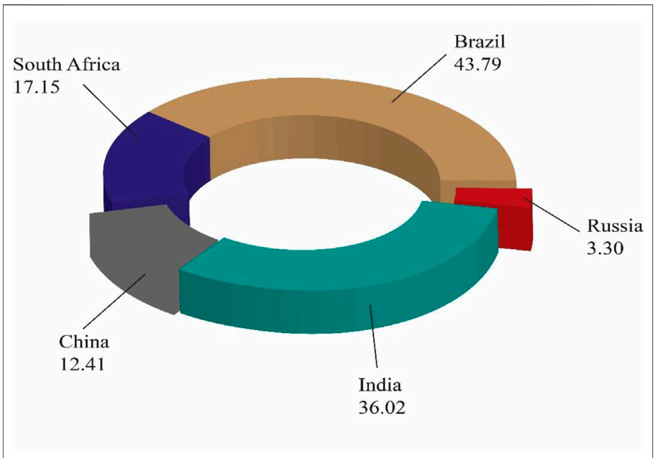

FIGURE 1 | Renewable energy consumption (REC), % of final energy consumption.

Why BRICS countries? This study focuses on BRICS economies for many reasons. First, BRICS countries represent an overall 21% of global GDP, covering half of the world's population and consuming 40% of total energy. Second, for the past two decades, these BRICS countries have been at the forefront of global economic progress, and their GDP increased from $4,985 US billion (constant 2010) to $7,719 US billion from 1990 to 2018. Investment in BRICS is rapidly growing (Zeng et al., 2017). Furthermore, financial cooperation among BRICS economies is continually increasing. However, the ambitious pace of economic growth creates significant challenges to their development paths, and these countries are responsible for increasing global carbon emissions (Danishwang, 2019). Third, The BRICS economies face a severe conditions concerning environmental sustainability and energy security.

Moreover, BRICS economies face internal and external pressure to reduce environmental degradation because rapid economic growth has created far-reaching environmental issues. Four, previous research has concentrated on the relationship between globalization and REC; however, the linkage between financial globalization and REC remains un-investigated. Therefore, because of the prominence of financial globalization and environmental innovation, ongoing research aims to fill this gap and examine the linkage among financial globalization, environmental innovation, energy productivity, economic growth, and REC in BRICS economies.

This research contributed to the present literature in several respects. Firstly, the current literature is silent on how financial globalization affects REC. Therefore, this research fills this gap by using the recently developed financial globalization index (Gygli et al., 2019). Secondly, research on environmental innovation and energy productivity is very thin, so our research investigates the effect of financial globalization, environmental innovation, and energy productivity on REC in BRICS economies. Lastly, the advanced panel estimation methodology is applied for this study that counters cross-sectional dependence. Conventional panel data estimators like fully modified ordinary least squares (FM-OLS) and dynamic (D-OLS) consider the panels' cross-sections are independent. They infer that shocks in one country do not affect other countries. In spite of this, globalization has made economies economically, politically, and socially interconnected. Therefore, this study employs continuously updated full modified (CUP-FM) and continuously updated bias-corrected (CUP-BC) techniques presented by Bai et al. (2009) to get robust and reliable findings.

The remaining article is structured in this way. **Section 2** unveils the literature review encompassing the determinants of REC. **Section 3** presents the theoretical framework, model construction, and data. **Section 4** explains the econometric methods. **Section 5** debates the results and discussions. The conclusion and policy recommendations are summarized in **Section 6**.

2 LITERATURE REVIEW

Considering the increasing threat of climate change and global warming because of greenhouse gas emissions (GHG), A growing global consensus favours the development and usage of renewable energy to reduce fossil fuels. Nevertheless, renewable energy sources are rapidly increasing (International Energy Outlook, 2020), but it still has a relatively small share of overall energy consumption. Recently, a significant volume of literature emerged to determine renewable energy development (Sadorsky, 2009; Salim and Rafiq, 2012; Omri and Nguyen, 2014; Zhao and Luo, 2017; Ali et al., 2018; Buturache and Stancu, 2021). Bhattacharya et al. (2016) stated that energy sustainability is related to a clean environment, a productive energy structure, and fewer carbon emissions.

