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REVIEW ARTICLE

Do drivers of renewable energy consumption matter for BRICS economies? Nexus among technological innovation, environmental degradation, economic growth, and income inequality

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Abstract

In light of increasing concerns about climate change and energy security, renewable energy has been seen as the most promising solution to fulfil future energy needs. This study examines the drivers of renewable energy consumption (REC) and the nexus between GDP growth, technological innovation, gross fixed capital formation, CO2 emissions, income inequality, and renewable energy consumption (REC) using annual data from BRICS countries. To this end, the study uses the augmented mean group (AMG) estimator, a second-generation estimator that takes slope homogeneity and cross-sectional dependence into consideration. For robustness, the pooled mean group (PMG) estimator has also been utilized. The findings of both estimators indicate that carbon emissions, technological innovation, and gross fixed capital formation exert adverse and significant impacts on REC. The findings also show that the use of renewable energy will rise as income inequality declines. We also employ the Dumitrescu and Hurlin (DH) granger causality test. The results of the analysis demonstrate a one-way causal association between income inequality and REC. This finding confirms that a reduction in income inequality will have a major impact on the adoption of renewable energy sources.

Keywords Income inequality · Renewable energy · Technological innovation · AMG technique · BRICS economies

JEL Classification O3 · O15 · Q2 · Q4 · Q5

Introduction

The sustainable development aims to conserve the environment for present-day needs as well as those of future generations (Wang et al. 2022a, b; Usman and Radulescu 2022). To solve environmental challenges, such as global warming, it is essential to adhere to the 17 Sustainable Development Goals (SDGs) (IPCC 2014). Various recommended approaches include developing new, efficient, and environmentally friendly technology, increasing the effectiveness of existing technologies, and/or making a partial or complete switch to renewable energy sources (RES). The latter, i.e., dependence on RES, is the approach that offers the best chance of rapidly replacing non-renewables (Olabi et al. 2021; Shabbir 2022; Mahalik et al. 2021; Sayed et al. 2021).

Renewable energy must be incorporated into economical and technically practical GHGs reduction strategies (Gyamfi et al. 2018; Wang et al. 2022a, b). By lowering reliance on fossil fuels, renewable energy can help in reducing emissions and ensure energy security (Saboori et al. 2022). RES can

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enhance air quality and human health, reduce energy costs, lessen negative effects on the environment, and create jobs (REN21 2020). Furthermore, energy import prices can be decreased by utilizing indigenous RES including wind, biomass, solar, hydropower, and geothermal (Duan et al. 2022).

Recent studies have explored the variables that affect the uptake of renewable energy in light of its importance (Zhao et al. 2022; Chen et al. 2021). Some of these researches looked at how REC and technical innovation are related (Khan et al. 2022; Alam and Murad 2020). The rapid deployment of RES to satisfy energy needs and alter the pattern of energy use could result from technological innovation. Due to profit-seeking conduct, it is difficult for less fortunate populations to benefit from the usage of renewables (Castrejon-Campos et al. 2022).

The BRICS economies—Brazil, Russia, India, China, and South Africa—are the subject of a case study. The BRICS economies have significantly influenced global energy consumption and production because of their rapid economic expansion and large population levels. Due to their size and rapid economic expansion, the BRICS economies have a huge impact on the advancement of the global economy. Furthermore, renewable energy sources are used to produce clean energy, which can lessen carbon emissions. Hence, a significant factor of renewable energy could be CO2 emissions (Samour et al. 2022; Dogan and Muhammad 2019; Shabbir et al. 2020; Omri and Nguyen 2014).

