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RESEARCH ARTICLE

Can undergoing renewable energy transition assist the BRICS countries in achieving environmental sustainability?

Mohammad Mahtab Alam[1] · **Mehmet Akif Destek**[2,3,8] · **Ansarul Haque**[4] · **Dervis Kirikkaleli**[5] · **Stefania Pinzón**[6] · **Khurshid Khudoykulov**[7]

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Abstract

The BRICS countries ratified the 2030 Sustainable Development Goals agenda whereby ensuring environmental sustainability is of paramount importance for these emerging market economies. Although the BRICS nations have recorded noteworthy economic growth trajectories over the last couple of decades, these nations have not fared well in terms of improving their environmental indicators, especially due to gradually becoming more fossil fuel dependent over time. Hence, this study aims to explore whether undergoing the renewable energy transition can directly and indirectly establish environmental sustainability in the BRICS countries by containing their annual growth rates of carbon dioxide emissions. Additionally, the emission growth rate–influencing effects of technological innovation, foreign direct investment receipts, urbanization, and institutional quality are also evaluated. Based on data spanning from 1996 to 2021 and considering the result obtained using advanced panel data estimators, the findings endorse that the yearly carbon emission growth rates are (a) unaffected by undergoing the renewable energy transition on its own; (b) positively impacted by technological innovation, net receipts of foreign direct investment, and urbanization; and (c) negatively impacted by improving institutional quality through effective controlling of the spread of corruption. More importantly, the results verify the joint carbon emission growth rate–mitigating impact of renewable energy transition and institutional quality improvement. Hence, for abating the emission growth rate figures, several policies are prescribed.

Keywords Carbon emissions · Renewable energy · Institutional quality · Sustainable Development Goals · BRICS

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✉ Ansarul Haque
ansarul.haque@utas.edu.om

Mohammad Mahtab Alam
mmalam@kku.edu.sa

Mehmet Akif Destek
adestek@gantep.edu.tr

Dervis Kirikkaleli
dkirikkaleli@eul.edu.tr

Stefania Pinzón
yajairapinzon61@gmail.com

Khurshid Khudoykulov
kh.khudoyqulov@tsue.uz

1 Department of Basic Medical Sciences, College of Applied Medical Science, King Khalid University, 61421 Abha, Saudi Arabia

2 Department of Economics, Gaziantep University, Gaziantep, Turkey

3 Adnan Kassar School of Business, Lebanese American University, Beirut 1102-2801, Lebanon

4 College of Economics and Business Administration, University of Technology and Applied Sciences, Ibri, Oman

5 Faculty of Economic and Administrative Sciences, Department of Banking and Finance, European University of Lefke, Lefke, TR-10, Mersin, Northern Cyprus, Turkey