Besides, a substantial part of the research explores the determining factor of REC. The most widely known elements that affect REC are energy prices, regulatory system, environmental pollution, energy consumption, energy security, renewable energy potential, political environment, financial flows, and economic growth. The pivotal study of Sadorsky (2009) and Chang et al. (2009) established a sound base for forthcoming researchers to explore the determining factor of REC. In the past 10 years, most researchers deemed energy prices and economic growth are the core variables of REC (Sadorsky, 2009; Lucas et al., 2016; Romano and Scandurra, 2016; Lin and Omoju, 2017; Lu, 2017; Nicolini and Tavoni, 2017; Nyiwul, 2017; Oláh et al., 2020; Shahzad et al., 2021a; Shahzad et al., 2021b). The researchers subsequently incorporated environmental variables to investigate the link between REC and economic growth (Lucas et al., 2016; Romano and Scandurra, 2016; Lu, 2017; Nicolini and Tavoni, 2017; Nyiwul, 2017; Shahzad, 2020). Lucas et al. (2016) proposed energy consumption and energy security as the determining factor of REC. Lin and Omoju (2017) incorporated fossil fuels, renewable energy potential, and regulatory framework into the existing literature listing determinant factors of REC. Nyiwul (2017) introduced the population, and Yao et al. (2019) described human capital as determining REC. Recently, Li et al. (2020) included environmental innovation and energy productivity in explaining REC.

Following a review of the research on REC determinants, certain important conclusions can be reached. Firstly, economic growth and energy prices gained more attention. Secondly, minimal importance is devoted to financial development and other important variables that can affect REC, for example, structural and institutional variables. A few studies also examine the connection between financial development and REC; however, their findings are inconclusive. The literature's mixed results may also be due to non-financial factors such as availability of resources, geographic location, orography, and the country's own social and political context (Anton and Afloarei Nucu, 2020; Wang, 2022; Wang et al., 2022). The overall KOF globalization indices introduced the specific dimension as a sub-indices called the financial globalization index (Gygli et al., 2019).

Financial globalization may help countries lower energy demand by importing energy technologies (Baek et al., 2009). Also, there is a disagreement about using the dependent variable to evaluate REC determinants. For example, some researchers used all levels of REC per capita (Sadorsky, 2009). Some scholars have adopted the share of all renewable energy in whole energy consumption (Marques et al., 2010; Martínez-Zarzoso and Maruotti, 2011; Majeed et al., 2021a), whereas others employed non-hydro-renewable energy produced from electricity (Omri and Nguyen, 2014; Zeb et al., 2014; Cadoret and Padovano, 2016; Romano and Scandurra, 2016; Carley et al., 2017; Mariyakhan et al., 2020). Following previous studies of Apergis and Eleftheriou (2015); Li et al. (2020) this research utilizes total REC as the response variable. This research fills the literature gap by proposing new determinants that may impact REC. In approximating the equation for REC, we add energy productivity as a control variable. However, to our best knowledge, no single research has investigated the effect of financial globalization on REC. This research contributes to the current literature by identifying financial globalization as a new determinant of REC.

3 THEORETICAL BACKGROUND, DATA, AND MODEL CONSTRUCTION

3.1 Theoretical Background

The theoretical mechanism through which financial globalization and environmental innovation, energy productivity, economic growth, and energy prices affect REC is described in this section. The existing literature is silent on the association between financial globalization and REC. So, for the intent of this research, we have explained the effect of financial development on REC because financial globalization demonstrates the global impact of financial development (Gygli et al., 2019). Existing literature has provided mixed results for the association between financial development and REC (Shahbaz et al., 2016; Topcu and Payne, 2017; Destek, 2018; Zuo et al., 2022). The overall interpretation of the positive association can be split into three ways: direct impact, business impact, and wealth impact (Sadorsky, 2011a; Sadorsky, 2011b). The direct impact is where the demand for durable products is raised by financial easing, contributing to greater energy usage. The business impact indicates the firm's response to the growing demand occurs by utilizing financial resources (loans) to extend the production base, resulting in a rise in energy use. Finally, the wealth impact takes capital market behaviour into account and reflects customers' and businesses' confidence in the economy. Such confidence is fueled by the rising stock market, thereby providing customers and businesses with confidence in economic growth, rising energy demand.