Due to their rapid economic growth and high energy consumption, the BRICS nations now place a high priority on energy security. In this case, using renewable energy might be a good way to achieve sustainable energy usage. Using the bootstrap panel cointegration technique (2007), AMG estimator, PMG estimator, and Dumitrescu and Hurlin (DH) causality test, this research attempts to analyze the factors influencing REC in BRICS economies over the period 1992–2019. This research contributes into the present body of knowledge in the following ways: (I) various empirical studies have analyzed the link between REC and CO2 emissions, utilizing a variety of modeling approaches, methodologies, and results. However, few of them have analyzed the connection between technological innovation, GDP growth, income inequality and REC, particularly in BRICS economies. (II) for the policy/decision makers, an understanding of the connections between economic growth, technological innovation, capital formation, environmental degradation, and income inequality with REC is crucial in order to help them design strategies for the efficient use of RES. (III) on the empirical side, it is acknowledged that slope homogeneity (SH) and cross-sectional dependence (CD) are renowned issues in panel econometrics. The remaining sections of the study include a review of the literature, data and methodology, findings, and a conclusion with policy implications.

Literature review

In the literature for studies on renewable energy, there has been a clear progression in recent years. This is due to the fact that using RES is acknowledged as one of the key ways to lower the quantity of CO2 emissions in the energy system and combat climate change (Zhao et al. 2022; Muhammad et al. 2022). Several studies have been conducted on the variables affecting the utilization of renewable/green energy. For instance, over the past decade, several researchers have researched the association between REC and GDP growth. Some of them have discovered a positive association (Namahoro et al. 2021; Ullah et al. 2021; Ahmad et al. 2022; Ehigiamusoe and Dogan 2022; Wang et al. 2022a, b; Shabbir and Zeb 2020; Liu et al. 2022a, b, c, d; Aslan et al. 2022; Chen et al. 2022a, b), while others have discovered a negative association (Ocal and Aslan 2013; Bhattacharya et al. 2016). The negative association between GDP growth and REC points to the likelihood that the economy is being overburdened by the high costs of renewable energy deployment, which in turn causes economic activity to slow down as a result of rising expenses. For example, Bhattacharya et al. (2016) found that the increased usage of green energy resulted in a slowdown in economic growth in Israel, the USA, India, and Ukraine, indicating that these nations may continue to use fossil fuels for future growth.

Therefore, CO2 emissions were included as one of the explanatory variables in earlier research that looked at the variables affecting REC. For instance, Sadorsky (2009) revealed that REC in G7 nations is significantly influenced by increases in CO2 emissions. A study by Salim and Rafiq (2012) demonstrated that REC in India, China, Brazil, and Indonesia was significantly influenced by carbon emissions. Regardless of how they classified their sample, Omri and Nguyen (2014) discovered that rising CO2 emissions were the primary factor driving the REC. However, when Apergis and Payne (2014) looked at the link for the Central American countries, they also discovered a strong link between REC and carbon emissions. Mac Domhnaill and Ryan (2020) showed that over the period from 2000 to 2015, greater levels of carbon emissions encouraged the adoption of renewable energy in the production of electricity in EU. Moreover, Nguyen and Kakinaka (2019) discovered that the REC and CO2 emissions had different relationships.

According to Jamil et al. (2022), renewable energy considerably lowers CO2 emissions and accelerates GDP growth. According to Khezri et al. (2022), who give evidence from diverse economies that REC reduces the risk of environmental deterioration. According to Jebli and Youssef (2017), using RES can assist increase agricultural production and fight global warming. In a same vein, Wang et al. (2021) show that REC is adversely connected with carbon emissions and recommend creating strategies for easy access to renewable energy to combat climate change. The same conclusion, which shows that renewable energy is favorable to CO2 mitigation, is reported by Sinha and Shahbaz (2018), Liu et al. 2022a, b, c, d; Saleem et al. 2019; Shabbir 2020; Wen et al. 2022; Yikun et al. 2021; Yu et al. 2020; Mughal et al 2022; Muhammad et al. 2021; Balsalobre-Lorente and Leitão (2020), and Bilgili et al. (2021). However, economic growth may increase environmental degradation. Moreover, Belaïd and Zrelli (2019) discovered short-term two-way causal association between carbon emissions and REC using a panel of nine Mediterranean nations.