6 Esai Business School, Universidad Espíritu Santo, Samborondón 091650, Ecuador

7 Department of Finance, Tashkent State University of Economics, Tashkent, Uzbekistan

8 Research Methods Application Center of UNEC, Azerbaijan State University of Economics (UNEC), Baku AZ1001, Azerbaijan

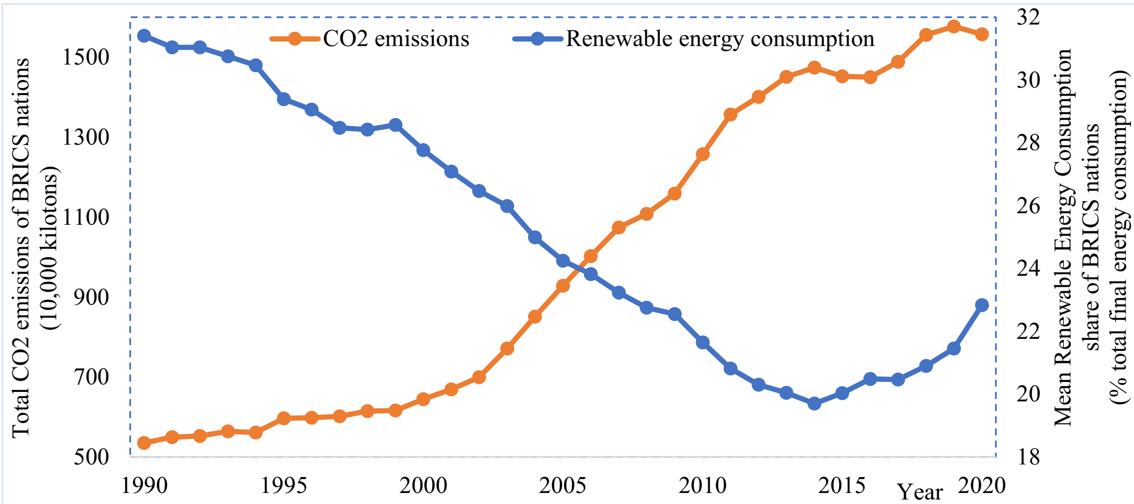

Fig. 1 Trends in CO_2 emissions and renewable energy consumption shares

Introduction

The BRICS, short form for Brazil, the Russian Federation, India, China, and South Africa, consists of a couple of rapidly emerging market economies that are recognized as leading consumers of energy resources worldwide (Murshed 2023). However, despite accounting for more than two-fifths of global investments made in renewable energy projects (Sadiq et al. 2023), these nations are still vastly dependent on fossil fuels to meet their national energy requirements (Qin and Ozturk 2021; Ibrahim et al. 2022). As a result, these nations have not been able to contain their respective yearly discharges of greenhouse gases (Caglar et al. 2022a; Agozie et al. 2022; Naseem et al. 2022). Notably, China is the highest discharger of carbon across the globe while the rest of the BRICS members find themselves in the list of the topmost dischargers of carbon dioxide (CO_2) in the world, as well (Sachan et al. 2023). Therefore, in this regard, it appears as if high dependence on fossil fuel, amidst relatively underdeveloped states of renewable energy sectors, is a major driver of the surging annual atmospheric CO_2 discharge levels of the BRICS countries.

A closer look into the inter-temporal trends in CO_2 emission levels and the shares of renewables in the final energy consumption bundles of the BRICS nations (as illustrated in Fig. 1) reveals a couple of interesting issues. First, the trends show that the total volume of CO_2 emitted annually by the BRICS nations has progressively gone up; precisely, between 1990 and 2020, the cumulative annual CO_2 emission figures of these emerging countries rose by around 6.4% year-on-year. Thus, the growing carbon emission–induced climatic concerns across the BRICS nations are supported by this statistical trend assessment. Second, in the context of undergoing the renewable energy transition[1] (RET), it is evident that the BRICS nations have miserably failed in developing their respective renewable energy sectors; consequently, between the 1990 and 2020 period, the mean share of renewables in the final energy consumption profiles of the BRICS countries was merely 25%. This implies that in the last three decades or so, three-quarters of the energy demand of the BRICS nations have been met by fossil fuels. More alarmingly, the trends certify that rather than reducing fossil fuel dependency, these emerging nations have become more intensive in the use of fossil fuels over time. Notably, between 1990 and 2020, the collective fossil fuel share of energy consumption profiles of the BRICS has gone up by more than 8.5 percentage points.

Therefore, under circumstances of rising CO_2 emission levels and declining renewable energy shares, it is of prime importance for the BRICS countries to understand the importance of switching from the employment of non-renewable to renewable energy (i.e., undergoing the RET) so that these emerging market economies in the future can produce economic outputs without harming the environment in the process. Against this backdrop, this current study questions whether undergoing the RET can assist the BRICS countries in realizing the objective of establishing environmental sustainability, especially by reversing the surging trends in their CO_2 emission levels. Moreover, since ensuring a sustainable environment worldwide is currently

[1] Typically, it refers to simultaneously enhancing and reducing the shares of renewables and non-renewables, respectively, in the energy consumption profiles. For more information in the context of this energy transition procedure, see Murshed (2021) and Yan et al. (2023).

under the spotlight (Belaïd and Arora, 2023), this study is of utmost relevance in designing net-zero emission[2] policies in line with the environmental sustainability agenda under the 2030 Sustainable Development Goals (SDG) of the United Nations. Notably, in the 13th SDG (SDG-13 from hereafter), the utmost importance of reducing carbon emissions for battling climatic adversities has been duly manifested (He et al. 2023; Yang et al. 2023). On the other hand, the 7th SDG (SDG-7 from hereafter) insists on ensuring plentiful access to clean/renewable energy globally (Saqib et al. 2024; Murshed et al. 2022; Huang et al. 2022). Therefore, the policy takeaways from this study can be assumed to guide the BRICS nations in making plans relevant for partially realizing the 2030 SDG agenda.

Though several previous studies have empirically tested the renewable energy consumption-CO_2 emission nexus using BRICS data (Banerjee and Murshed, 2020; Ibrahim et al. 2022; Adebayo et al. 2023), this study bridges a couple of the existing literature gaps. First, mostly, the previous works have used annual CO_2 emission levels as the measure of environmental sustainability in the BRICS; however, since these countries are yet to undergo the RET in full swing, it is not possible for them to curtail their annual emission figures. Thus, under such circumstances, ensuring environmental sustainability in the BRICS countries would require a reduction in the growth rate of their annual CO_2 emission levels. In this regard, the previous studies have largely overlooked the significance of lessening annual carbon emission growth rates in the BRICS countries while predominantly focusing on reducing their yearly level of CO_2 emissions, which is practically impossible in the current context. Second, the existing studies have stressed the pertinence of testing the direct environmental repercussions of undergoing RET while not putting much emphasis on predicting the indirect mechanisms through which RET can affect the environment. Accordingly, filling these two important gaps in the extant literature, this current study examines how undergoing RET both directly and indirectly[3] (via other macroeconomic factors) influences annual CO_2 emission growth rates of the BRICS nations.