The existing literature shows that financial development facilitates sustainable energy sources, resulting in renewable energy ventures (Chandrashekeran et al., 2015; Neville et al., 2019). Further, economic growth raises energy demand and places pressure on the economy to ensure the sustained availability of energy to ensure a steady growth trend (Ozcan and Ozturk, 2019). But the effect of extensive utilization of resources, especially traditional energy sources such as fossil, coal, and oil, leads to a deterioration of the environment and additional economic costs. Bhattacharya et al. (2016) assert the negative economic growth resulting from higher investment costs in renewable energies. Thus, countries have shown a keen interest in finding and using alternative renewable energy sources over the past decade and trying to replace them with the impacts of green environmental concerns. Research should focus on more significant environmental innovation (de Jesus et al., 2016; Park et al., 2017). Hojnik and Ruzzier (2016) indicate that laws serve as a mainspring for businesses to embrace environmental innovation by reducing manufacturing costs and compliance with environmental policies. This competition also pushes enterprises to be leaders in environmental innovation and gain an advantage of the first mover (Nidumolu et al., 2009; Ahmad et al., 2022).

These organisational measures encourage new green manufactured goods and focus on a new marketplace for customers and investors with environmental concerns (Porter and Van Der Linde, 2017). Therefore, environmental innovation could promote a change from non-REC to REC to reinforce their reputation in stakeholders' eyes. Energy productivity also improves energy efficiency and reduces CO_2 emission and GHG, which is linked to the greater usage of renewable energy sources (Li et al., 2020). However, energy is an essential component of residential use and commercial output. REC is obtaining traction as an alternate energy source because of increasing energy prices and the control of conventional energy supplies by a small number of vendors, which also describes the positive link between energy prices and REC (Ju et al., 2017; Troster et al., 2018). Evidence indicates that increasing energy prices often push innovation Popp (2002) which inevitably results in cheaper renewable energy sources than conventional energy sources. Leng Wong et al. (2013) also reported that increased energy prices decrease traditional energy usage and increase REC.

3.2 Model Construction

In order to look into the effect of financial globalization on REC in the existence of economic growth, environmental innovation, energy productivity, and energy prices explained in the theoretical framework. The econometric model used is as follows:

$$REC = f\ (FG, GDP, ET, EPR, EP) \tag{1}$$

The model variables are changed into natural logarithm form for empirical estimation to reduce data sharpness and improve distributional properties. Data autocorrelation and heteroskedasticity can be curbed by natural logarithmic conversion. The results of a log-transformed model are more reliable and effective than linear transformation. The empirical model's log-transformed version is as follows:

$$REC_{it} = \alpha_0 + \beta_1 FG_{it} + \beta_2 GDP_{it} + \beta_3 ET_{it} + \beta_4 EPR_{it} + \beta_5 EP_{it} + \varepsilon_{it} \tag{2}$$

Eq. 2 i signifies the countries, and t describes the year. ε expresses the error term, and β describes the coefficients. REC indicates renewable energy consumption. FG, GDP, ET, EPR, and EP show financial globalization, economic growth, environmental innovation, energy productivity, and energy prices.

The study included financial globalization as a new determinant of REC. As a subset of the KOF Globalization Index, financial globalization illustrates the global impact of financial development (Gygli et al., 2019). Countries can embrace new technology and transition the economy to a more sustainable energy source (Anton and Afloarei Nucu, 2020; Shahzad et al., 2022). Therefore, we expect that financial globalization in BRICS countries will increase REC, i.e., $\beta_1 = \partial RE/\partial FG$. Following previous studies, Anton and Afloarei Nucu (2020); Moreno et al. (2012); Uzar (2020), we employ GDP to measure economic growth when determining the economic growth effect on REC for the BRICS countries. The

TABLE 1 | Variable description.

Variable	Symbol	Measurement	Source
Renewable energy consumption	REC	Renewable energy consumption (% total energy)	WDI
Financial globalization	FG	Financial globalization index	SWI
Economic growth	GDP	GDP (constant 2010)	WDI
Environmental innovation	ET	Environmental related technologies (% of total technologies)	OECD
Energy productivity	EPR	GDP/Primary energy consumption	OECD
Energy prices	EP.	Consumer price index	WDI

WDI, World Development Indicators; SWI, Swiss Economic Institute; OECD, Organization for.Economic Cooperation and Development.