Furthermore, current research has examined the linkage between income disparity and REC (McGee and Greiner, 2019; Uzar 2020; Muhammad et al. 2022; Shahbaz et al. 2022; Sharma and Rajpurohit 2022). Using parametric approach, Uzar (2020) analyzes the influence of income disparity on REC from 2000 to 2015. In 175 countries between 1990 and 2014, McGee and Greiner (2019) investigate how economic disparity modifies the relationship between REC and carbon emissions. In order to effectively replace fossil fuels, they argue that measures intended to increase the REC should be geared toward lowering income inequality. Besides, Bai et al. (2020) are concerned about the possibility that income disparity may reduce the impact of green energy technological innovation on the deterioration of the environment in terms of carbon emissions. For instance, inequality has been linked to many variables, including GDP growth, health and wellbeing, and the environment (Sager 2019; Gugushvili et al. 2020; Shabbir et al. 2020; Yaqoob et al. 2022a, b; Hayat et al. 2022a, b; Saleem et al. 2022; Sadiq et al. 2022; Nawaz et al. 2021b; Ramos et al. 2021; Liu et al. 2022a, b, c, d; Asongu and Odhiambo 2021). The societal benefits and favorable externalities from tackling economic disparity can assist expedite the deployment of green energy. Therefore, in order to steer policy, it is crucial to demonstrate empirically the link between green energy and inequality.

Data and methodology

Using annual data from 1992 to 2019, the paper examines the impact of CO2 emissions, capital formation, technological innovation, GDP growth and income disparity on REC in BRICS economies. The study takes into account six variables: economic growth or per capita GDP (constant 2020 US$), REC (share of overall energy consumption), gross fixed capital formation (% of GDP), CO2 emissions per capita (metric tons), technological innovation (patent applications, residents), and income inequality (Gini index). The data on income inequality is sourced from Solt (2021), while the data on the other variables is gathered from World Development Indicators (WDI, 2021). All of the chosen variables are transformed using a natural logarithm, allowing elasticity to be utilized to explain the derived slope coefficients.

Consistent with the literature (Alam and Murad 2020; Uzar 2020), REC is defined as a function of GDP growth, CO2 emissions, technological innovation, income inequality, and gross fixed capital formation and can be expressed empirically in the following way:

$$\begin{aligned}\mathrm{lnREC}_{\mathrm{it}} &= \beta_0 + \beta_1 \mathrm{lnGDP}_{\mathrm{it}} + \beta_2 \mathrm{lnCO2}_{\mathrm{it}} \\ &\quad + \beta_3 \mathrm{lnINN}_{\mathrm{it}} + \beta_4 \mathrm{lnGN}_{\mathrm{it}} + \beta_5 \mathrm{lnGFCF}_{\mathrm{it}} + \varepsilon_{\mathrm{it}}\end{aligned} \tag{1}$$

where REC stands for consumption of renewable energy. GDP, CO2, INN, GN, and GFCF stand for economic growth, carbon emissions, technological innovation, income inequality, and gross fixed capital formation, respectively. Finally, "t," "i," and "ε" stand for time dimension, cross-sections of countries, and the error term, respectively.

The study adopts the AMG estimator presented by Bond and Eberhardt (2013) to examine the long-term relationship between the variables. In the presence of slope heterogeneity (SH), and cross-sectional dependence (CSD), the AMG estimator has the potential to generate effective estimates (Sadorsky 2012).

$$Step-1:\ \Delta Y_{it} = a_i + \beta_i \Delta X_{it} + c_i f_t + \sum\nolimits_{t=2}^{T} d_i \Delta D_t + e_{it} \tag{2}$$

$$Step-2:\ \widehat{\beta}_{AMG} = N^{-1} \sum\nolimits_{i=1}^{N} \widehat{\beta}_i \tag{3}$$

In the above equations, $\Delta \mathrm{Y}_{\mathrm{it}}$ represents the dependent variable; $\Delta \mathrm{X}_{\mathrm{it}}$ denotes the explanatory variable; f_{t} represents the heterogeneous element; β_{i} represents country-specific estimation coefficients; $\widehat{\beta}_{\mathrm{AMG}}$ represents the mean group estimator; the coefficient of time dummies is indicated by di and the intercept and error component are denoted by a_{i} and e_{it}, respectively.