In the rest of the study, the literature review, methodology, analytical results, and conclusion are put forward.

[2] For an in-depth understanding of the concept of net-zero emissions, see Ben Abdeljelil et al. (2023) and Belaïd and Massié (2023).

[3] Indirect impacts typically refer to whether RET mediates/moderates the association between CO_2 emission growth rate and other macroeconomic factors. For more information regarding the indirect influencing mechanism, see Siddik et al. (2023) and Khan and Ozturk (2021).

Literature review

This section summarizes the previous published works that explored how renewable energy use influences CO_2 emission levels in the BRICS and non-BRICS countries. Based on the review of the extant literature, the gaps bridged by this current study are re-highlighted.

The literature on renewable energy-CO_2 emission nexus in the BRICS context

The previous studies focusing on the BRICS countries have empirically checked whether renewable energy use can inflict environmental quality–improving effects by reducing the yearly level of CO_2 emitted by these major emerging market economies. Among these, Ibrahim et al. (2022), considering data from 1996 to 2019, recorded proof regarding consumption of renewable energy, as opposed to consuming non-renewable energy, is likely to curb CO_2 emissions. Consequently, Ibrahim et al. (2022) verified the environmental sustainability–driving impact of RET for the cases of the BRICS. Likewise, the authors also pointed out the relevance of scaling nuclear energy for reducing the CO_2 emission levels of these emerging market countries. Furthermore, the other key results found in that study certified the CO_2 emissions boosting and mitigating impacts of financial development and structural transformation, respectively.

Similarly, emphasizing the relevance of innovating technologies and undergoing RET for establishing environmental sustainability, Adebayo et al. (2023) used BRICS data from 1990 to 2019 and discovered that more use of renewable energy leads to reductions in CO_2 emission levels, in both the short and long run. Likewise, technological innovation and natural resource consumption were identified as CO_2 emission level inhibitors. Consequently, these factors were claimed to facilitate the attainment of SDG-13 in the BRICS nations. In another relevant study exploring the renewable energy-CO_2 emission nexus for BRICS countries, Fu et al. (2021) argued that economic growth processes in the BRICS nations are usually fossil fuel–intensive whereby more growth of these emerging economies leads to greater discharges of CO_2; however, the authors mentioned that this economic growth-environmental degradation trade-off can be nullified given the BRICS nations consume more volumes of renewable energy. Precisely, verifying the environmental quality–improving impact of undergoing RET, the authors found that as the renewable energy consumption level goes up, the BRICS nations' CO_2 emission levels are likely to go down in the long run.

Banday and Aneja (2020) utilized BRICS data for the 1990–2017 period and tried to distinguish the environmental quality–influencing effects exerted through the employment of renewable and non-renewable energy resources. The results confirmed that consumption of both these types of energy is responsible for affecting the CO_2 emission levels of India, Russia, and South Africa but not in the cases of China and Brazil. Accordingly, the authors recommended the BRICS nations to promote renewable energy use while avoiding non-renewable energy use to curb CO_2 emission levels in the long run. Meanwhile, Khattak et al. (2020) considered the period from 1980 to 2016 and found that renewable energy consumption assists in containing CO_2 emission levels in Russia, China, and India but not in Brazil and South Africa. In addition, the authors showed that technological innovation helps in abating CO_2 emissions only in Brazil while it is ineffective in reducing CO_2 emission levels in the other four BRICS countries.

The literature on renewable energy-CO_2 emission nexus in the non-BRICS context

Among the previous studies exploring the CO_2 emission level–influencing effects of renewable energy consumption in the context of the non-BRICS nations, Omri and Saidi (2022) concentrated on 14 countries from the Middle East and North African region and recorded statistical proof which endorsed that more use of renewable energy and non-renewable energy is respectively accounting for lower and higher CO_2 discharge levels. Hence, based on these findings, it was claimed that undergoing the RET is essential for reducing CO_2 emission levels in order to set a sustainable environment. Furthermore, the authors recorded evidence certifying the CO_2 emission surging impacts industrialization in the concerned countries. Similarly, Vo and Vo (2021), in the context of selected Southeast Asian states, asserted that more use of renewable energy accounts for lower discharges of CO_2. Accordingly, the Southeast Asian countries were recommended to make greater use of renewable energy (i.e., undergo the RET) to tackle their environmental issues.

Grodzicki and Jankiewicz (2022) concentrated on the European region and tried to predict the environmental quality–influencing effects associated with more consumption of renewable energy and urbanization. The results certified that as more volume of renewable energy is employed, the level of CO_2 emissions in the European nations of concern is expected to go down. Conversely, the results verified that urbanization amplifies CO_2 emissions across Europe. On the other hand, utilizing data from the highly developed Group of Seven (G7) countries, Li and Haneklaus (2022) highlighted the importance of adopting clean energy while withdrawing from fossil fuel consumption to establish environmental sustainability. Notably, the results confirmed that more use of renewable energy resources mitigates the yearly discharges of CO_2 in the G7 nations; albeit, compared with the short run, the marginal log-run CO_2 emission level–reducing impact is relatively lower. Besides, the results also supported the idea that urbanization within the G7 countries helps in reducing their CO_2 emission levels. Alternatively, the authors argued that participation in international trade leads to higher CO_2 emission levels in these developed countries.