anticipated impact of economic growth on REC is negative, i.e., $\beta_2 = \partial RE/\partial GDP$ As a result of significant research and development investment, environmental innovation can transform the economy into renewable energy sources (Alvarez-Herranz et al., 2017; Li et al., 2020). Therefore, in BRICS countries, we anticipate the positive effect of environmental innovation on REC, i.e., $\beta_3 = \partial RE/\partial ET$. This study introduces energy productivity in addition to environmental innovation, which is an attempt to enhance energy efficiency and minimize carbon emission and other GHG that are directly connected to the surge REC (Li et al., 2020). We expect energy productivity to impact REC, i.e., positively $\beta_4 = \partial RE/\partial EPR$. Prior studies found that energy prices are one of the most important variables to describe REC (Chang et al., 2009; Sadorsky, 2009; Carley et al., 2017; Lin and Omoju, 2017; Lu, 2017; Nicolini and Tavoni, 2017; Nyiwul, 2017; Li et al., 2020). According to Khan et al. (2020) renewable energy replaces non-renewable energy, like fossil fuels, especially caused by the substitution impact; we anticipate a positive effect on REC from the energy prices, i.e., $\beta_5 = \partial RE/\partial EP > 0$

3.3 Data

This research explores the determinants of REC in BRICS economies, covering the years 1990–2018. The study has used REC as a dependent variable. Financial globalization, economic growth, environmental innovation, energy productivity, and energy prices are independent variables. Data on REC, economic growth, and energy prices are taken from the World Bank database; financial globalization is from Swiss Economic Institute; environmental innovation and energy productivity are retrieved from the OECD database. **Table 1** shows the description, measurement, and data resources for variables.

4 ECONOMETRIC METHODOLOGY

Before testing the stationarity properties and the long-run association between the variables, we incorporate the cross-sectional dependence (CD) analysis introduced by Pesaran (2004).Because the panel data typically display CD because countries are interconnected at the global and regional levels. If the research findings do not evaluate CD, the estimation methods would be inconsistent and biased (Phillips and Sul, 2003; Paramati et al., 2017). Thus, In the panel data, the CD must be checked. In this analysis, to measure CD, two distinct methods are used. First, the CD examination was developed by Pesaran (2004). The calculation for the CD assay is given as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{ij}\right) \quad (3)$$

Where sample size is shown by N, time is indicated by T, and ρ_{ij} demonstrates the cross-sectional error correlation estimation of economy i and j. Breusch and Pagan (1980) proposed the Lagrange Multiplier (LM) technique to examine CD. The following equation is used to test CD for the LM test:

$$y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it} \quad (4)$$

Where i stands for cross-section measurements, t reflects the duration of the research.

4.1 Unit Root Tests

The first-generation unit root scrutiny results are unreliable in the presence of CD. Therefore, the second-generation unit root techniques have gained popularity (Zafar et al., 2019). Thus, this research analyzed the stationarity of the studied variables by applying CADF and CIPS to stand for cross-sectional augmented ADF and augmented IPS, respectively. The credibility of the analyses improves by utilizing the appropriate unit root examination within panel data in the existence of CD. Pesaran (2007) developed the following equation to evaluate the unit root:

$$\Delta x_{it} = \alpha_{it} + \beta_i x_{i,t-1} + \rho_i T + \sum_{j=1}^{n}\theta_{ij}\Delta x_{i,t-j} + \varepsilon_{it} \quad (5)$$

Where difference operator denotes by Δ, evaluated variable shown by $x_{i,t}$, individual intercept expressed by α, time trend represented by T and error term explained by ε_{it}. The Schwarz Information Criterion approach defines the lag length. The null hypothesis for both measures is that neither variable is stationary, but the alternative hypothesis is that at least one individual in a panel data time series is stationary.

4.2 Panel Cointegration Test

Before calculating the long-term variables, we confirm the underlying variables are cointegrated or not. As the panel cointegration tests of the first and second generation cannot jointly cope with structural breaks and CD, i.e., (Pedroni, 2004; Westerlund, 2005; Larsson et al., 2001; McCoskey and Kao, 1998; Westerlund, 2007). Phillips and Sul (2003), Ozcan and Ozturk, (2019) described that traditional cointegration

TABLE 2 | CD test findings.