The panel AMG estimate approach offers a long-run parameter but is unable to indicate whether factors are causally related, even though causality is crucial for formulating policy recommendations. Therefore, our study adopts the Dumitrescu and Hurlin (DH) (2012) test to explore the causal association between the selected variables as well as their directions. In balanced and heterogeneous panel models, the test can also be used when the time period (T) exceeds the cross-sections (N), i.e., T > N.

$$WD_{N,T}^{HNC} = N^{-1} \sum\nolimits_{i=1}^{N} WD_{i,t} \tag{4}$$

whereas $WD_{i,t}$ represents the Wald statistics and averaging each Wald statistic for cross-sections yields the $\mathrm{WD}_{\mathrm{N,T}}{}^{\mathrm{HNC}}$ statistic.

Table 1 Descriptive statistics

Countries	Statistics	lnREC	lnGDP	lnCO2	lnINN	lnGN	lnGFCF
Brazil	Mean	3.8118	9.1716	0.6456063	8.1619	3.9254	2.9369
	Std. dev	0.0499	0.1383	0.1600	0.2677	0.0510	0.0789
	Minimum	3.7252	8.9608	0.3582	7.6497	3.8330	2.8097
	Maximum	3.8941	9.3921	0.9675	8.5090	3.9908	3.1269
	Observations	24	24	24	24	24	24
Russia	Mean	1.2754	9.0177	2.4383	10.0954	3.5721	2.9817
	Std. dev	0.0634	0.2726	0.0783	0.2167	0.0504	0.1202
	Minimum	1.1718	8.6135	2.3152	9.6228	3.3911	2.6663
	Maximum	1.3958	9.3700	2.6386	10.5839	3.6163	3.1753
	Observations	24	24	24	24	24	24
India	Mean	3.8527	6.8931	0.1017	8.2544	3.8267	3.3719
	Std. dev	0.1510	0.3311	0.2597	0.7732	0.0675	0.1358
	Minimum	3.5841	6.3886	-0.2629	7.0975	3.7184	3.1510
	Maximum	4.0471	7.4683	0.5790	9.4398	3.9060	3.5783
	Observations	24	24	24	24	24	24
South Africa	Mean	2.8471	8.7779	2.1696	6.5709	4.1310	2.8894
	Std. dev	0.0586	0.1224	0.0670	0.5032	0.0163	0.1193
	Minimum	2.7454	8.6157	2.0448	4.9273	4.1043	2.7180
	Maximum	2.9508	8.9336	2.3005	6.9108	4.1510	3.1575
	Observations	24	24	24	24	24	24
China	Mean	3.0172	7.8144	1.4004	11.1418	3.6797	3.6191
	Std. dev	0.4018	0.6188	0.4362	1.5901	0.0798	0.1303
	Minimum	2.4592	6.7878	0.8356	9.2114	3.5175	3.4127
	Maximum	3.4944	8.7796	2.0225	13.7833	3.7612	3.7959
	Observations	24	24	24	24	24	24
Panel	Mean	2.9608	8.3349	1.3511	8.8449	3.8269	3.1598
	Std. dev	0.9593	0.9299	0.9198	1.8063	0.2035	0.3104
	Minimum	1.1718	6.3886	−0.2629	4.9273	3.3911	2.6663
	Maximum	4.0471	9.3921	2.6386	13.78325	4.1510	3.7959
	Observations	120	120	120	120	120	120

Empirical results and discussion

An overview of descriptive statistics is provided in Table 1. According to the results, the greatest and smallest lnREC average values are 3.8527 and 1.2754 for India and Russia, respectively. India has the lowest average GDP value (6.8931), while Brazil has the highest average GDP value (9.1716). In terms of carbon emissions, Russia has the greatest mean lnCO2 value (2.4383), whereas India has the lowest (0.1017). Among BRICS countries, the highest and lowest lnINN mean values are 11.1418 and 6.5709 for China and South Africa, respectively. Moreover, according to the mean lnGN values, the highest income disparity is seen in South Africa, whereas Russia has the lowest.