Gyamfi et al. (2022) utilized data from the Next Eleven countries and found that scaling investment in renewable energy development programs helps mitigate CO_2 emission levels in the long run. This finding endorsed the idea that financing initiatives linked with the RET process are indeed effective in harnessing the environmental sustainability agenda of the concerned emerging nations. In addition, the authors found evidence regarding the environmental quality–dampening impacts exerted by incoming foreign direct investment (FDI). Basically, this particular finding indicated that the financial globalization strategies followed by the Next Eleven nations are not in line with establishing a sustainable environment since more influxes of FDI were evidence to raise their long-run CO_2 emission figures. In another relevant study featuring several Asian economies, Rahman and Alam (2022) stated that although more use of renewable energy reduces CO_2 emission levels, failure to control corruption across the concerned Asian countries inflates their annual CO_2 emission figures. In this regard, the finding related to the corruption-CO_2 emission nexus showed that if the quality of institutions is poor due to high incidences of corruption, it is not possible to implement environmental quality–improving policies; consequently, under circumstances of high corruption, it is cumbersome to reduce the annual CO_2 emission levels across Asia. Moreover, the authors reported a puzzling finding regarding the development of technologies resulting in higher CO_2 emission levels in the selected Asian countries.

Literature gaps and contributions

Therefore, based on the summarized findings presented in the previous sub-sections, it is once again highlighted that the preceding studies have not emphasized the pertinence of reducing the annual growth rate of CO_2 emission levels in the context of both the BRICS and non-BRICS countries. However, in the contemporary era of vast reliance on fossil fuels across the globe, reducing annual emissions of CO_2 is quite impossible. As a result, the aim should not be to reduce the CO_2 emission level, which is practically impossible at this moment; rather, effective measures need to be taken so that the growth of the annual CO_2 emission figures is reduced over time. Moreover, it is also apparent that the previously published studies have not dug deep into unearthing the indirect mechanisms through which undergoing RET can facilitate the objective of establishing environmental sustainability. Instead, these studies have predominantly assumed the RET-CO_2 emission reduction nexus to be direct and not mediated/moderated by other major macroeconomic factors. Hence, this study aims to bridge these key literature gaps, especially by assessing the direct and indirect impacts exerted by renewable energy on the annual CO_2 emission growth rates of the BRICS economies.

Methodology

In this section, the empirical models used for identifying the macroeconomic determinants of CO_2 emission growth rates in the context of the BRICS are presented followed by an overview of the estimation tools used for predicting these models.

Empirical models

To investigate how the annual CO_2 emission growth rates are determined, this study primarily considers the model presented as follows:

$$CO_2GR_{i,t} = \partial_0 + \partial_1 REC_{i,t} + \partial_2 lnTECH_{i,t} + \partial_3 FDI_{i,t} + \partial_4 URB_{i,t} + \partial_5 INSTQ_{i,t} + \varepsilon_{i,t} \quad (1)$$

The dependent variable CO_2GR refers to the annual CO_2 emission growth rate. Hence, the elasticity parameter ∂_m, where $m = 1, 2, \ldots, 5$, would indicate the marginal impact of positive changes in the values of the associated explanatory variables (REC, lnTECH, FDI, URB, and INSTQ) on the annual CO_2 emission growth rate. Among the explanatory variables, REC refers to renewable energy consumption which is measured in terms of renewable energy's share of total final energy consumption level. This variable is often said to be indicative of the extent of the RET whereby a rise in this share denotes a successful transition from non-renewable to renewable energy and vice versa (Murshed 2023; Awijen et al., 2022; Murshed et al. 2022). Theoretically, due to renewable energy being considered clean (Mohsin et al. 2023; Tiba and Belaid 2021; Ahmed et al., 2022), the transition to renewable energy can be expected to cut down emissions whereby the annual CO_2 emission growth rate can be expected to decline (thus, ∂_1 is hypothesized to be negative).