Variables	Breusch-pagan LM	Pesaran Scaled LM	Pesaran CD
*ln*RE	79.900***	15.630***	7.411***
*ln*FG	204.970***	43.597***	14.303***
*ln*GDP	209.648***	44.643***	14.328***
*ln*ET	13.0078	0.673	0.244***
*ln*EPR	134.763***	27.898***	5.728***
*ln*EP	216.459***	46.166***	14.670***

*Note: ***, **, * is for* p-values *<0.01, 0.05 & 0.10.*

TABLE 3 | Unit root test findings.

Variable	CIPS		CADF	
	Level	First-difference	Level	First-difference
*ln*RE	−2.059	−3.689***	−2.119	−3.689***
*ln*FG	−3.027***	−5.321***	−2.334	−3.859***
*ln*GDP	−1.455	−2.855**	−1.455	−3.044***
*ln*ET	−4.728***	−6.068***	−3.083***	−4.873***
*ln*EPR	−2.570	−4.027***	−2.656	−4.027***
*ln*EP	−1.675	−4.956***	−1.675	−4.053***

*Note: ***, **, * is for* p-values *<0.01, 0.05 & 0.10.*

techniques produce deceptive and erroneous outcomes when the model undergoes CD and heteroscedasticity. For that reason, this research employs the Durbin Hausman Group Mean (DHGM) cointegration method proposed by Westerlund and Edgerton (2008). DHGM cointegration method is an advanced method and robust for CD and incorporates multiple structural breaks. Westerlund and Edgerton (2008) approach examines the series through the structural break and regime shift. Westerlund and Edgerton (2008) cointegration analysis presumes that there is no cointegration under null hypotheses compared to the alternate hypothesis of long-run variable relationships. Thus, this analysis should first employ Westerlund and Edgerton (2008) panel cointegration method before obtaining a long-run estimate.

The Westerlund and Edgerton (2008) cointegration analysis equations are described as:

$$L\,log\,(L) = a_0 - \frac{1}{2}\sum_{i=1}^{N}\left(T\,log\left(\sigma_{i,t}^2\right) - \frac{1}{\sigma_{i,t}^2}\sum_{t=1}^{T} eit^2\right) \quad (6)$$

4.3 Long-Run Estimation

Next, we evaluate the long-run connection between financial globalization and REC in the existence of environmental innovations, energy productivity, economic growth, and energy prices. For long-run analysis, Economists suggest several analytical techniques for panel data. In summary, different methods are prone to different shortcomings. Prior studies used first-generation techniques to calculate long-run elasticity, but these techniques overlook the CD (Ulucak and Bilgili, 2018). In the case of CD, the Dynamic Seemingly Unrelated Cointegrating Regressions (DSUR) method produces consistent results in recent literature. However, it ignores the problem of serial correlation and endogeneity. The Mean Group (MG) estimation method introduced by Pesaran and Smith (1995) and the Augmented Mean Group (AMG) approach suggested by Bond and Eberhardt (2013) provide accurate measurements with significantly larger sample size. However, in endogeneity and serial correlation, these techniques are not effective (Ahmed et al., 2020).

In the light of the above discussion, the present research relies on the CUP-FM presented by Bai and Kao (2006). For robustness, the CUP-BC approach was introduced by Bai et al.(2009) to consider some recent research (Ulucak and Bilgili, 2018; Zafar et al., 2019; Ahmed et al., 2020; Xiaoman et al., 2021). We have large samples with high power values by applying these two estimating methods, CUP-FM and CUP-BC. These approaches are more efficient for panel data than other estimating techniques because they can generate correct results even when CD, endogeneity, and autocorrelation are present. These techniques produce unbiased and reliable findings when used with exogenous regressors. These techniques can also deal with mixed *I(1)/I(0)* factors and produce reliable outcomes. These methods can estimate consistent results even if there is no endogeneity (Bai et al., 2009).

The authors adapted the CUP-BC estimation method to control the serial correlation and endogeneity resulting from the asymptotic bias. The CUP-FM estimating method maintains a consistent distribution of the limited model factors. These variables are continually updated (CUP) with time until they attain convergence *via*. simulations. The error term is assumed to follow the factor model. The factor model is defined as follows:

$$\hat{\beta}cup, \hat{F}cup = \text{argmin}\frac{1}{nT^2}\sum_{i=1}^{n}(y_i - x_i\beta)' M_F (y_i - x_i\beta) \quad (7)$$

where; $M_F = I_T - T^{-2}FF^{'}, I_T$ illustrates the components $T_S^{'}$ demonstrates the identity matrix. The "error term" denotes the presence of common latent elements. Then, the initial estimates are assigned to F. It is performed repeatedly until the desired level of convergence is obtained.