Further, the findings of correlation analysis, presented in Table 2, reveal that there is a significant correlation among selected variables, indicating that economic growth, CO2 emissions, income inequality, technological innovation, and gross fixed capital formation are all significant drivers of REC.

Table 2 Matrix of correlation coefficient (after logarithm)

Variables	lnREC	lnGDP	lnCO2	lnINN	lnGN	lnGFCF
lnREC	1.0000					
lnGDP	−0.4743	1.0000				
lnCO2	−0.8798	0.6269	1.0000			
lnINN	−0.4122	0.0228	0.2087	1.0000		
lnGN	0.4496	0.1847	−0.0788	−0.7053	1.0000	
lnGFCF	0.1966	−0.5856	−0.2907	0.6312	−0.3633	1.0000

Table 3 Findings of cross-sectional dependence (CSD) tests

Variable	Breusch-Pagan LM	Pesaran scaled LM
lnREC	73.8690***	14.2816***
lnGDP	217.1780***	46.3264***
lnCO2	79.5485***	15.5515***
lnINN	88.4409***	17.5399***
lnGN	129.3572***	26.6891***
lnGFCF	56.2924***	10.3513***
CSD for Model	107.0501***	21.7011***

*** denotes 1% level of significance

Table 4 Findings of slope homogeneity test

	Statistic	*P*-value
$\tilde{\Delta}$	1690.5247***	0.0000
$\tilde{\Delta}_{adj}$	2050.0623***	0.0000

*** denotes 1% level of significance

We use the Pesaran scaled and Breusch-Pagan LM tests to examine whether the variables have CSD as mentioned on Table 3. At the 1% level of significance, the CSD test statistics indicate that the chosen variables are cross-sectionally dependent, rejecting the null hypothesis of cross-sectional independence. Furthermore, Table 4 demonstrates that the null hypothesis of the SH test is rejected, demonstrating the heterogeneity of the slope parameters.

To test for data stationarity, we employed the first- and second-generation unit root tests, including IPS, ADF, LLC, and CIPS, and the findings are shown in Tables 5 and 6 respectively. Although the findings of all unit root tests are similar (mixed order of integration), the findings of the CIPS test are more significant since the CIPS test not only addresses the CSD problem but is also robust to the heterogeneity problem.

After examining the stochastic nature of the variables, several panel cointegration tests, including Pedroni, Fisher, Kao, and Westerlund (2007), are employed. The rejection of the null hypothesis in each cointegration test provided in Table 6 indicates that there is evidence of a long-term association between the variables. The long-run associations between the variables are evident in all cointegration tests, but the Westerlund (2007) test is more noteworthy because it incorporates the CSD issue using the bootstrap approach.

The findings of the AMG and PMG techniques are shown in Table 7. The direction of the predicted coefficient remains the same when using different estimators, but the size and levels of significance have changed. Destek and Aslan (2020), Abbasi et al. (2021), Namahoro et al. (2021), Anser et al. 2021; Nawab et al. 2022; Arslan et al. 2021; Bai et al. 2022; Cao et al. 2022; Dai