Among the other explanatory variables, lnTECH[4] refers to technological innovation which is proxied by the annual counts of patents applied by residents. Patent applications when granted are indicative of technological progress which is derived through investment in research and development programs (Belaïd and Massié, 2023). In this regard, if newly patented technologies are green, they can be expected to reduce atmospheric discharges of carbon (Li et al. 2023); consequently, technological innovation can be linked with lower CO_2 emission growth rates (thus, ∂_2 is hypothesized to be negative). Conversely, the development of unclean technologies can induce environmental complications (Rahman and Alam 2022; Qiao et al., 2024) and, therefore, lead to higher CO_2 emission growth rates (thus, ∂_2 can be positive, as well). Next, the variable FDI refers to net receipts of FDI (expressed as the percentage share of the GDP) which captures the extent of financial globalization in the BRICS nations. Theoretically, in line with the concept of the pollution haven hypothesis (PHH), if incoming FDI amplifies unclean economic activities, a rise in CO_2 emissions can be expected. As a result, under such a scenario, more influx of FDI can result in a rise in the CO_2 emission growth rate (thus, ∂_3 is hypothesized to be positive). On the flip side, using the conceptual framework of the pollution halo effect hypothesis (PHEH), if inward FDI assists in the dissemination of clean technologies (Murshed et al. 2022), then a CO_2 emission growth rate-reduction impact can be expected (thus, ∂_3 can be negative, as well). Furthermore, considering the relevance of greening financial mechanisms in ensuring environmental sustainability (Zhang et al. 2022; Lu et al. 2023), the inclusion of this foreign financial variable in our model can be deemed justified.

The variable URB refers to urbanization which is proxied by the annual growth rate of the size of the urban populations of the respective BRICS countries (i.e., the greater the growth rate, the greater the speed of urbanization and vice versa). From the theoretical viewpoint, urban activities are often alleged to trigger higher emissions of CO_2 (Anwar et al. 2022; Bakry et al. 2023); consequently, it can raise the rate of CO_2 emission growth (thus, ∂_4 is hypothesized to be positive). Finally, INSTQ stands for institutional quality which is particularly captured by the level of corruption control[5] in the respective BRICS nations. Corrupt practices are assumed to deteriorate institutional quality which, in turn, may reduce the efficacies of the concerned environmental development agencies in containing annual CO_2 discharges (Rafei et al. 2022; Yang et al. 2022); consequently, institutional quality improvement (i.e., better corruption control) can be linked with lower CO_2 emission growth rates (thus, ∂_5 is hypothesized to be negative).

Though the aforementioned model is assumed to predict how undergoing the RET can directly impact the

[4] The prefix ln indicates the natural log transformation of the variable to tackle heteroskedasticity concerns.

[5] Corruption control is "measured as an index that assigns" a higher score to relatively better control of corruption and vice versa (World Bank 2023b).

Table 1 Summary statistics

Statistics	CO_2GR	REC	lnTECH	FDI	URB	INSTQ
Mean	2.709	23.370	9.164	2.301	1.862	−0.350
Standard deviation	4.954	16.867	2.057	1.442	1.208	0.408
Variance	24.551	284.832	4.233	2.079	1.459	0.166
Skewness	−0.043	0.242	0.647	1.231	−0.272	0.092
Kurtosis	3.508	1.411	3.177	6.736	2.377	2.797
Observations	130	130	130	130	130	130

Table 2 Correlation matrix

Correlation	CO_2GR	REC	lnTECH	FDI	URB	INSTQ
CO_2GR	1.000					
REC	0.140	1.000				
lnTECH	0.119	−0.242	1.000			
FDI	0.248	0.155	0.225	1.000		
URB	0.428	0.310	0.117	0.110	1.000	
INSTQ	0.103	0.289	−0.479	−0.141	0.429	1.000

Table 3 CD test (Pesaran 2021) results

Variable	CO_2GR	REC	lnTECH	FDI	URB	INSTQ
Test statistic	3.816***	−1.554	0.407	0.037	0.240	−2.061**
Probability	0.001	0.120	0.684	0.970	0.810	0.039
Issue of CD	Exists	Does not exist	Does not exist	Does not exist	Does not exist	Exists

***Statistical significance at 1%

**Statistical significance at 5%

CO_2 emission growth rate in the long run, it cannot give an understanding of whether the RET-CO_2 emission growth rate nexus is influenced by other factors. Hence, in this regard, Model 1 is augmented by an interaction term concerning the variables REC and INSTQ (refer to the variable REC × INSTQ in Model 2) whereby the parameter ∂_6 shall denote whether renewable energy consumption and institutional quality improvement can combinedly influence the CO_2 emission growth rate. In this regard, if the parameter ∂_6 is found to be statistically significant, it can endorse a moderating/mediating[6] impact of institutional quality on the renewable energy consumption-CO_2 emission growth rate nexus.

Data

Considering the availability of data concerning the BRICS countries, this study considers the period of analysis from 1996 to 2021 while the data gaps are filled using the method of linear interpolation. Besides, regarding the sources, the data regarding the variables CO_2GR, REC, lnTECH, FDI, and URB are acquired from the World Development Indicators database (World Bank 2023a) while data regarding the variable INSTQ is sourced from the Worldwide Governance Indicators database (World Bank 2023b). The summary statistics related to these variables are shown in Table 1 while the pair-wise correlation matrix regarding these variables is presented in Table 2.

$$CO_2GR_{i,t} = \partial_0 + \partial_1 REC_{i,t} + \partial_2 lnTECH_{i,t} + \partial_3 FDI_{i,t} + \partial_4 URB_{i,t} + \partial_5 INSTQ_{i,t} + \partial_6 \left(REC_{i,t} \times INSTQ_{i,t}\right) + \varepsilon_{i,t} \quad (2)$$

Estimation strategy

In the first stage, the cross-sectional dependency (CD) issue is investigated using the method proposed by Pesaran (2021). It is worth noting that the presence of CD can generate biased and inconsistent outcomes; consequently, it is pertinent to check this panel data–related concern.