5 RESULTS AND DISCUSSION

The CD in the model is checked first in the empirical evaluation. The assessment of CD has become the key focus of the current literature. The failure to manage the CD could generate biased outcomes (Ahmed et al., 2020; Majeed et al., 2021b). The findings of the CD and LM examinations are summarized in **Table 2**. The findings are significant at the 1% significance level and confirm the null hypothesis' rejection. The findings of **Table 2** verify the existence of CD. The presence of the CD allows the use of second-generation unit root assessments to analyze the variables' integration order. The panel unit root tests CADF and CIPS are used for this, and **Table 3** summarizes the results of both tests. The CIPS test's empirical outcomes show that REC, energy productivity, economic growth, and energy prices have a unit root at the level. These variables have no unit root in the first difference, and they are integrated at *I(1)*. The CADF panel unit

TABLE 4 | Findings of Westerlund and Edgerton cointegration test.

	Level shift	Regime shift
$LM\tau$	–3.740***	–4.056***
$LM\phi$	–2.368**	–2.835****

*Note: ***, **, * is for* p-values *<0.01, 0.05 & 0.10.*

TABLE 5 | Structural breaks of Westerlund and Edgerton cointegration test.

Countries	Level shift	Regime shift
Brazil	2002	2002
Russian federation	2012	2003
India	2008	2008
China	2002	2003
South Africa	2009	2009

*Note: ***, **, * is for* p-values *<0.01, 0.05 & 0.10.*

TABLE 6 | CUP-FM and CUP-BC test findings.

Variable	Cup-FM		Cup-BC	
	Coefficient	T-Statistics	Coefficient	T-Statistics
*ln*FG	0.10346***	2.8228	0.08690***	4.29829
*ln*GDP	–0.5428***	17.8395	–0.6235***	17.0217
*ln*ET	0.06450***	3.0158	0.06381***	3.0197
*ln*EPR	0.42135***	3.3189	0.4111***	3.115
*ln*EP	0.0409***	14.0292	0.05121***	15.1797

*Note: ***, **, * is for* p-values *<0.01, 0.05 & 0.10.*

root test findings show the unit root at the level, except for environmental innovation, and in the first difference, all variables are stationary.

The Westerlund and Edgerton (2008) cointegration technique investigated the long-run cointegration connection. The statistically significant test of τ and ϕ imply a long-term relation between independent and dependent variables, in **Table 4**, both at the level and regime shift. For each country, the findings also found many structural breaks. The logic behind each structural break for the BRICS economies is described in-depth with their relative significance. In particular, we have observed multiple structural break periods in 2002, 2003, 2008, 2009, 2012, and the results are presented in **Table 5**. These breaks impact each country subject to both global and local shocks. The South American economic crisis is the economic turmoil that happened in Brazil in 2002. Russia's debt increased to 19 billion US dollars in 2003 because of higher finance ministries and Euro-bonds disbursements. In addition to the structural crisis in 2012, Russia has to contend with cyclical and idiosyncratic economic challenges (Grant and Hansl, 2015). Furthermore, the recession in 2008-09 has had an acute impact on the Indian and South African economies. Lastly, In 2003, a $12.3–28.4 billion loss was caused by the SARS epidemic and the projected 1% fall in GDP in China (Qiu et al., 2018).

After completing the cointegration evaluation, a precondition for long-run analysis, we used the effectual CUP-FM approach. We also used the CUP-BC approach for robustness purposes. **Table 6** reveals the long-run outcomes are positive and significant. The coefficients of financial globalization, environmental innovations, energy productivity, and energy prices signify that the rise in these variables improves REC. At the same time, economic growth has a negative connection with REC in BRICS countries. The CUP-FM shows coefficients values for financial globalization, environmental innovations, energy productivity, energy prices and economic growth are 0.103, 0.064, 0.421, 0.040%, and −0.542% respectively. Firstly, it is observed that economic growth reduces REC. It can be discussed from two viewpoints: First, economic growth may also entail increased energy consumption. In this sense, growing energy demands can be fulfilled from various sources. It could lead to an escalation in demand for renewables. Secondly, increasing energy consumption can raise the demand for readily available and inexpensive conventional energy rather than renewable energy. These results are consistent with earlier studies (Moreno et al., 2012; Uzar, 2020; Chen et al., 2021). Our results oppose Li et al. (2020) the OECD economies that access the GDP as a driver of the REC. The difference between Li et al. (2020) results can be justified because the BRICS countries are still emerging while OECD countries are developed.