Table 5 Findings of the 1st generation unit root tests

Variables	Level		1st difference		Integration order
	Intercept	Intercept & trend	Intercept	Intercept & trend	
Im, Pesaran and Shin					
lnREC	0.5845	−0.5594	−6.0556***	−4.6138***	I(1)
lnGDP	3.3585	−0.7211	−3.7947***	−2.1381***	I(1)
lnCO2	0.8271	−0.6278	−5.9592***	−4.6884***	I(1)
lnINN	1.2578	−1.7680**	−4.9303***	−4.2721***	I(0)
lnGN	−2.0599**	−1.2366	−2.4278***	−1.4292*	I(0)
lnGFCF	−0.4351	−0.1631	−7.3791***	−6.3573***	I(1)
ADF – Fisher					
lnREC	11.4198	13.4609	52.2532***	38.5385***	I(1)
lnGDP	1.47236	14.6388	32.3198***	20.3830**	I(1)
lnCO2	10.5745	13.3170	50.7522***	37.7255***	I(1)
lnINN	9.85442	18.6642**	44.4655***	35.2486***	I(0)
lnGN	24.3277***	26.1349***	25.8978***	18.2252**	I(0)
lnGFCF	9.06748	12.3440	63.8306***	50.7727***	I(1)
Levin, Lin and Chu					
lnREC	0.7362	−0.4101	−5.3122***	−4.0985***	I(1)
lnGDP	0.4246	−0.8506	−3.6202***	−3.5199***	I(1)
lnCO2	0.4349	−1.5510*	−5.9983***	−4.8444***	I(0)
lnINN	1.2999	−1.7566**	−5.1640***	−4.0316***	I(0)
lnGN	−2.6644***	−2.5758***	−3.3353***	−2.3417***	I(0)
lnGFCF	−0.9125	0.0921	−7.5619***	−6.5681***	I(1)

The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively

Table 6 Findings of the 2nd generation unit root test—CIPS

Variables	Level		1st difference		Integration order
	Intercept	Intercept & trend	Intercept	Intercept & trend	
lnREC	−2.4690**	−2.1081	−1.8496	−1.8178	I(0)
lnGDP	−1.9059	−2.7819*	−2.4676**	−2.0666	I(0)
lnCO2	−2.0227	−3.2672***	−2.8960***	−2.9489**	I(0)
lnINN	−3.5374***	−1.5859	−2.3264*	−2.2531	I(0)
lnGN	−1.6055	−2.3463	−2.4321**	−2.5578	I(1)
lnGFCF	−1.8639	−2.1865	−2.4406**	−2.4109	I(1)

The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively. The critical values for CIPS test were tabulated by Pesaran (2007)

et al. 2022; Ge et al. 2022; Ji et al. 2022; Jun et al 2021; Khan et al. 2021a, b; Khuong et al. 2021; Li et al. 2021; Liu et al. 2022a, b, c, d; Nawaz et al. 2021a; Hayat et al. 2022a, b; Yaqoob et al. 2022a, b; Shabbir and Wisdom 2020; Shabbir et al. 2021; Radmehr et al. (2021), Jamil et al. (2022), Khezri et al. (2022), Samour et al. (2022), and Muhammad et al. (2022) all back up this finding. Using the PMG estimator, it is discovered that the coefficient for technological innovation is negative and statistically significant. A 0.1204% decrease in REC results from a 1% rise in technical innovation. This suggests that technological development does not support the supply side economy of green energy. This finding is consistent with what Suki et al. (2022) discovered.

Table 7 Panel cointegration tests

Pedroni (Within-Dimension)		
	Statistic	Weighted Statistic
Panel v-Statistic	1.3961	0.2900
Panel rho-Statistic	0.0402	0.6503
Panel PP-Statistic	−3.3306***	−2.2614***
Panel ADF-Statistic	−3.3349***	−1.9030***
Pedroni (Between-Dimension)		
	Statistic	*P*-value
Group rho-Statistic	1.4123	0.9211
Group PP-Statistic	−2.7676***	0.0028
Group ADF-Statistic	−2.2241***	0.0131
Fisher		
No of CE(s)	Trace test	Max-Eigen test
None	218.0***	118.3***
At most 1	123.1***	75.58***
At most 2	60.95***	35.17***
At most 3	33.78***	19.16**
At most 4	24.18***	18.11**
At most 5	21.87**	21.87**
Kao	Statistic	*P*-value
ADF	−2.5643***	0.0052
Westerlund (2007)		
Statistic	Value	Robust *P*-value
Gt	−3.595**	0.028
Ga	−3.293	0.495
Pt	−6.960**	0.015
Pa	−1.562	0.753