[6] For an in-depth understanding of the moderating/mediating impact, see Razzaq et al. (2023).

Table 4 SH test (Pesaran and Yamagata 2008) results

Model	Delta stat	Prob	Adjusted delta stat	Prob	Issue of SH
Model 1	3.515***	0.000	4.032	0.000	Exists
Model 2	3.550***	0.000	4.184***	0.000	Exists

***Statistical significance at 1%

Notably, the method recommended by Pesaran (2021) affirms the issue of CD for a particular variable if the associated test statistic is statistically significant. Hence, the null hypothesis of cross-sectional independence can be rejected. Table 3 displays the outcomes derived from the CD test of Pesaran (2021). It is evident that only for the variables CO_2GR and INSTQ the predicted CD test statistics are statistically significant. Thus, these findings confirm the issue of CD in the data set used in this study. In the second stage, the other concerning panel data–related issue of slope heterogeneity (SH) is examined using the method proposed by Pesaran and Yamagata (2008). Notably, this method calculates two test statistics for each model. In this regard, the statistical significance of either of the two test statistics shall affirm the issue of SH by rejecting the null hypothesis of slope homogeneity. Table 4 displays the outcomes derived from the SH test of Pesaran and Yamagata (2008).

Considering the CD and SH-related findings, in the third stage, the panel unit root analysis is conducted using the method proposed by Pesaran (2007). In general, unit root tests help in understanding the order of stationarity of the variables included in the models; notably, the stationarity order is important to avoid the prediction of spurious regression outcomes (Saqib 2022; Saqib and Dincă, 2023). The technique introduced by Pesaran (2007) offers two tests: (a) cross-sectionally augmented Dickey-Fuller (CADF) and (b) cross-sectionally Im-Pesaran-Shin (CIPS). Under both these tests, the predicted test statistic was found to be statistically significant. Hence, it can be concluded that the concerned series of the variable in question is stationary (i.e., statistical significance rejects the null hypothesis of non-stationarity). In the fourth stage, considering the issue of CD, the cointegration analysis is performed using the error correction model–based technique proposed by Westerlund (2007). In general, cointegration analysis helps in ascertaining long-run connectedness amidst the models' variables (Azam et al. 2023; Wang et al. 2023). The method recommended by Westerlund (2007) predicts several test statistics which, if found to be statistically significant, affirms the presence of at least one cointegrating equation in the concerned model (Destek et al. 2023; Shahzad et al. 2023); notably, the statistically significant predicted test statistics rejects the null hypothesis of no cointegration.

In the fifth stage, the long-run marginal CO_2 emission growth rate–influencing impacts of renewable energy, technological innovation, FDI inflows, urbanization, and institutional quality are ascertained by the panel regression analysis. In this regard, the augmented Dickey-Fuller (ADF) regression estimator proposed by Eberhardt and Bond (2009) and Eberhardt and Teal (2010) is employed. This method has several advantageous properties. First, this panel regression method neutralizes the issues of CD and SH within the estimation process (Ahakwa et al. 2023). Second, the problematic issue of endogeneity is also accounted for within the augmented mean group (AMG) regression analysis (Shahzad and Aruga 2023). Lastly, apart from predicting outcomes for the entire panel, the AMG estimator can also generate outcomes for each cross-sectional unit (Harb and Bassil 2023). In the sixth stage, the causal relationships among the variables are detected using the CD and SH-adjusted Granger causality estimation technique proposed by Dumitrescu and Hurlin (2012). Notably, for a pair of variables, a modified Wald test statistic is calculated which, if found to be statistically significant, affirms the unidirectional causality running from the specified independent to dependent variables (Kesar et al. 2023; Salinas et al. 2023). Notably, this statistical significance rejects the null hypothesis of the independent variable not causally influencing the dependent variable.

Results

Firstly, in this section, the findings derived from the unit root and cointegration analyses are reported and discussed accordingly. In the context of the outcomes from the analysis of unit root (see panel A in Table 5), it is evident that both the CADF and CIPS tests affirm the stationarity of all variables only at the first difference. Accordingly, the unique order of stationarity is predicted at $I(1)$. Moreover, regarding the cointegration test outcomes (see panel B in Table 5), it is apparent that there are cointegrating associations among the concerned variables. Consequently, for both models 1 and 2, in the long run, the series of the variables can be assured to make co-movements.