Secondly, Financial globalization devises a significant positive effect on REC as a 1% acceleration in financial globalization is correlated with a 0.103% rise in REC, with a statistically significant impact at a 1% level. Financial globalization represents global financial development as a sub-index for the overall KOF globalization index (Gygli et al., 2019). An established financial system offers an incentive to access capital that enhances living standards and stimulates economic growth. Besides the increasing quality of life in the economic dimension, which is an essential constituent of its overall perception (Tvaronavičienė et al., 2021), it also raises energy consumption (Saud et al., 2020). The introduction of modern manufacturing methods and the procurement of progressed technology that save more energy resources result in a well-functioning financial system. Additionally, the capital market's financial development and liberalization cause financial channel interactions and bring foreign direct investment to transfer green technology with ample financial and technical capacity (Kim and Park, 2016; Eren et al., 2019; Ji and Zhang, 2019; Anton and Afloarei Nucu, 2020; Halaskova et al., 2021; Zhuang et al., 2021).

Thirdly, environmental innovation has a positive and significant effect on REC. Environmental innovation is, on average, a rise in REC by 0.064%. The BRICS countries have developed the requisite environment to promote environmentally friendly and energy-saving technological innovations. These advances also lower the renewable energy cost, making it more convenient for the masses to switch from non-REC to REC (Murad et al., 2019; Khan et al., 2020). Therefore, environmental innovation moves economies to clean energy sources (Alvarez-Herranz et al., 2017), contributing to the low-carbon energy transition and Sustainable Development Goals achievement (Krzymowski, 2020; Zhu et al., 2020; Li et al., 2021; Štreimikienė, 2021). These findings endorse the

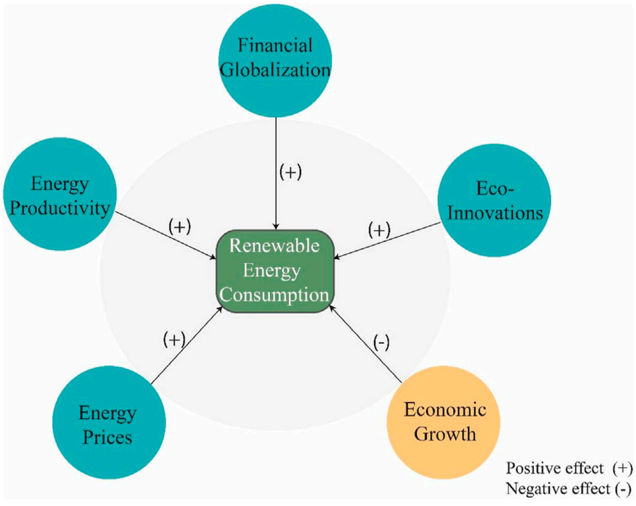

FIGURE 2 | Estimation outcomes from CUP-FM and CUP-BC.

results (Alvarez-Herranz et al., 2017; Li et al., 2020; Wang and Luo, 2022).

Fourth, similarly, energy productivity is positively connected with REC. On average, energy productivity results in a 0.790% rise in REC. Enhanced energy productivity could improve economic competitiveness, lower energy prices, and minimize carbon dioxide emissions. These outcomes confirm the research results (Bhattacharya et al., 2020; Li et al., 2020). Therefore, the endeavours to boost energy efficiency and minimize CO_2 emissions are also explicitly connected to REC improvement. Lastly, energy prices (assessed by the Consumer Price Index) are significantly linked to REC. An increase of 0.040% in REC, on average, is triggered by energy prices. These results confirm that energy price strategies can play an essential role in supporting REC. These findings affirm the results of (Ike et al., 2020; Khan et al., 2020; Li et al., 2020; Yayla et al., 2021). This study utilizes the CUP-BC technique to confirm the robustness of the analysis. The CUP-BC findings are congruent with the CUP-FM findings. **Figure 2** demonstrates a visual interpretation of the long-run parameters concerning their positive and negative signs. The positive effect indicates an increase in the related variable stimulates the REC, whereas the negative impact decreases the REC.