All cointegration tests are run with intercept only. The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively

For robustness, the PMG estimator is used since it is both stable and effective at handling heterogeneity. The findings of the PMG estimator, which are presented in Table 8, concur with the results of the AMG estimator. According to the findings of the PMG estimator, a 1% increase in CO2, INN, GN, and GFCF depletes REC by 0.7438%, 0.0678%, 1.402%, and 0.1843%, respectively. On the other hand, REC rises by 0.2230% for every 1% growth in GDP. Additionally, Table 9 presents the nation-specific findings of the AMG estimator. The results show that GDP and REC are significantly positively associated in China and Brazil.

Conclusion and policy implications

Climate change continues to be a global issue, and energy needs will continue to rise as population growth accelerates. The problem with the climate is directly caused by the emission of greenhouse gases. Energy demand, in the meantime, supports economic expansion. As a result, the issues are now interrelated. All countries value economic development, yet the significant CO2 emissions from current energy

Table 8 Results of the AMG and PMG estimators

	AMG		PMG	
Variables	Coefficient	*P*-value	Coefficient	*P*-value
lnGDP	0.0229	0.938	0.2230***	0.012
lnCO2	−0.5004***	0.000	−0.7438***	0.000
lnINN	−0.1204**	0.035	−0.0678**	0.020
lnGN	−0.8908***	0.008	−1.4027***	0.000
lnGFCF	−0.0679*	0.085	−0.1843***	0.011

The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively

Table 9 Country-wise results of AMG Estimator

Country	lnGDP	lnCO2	lnINN	lnGN	lnGFCF
Brazil	0.7219***	−0.7889***	−0.2509***	−0.4955	−0.1561***
Russia	0.3425	−0.3227	−0.2164**	−1.2126***	−0.0018
India	−0.0451	−0.5300***	−0.0204	−0.1903	0.0128
China	−0.8229***	−0.6033***	−0.1240***	−0.8655***	−0.0534
South Africa	−0.1421	−0.2629	0.0101	−1.7902	−0.1437

The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively

production directly contribute to environmental deterioration. Therefore, to maintain the economic significance of countries, green energy continues to be the most suitable replacement for the world's energy needs. Renewable energy is climate-friendly since it reduces or eliminates CO2 emissions. Several nations have already begun their journey towards a low-carbon economy by concentrating on RES. Given this information, the goal of the current study is to analyze the effects of economic growth, technological development, CO2 emissions, gross fixed capital creation, and income disparity on REC.

The following policy implications could be implemented based on the study’s findings to further enhance the quality of the environment in BRICS economies. To achieve a coherent decrease in carbon emissions, BRICS policymakers should prepare and implement economic expansion policies and agendas. For example, as BRICS economies' incomes grow, they will be able to increase environmental consciousness, create strict eco-friendly procedures, and implement environmentally friendly green technologies for REC. To boost renewable energy production, it is also critical to enhance technical advances across BRICS countries. Furthermore, subsidies could be provided by BRICS policymakers in order to minimize the expenses of REC, welcome business initiatives involving green energy sources, and create awareness of how to begin from the ground up to achieve the advantages of RES, such as lowering reliance on non-renewables and air pollution. In addition, in order to increase the usage of renewable energy, it is crucial to remove the economic and legal obstacles that prevent businesses and individuals from making investments in RES. Future research could also take into account the quantile- level analysis and spatial dimensions of multilateral trade and clean energy production.

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Author contribution Mr Iftikhar has completed the data analysis part, Dr Rasim completed the Introduction section, Dr. Vipin completed the Literature review section, Dr Chanchal Chawla wrote Methodology section, and interpreted the data analysis section, and Dr Carlos wrote conclusion, abstract parts, proofread of paper, and format the paper as per journal requirements.

Data availability The data is available on request from corresponding author.

Declarations

Ethical approval and consent to participate This study didn’t use any kind of human participants or human data, which require any kind of approval.

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