Next, the outcomes obtained from the AMG regression analysis are reported in Table 6. First, the regression results show that renewable energy adoption is not effective in realizing the environmental sustainability objective in the BRICS countries. To be precise, the associated coefficient estimate is seen to be statistically insignificant whereby renewable energy's impact on the annual CO_2 emission growth rate is inconclusive. Though renewable energy is a cleaner source of energy, it should have ideally assisted in reducing emissions and decreasing CO_2 emission growth rates. However, the finding in this study possibly indicates that perhaps the rise in renewable energy's share is insufficient in significantly lessening the

Table 5 Unit root (Pesaran 2007) and cointegration (Westerlund 2007) test results

Panel A: unit root analysis				
Variable	CADF test stat	Stationarity	CIPS test stat	Stationarity
CO_2GR	−2.342	Exists	−2.215	Exists
D.CO_2GR	−2.903*	Does not exist	−5.719***	Does not exist
REC	−1.783	Exists	−1.106	Exists
D.REC	−3.200***	Does not exist	−3.344***	Does not exist
lnTECH	−0.844	Exists	−1.308	Exists
D.lnTECH	−3.872***	Does not exist	−4.420***	Does not exist
FDI	−1.027	Exists	−2.498	Exists
D.FDI	−5.236***	Does not exist	−5.353***	Does not exist
URB	−2.044	Exists	−2.659	Exists
D.URB	−2.713**	Does not exist	−2.920***	Does not exist
INSTQ	−2.094	Exists	−1.793	Exists
D.INSTQ	−5.242***	Does not exist	−5.460***	Does not exist
Panel B: cointegration analysis				
Model	Gt stat	Ga stat	Pt stat	Pa stat
Model 1	−4.368***	−18.380***	−9.322***	−19.735***
Cointegration	Exists	Exists	Exists	Exists
Model 2	−4.354***	−12.800***	−9.501***	−13.646***
Cointegration	Exists	Exists	Exists	Exists

The prefix D denotes the first difference

***Statistical significance at 1%

**Statistical significance at 5%

*Statistical significance at 10%

Table 6 AMG regression results (CO_2 emission growth rate is a dependent variable)

Regressors	Model 1		Model 2	
	Coefficient	Std. error	Coefficient	Std. error
REC	−0.005	0.007	−0.004	0.005
lnTECH	0.158***	0.025	0.191***	0.028
FDI	0.569**	0.256	0.462*	0.271
URB	1.742***	0.361	2.200***	0.460
INSTQ	−1.131***	0.142	−1.497***	0.380
REC × INSTQ			−0.142**	0.071
Constant	−2.230	2.014	−3.124	2.107
Observations	130		130	

***Statistical significance at 1%

**Statistical significance at 5%

*Statistical significance at 10%

non-renewable energy dependencies of the BRICS nations. Notably, in 2020, only 22.83% of their total final energy consumption levels were accounted for by renewable energy (World Bank 2023a). Consequently, a mere 1% rise in this share would still imply that less than one-fourth of the energy demand in these countries is accounted for by clean energy resources. As a result, the impact of undergoing the RET on CO_2 emission growth rates is not likely to be prominent. This finding contradicts the CO_2 emission level–surging impacts of renewable energy recorded by Ibrahim et al. (2022), Adebayo et al. (2023), and Fu et al. (2021) for the BRICS countries and by Grodzicki and Jankiewicz (2022) for European nations. It is worth mentioning that these preceding studies have assessed how renewable energy influences the annual levels of CO_2 emissions; thus, the contrasting findings indicate that although a small rise in renewable energy's share of total final energy consumption level is effective in reducing the CO_2 emission level, which is practically not possible given the rising fossil fuel employment levels in these countries for generating respective economic outputs, it is not effective in containing the annual growth in these emissions.

Second, the regression results show that technological innovation is not likely to facilitate environmental sustainability attainment in the BRICS nations. Precisely, the regression coefficients show that as patent counts applied by residents increase by 1%, the yearly CO_2 emission growth rates go up on average by 0.16–0.19%. This is an important, albeit alarming, finding from the viewpoint of failing to green technologies for containing CO_2 discharge rates in these emerging market economies. This finding points out that the technologies that have been developed in the BRICS nations have technically promoted unclean economic activities, especially stimulating fossil fuel consumption for economic output production purposes. This scenario also explains why the BRICS nations are yet to undergo the RET in full swing; in this regard, it can be assumed that technological constraints have not let the BRICS nations replace unclean energy resources with cleaner options whereby these countries have failed over time in containing their CO_2 emission growth rates. Similar to this finding, Rahman and Alam (2022) also pointed out that technological progress hurts environmental well-being across Asia by boosting annual CO_2 emission levels. By contrast, for the BRICS case, Adebayo et al. (2023) recorded statistical evidence in favor of technological innovation leading to lower levels of CO_2 emissions.