6 CONCLUSION AND POLICY IMPLICATIONS

There is much discussion about the positive effect of developing and removing CO_2 emissions from renewable energy sources. In spite of this, it is essential to examine the aspects that influence the REC. In this study, we endeavoured the potential determinants of REC. This research empirically explores financial globalization as a new determinant of REC in BRICS countries from 1990 to 2018. This research adds to the literature on energy economics by presenting new empirical data on how REC is connected to economic activities. We used financial globalization, environmental innovation, energy productivity, and energy prices to observe the potential association between economic growth and REC to calculate the linkage between development alacrity and REC. Renewable energy in BRICS economies is developing at a high speed (Zeng et al., 2017). This study used two techniques for CD familiarized by Pesaran (2004) and the LM test by Breusch and Pagan (1980). This research applies the DHGM cointegration approach formed by Westerlund and Edgerton (2008) to evaluate the determinants of REC for the BRICS economies. The long-run coefficients are computed employing the CUP-FM methodology presented by Bai and Kao (2006). CUP-BC technique is used in this study to test the models' robustness presented by Bai et al. (2009).

We confirmed the existence of CD in the data. Furthermore, the CIPS and CADF results of Pesaran (2007) unit root investigations reveal that the variables' integration order is mixed, i.e., *I(0)* and *I(1)*. The second-generation cointegration methods are applied due to the mixed integration of variables. The cointegration methodology developed by Westerlund and Edgerton (2008) is employed to confirm the variables' long-run equilibrium. All variables are cointegrated with REC at both the level and the regime shift, showing significant structural breaks, e.g., financial crises of South American economic crisis in 2002, 2003 SARS outbreak, 2007–8, recession, the variables REC, financial globalization, economic growth, environmental innovation, energy productivity, and energy prices are cointegrated. The positive and significant coefficients of financial globalization, environmental innovations, energy productivity, and energy prices imply that an escalation in these factors increases REC. Simultaneously, economic growth is negatively related to REC in the BRICS economies. The coefficients values are displayed by the CUP-FM for financial globalization, environmental innovation, energy productivity, energy prices and economic growth are 0.103, 0.064, 0.421, 0.040%, and −0.542% correspondingly. The outcomes of the CUP-BC are in line with the results of the CUP-FM.

6.1 Policy Implications

In practical terms, we recommend adopting policies by BRICS economies to reshape their total energy mix for clean energy. Increasing energy prices will be another option; it will reduce commercial energy consumption and is one possible way of motivating customers to change their preferences toward renewable energy. In addition, BRICS countries should turn to using renewable energy sources through environmental innovation and increasing energy production to attain the goals outlined in the Paris Climate Agreement. More specifically, environmental innovation and financial globalization are highly complementary. It is often risky and expensive to develop renewable energy, particularly at the start. Policy support is necessary to build a favourable environment to improve this sector. The financial environment is one of the most important foundations. Financial globalization plays an important role in raising the REC in this context.

According to the International Renewable Energy Agency, converting to renewable energy sources by 2050 will increase global GDP by $98 trillion while creating 63 million jobs worldwide in the renewables and energy sectors. In India, where more than 100 million jobs were lost due to the shutdown. Increasing renewable energy capacity to 160 GW by 2022 might create 1.3 million full-time jobs. A transition to renewables will help countries like India and China save money by drastically lowering their import bills. India will save over $90 billion between 2021 and 2030 if half of its renewable energy is used to substitute imported coal.

The fact that renewables are now the more cost-effective option in many countries makes a persuasive case for redirecting expenditures on coal consumption to accelerate renewable energy sources. It is necessary to reduce fossil fuel consumption in areas that remain essential, particularly now that oil prices plummet. Other stakeholders must also take action: businesses must use sustainable and safe methods, and investors must decarbonize their investments and encourage renewable energy. Renewable energy has the potential to reinvigorate the economy by producing "green" jobs, improving energy efficiency, and increasing resilience. The Paris climate agreement targets could be met if countries commit to a renewable energy future. Policymakers have an important opportunity to promote the clean energy sector significantly. They can expedite permits for renewable projects, increase tax credits, provide more grants and loans, extend timelines for projects impacted by the pandemic, and directly invest in emerging clean energy sources such as offshore wind. This study is limited to BRICS economies. This study can be enhanced by comparing the developed and developing economies in future research.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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