Third, the PHH is verified which implies that as these emerging market economies become more financially globalized, their environmental qualities are likely to deteriorate in the long run. To be precise, the associated coefficient estimates show that if net FDI receipt's share of GDP goes up by 1% (indicating more financial globalization), the annual CO_2 emission growth rates of the BRICS countries can be expected to rise by 0.46–0.57%. This finding corroborates the idea that developing nations with highly fossil fuel–intensive energy structures and weak environmental protection initiatives often fall prey to incoming unclean FDI whereby the FDI-receiving nations become pollution havens. Therefore, the validation of the PHH for the BRICS can be deemed justified from the understanding that these nations have always banked on fossil fuels (World Bank 2023a) and their environmental laws have been weak, as well (Caglar et al. 2022b). Likewise, the PHH regarding the incoming FDI-CO_2 emission level nexus was also verified by Gyamfi et al. (2022) for developing (Next Eleven) nations while the PHEH was affirmed in the context of developed (G7) nations by Chien et al. (2023).

Fourth, the regression results confirm the environmental sustainability–hampering impact of urbanization. Specifically, the associated coefficient estimates reveal that if the urban population size of the BRICS countries grows by 1%, then their CO_2 emission growth rates may simultaneously go up by 1.74–2.20%. These findings are in line with the perception that since manufacturing industries are usually located in urban areas (Ahmad et al. 2021), it is expected that urbanization shall drive industrialization in the BRICS nations. Consequently, fossil fuel employment levels in these countries are likely to be driven by urbanization; thus, it may be expected to amplify the yearly CO_2 emission discharge rates in the BRICS nations. Moreover, apart from triggering greater emissions of CO_2, the implementation of non-green urbanization policies has been widely acknowledged to inflict other forms of environmental complications such as deforestation and loss of natural habitat for animals (Clement et al. 2015; Assennato et al. 2022). Likewise, in preceding studies that have improperly proxied environmental sustainability with annual CO_2 emission levels, the environmental quality–deteriorating impact of urbanization was highlighted by Grodzicki and Jankiewicz (2022) in the context of European nations.

Fifth, it is evident from the regression outcomes that institutional quality determines the scopes of establishing a sustainable environment in the BRICS countries. Notably, the associated coefficient outcomes verify that as institutions are made corruption-free, it eases the possibility of containing emission growth rates through proper implementation of environmental legislation. Precisely, the results show that if the corruption control index's value increases by 1% (indicating betterment in the quality of institutions), the annual CO_2 emission growth figures of the BRICS countries are likely to decline by 1.13–1.50%. These findings eclipse the preconceived hypothesis regarding good governance leading to better environmental outcomes (Safdar et al. 2022). This is because less corrupt officials in environmental protection–related institutions are most likely to disallow environmental misconduct in return for bribes. In the same sense, the CO_2 emission level–inhibiting effects of better corruption control were duly recorded in previous studies conducted by Rahman and Alam (2022) and Hasni et al. (2023) for Asian countries and members of the Asia–Pacific Economic Cooperation, respectively.

Lastly, especially in the context of the regression outcomes corresponding to Model 2, it is found that undergoing the RET and simultaneously improving institutional quality, especially by controlling the spread of corruption, can collectively facilitate environmental sustainability attainment by reducing the annual CO_2 emission growth rates of the BRICS nations. This statement is backed up by the negative sign and statistical significance of the predicted coefficient associated with the interaction term REC×INSTQ. Hence, it is apparent that for RET to be effective in containing emission growth rates, institutions need to be made free from corruption. Thus, these findings endorse a mediating impact exerted by institutional quality improvement on the renewable energy-CO_2 emission growth rate nexus. This mediating impact is justifiable from the viewpoint that if corrupt officials are withdrawn from environmental institutions, in particular, more compliance with environmental regulations can be ensured. Thus, the level of employment of environmental quality–degrading inputs for producing economic output in the BRICS can be reduced while encouraging more use of clean inputs in this regard. Conversely, in the presence of high corruption incidences in these institutions, producers can offer bribes to legalize the use of fossil fuels in the BRICS nations which, in turn, is likely to make the objective of controlling emission growth rates relatively more difficult. In the same sense, Li et al. (2024) highlighted the importance of

Table 7 AMG regression results (per capita CO_2 emission growth rate is a dependent variable)

Regressors	Model 1		Model 2	
	Coefficient	Std. error	Coefficient	Std. error
REC	−0.008	0.025	−0.014	0.039
lnTECH	0.140**	0.069	0.158***	0.032
FDI	0.636**	0.257	0.516*	0.272
URB	1.446***	0.362	1.944***	0.460
INSTQ	−3.189***	1.141	−3.745**	1.877
REC × INSTQ			−0.152**	0.075
Constant	−3.568*	2.014	−4.469**	2.105
Observations	130		130	

***Statistical significance at 1%

**Statistical significance at 5%

*Statistical significance at 10%

Table 8 Causality test (Dumitrescu and Hurlin 2012) results

Null hypothesis	Test statistic	Direction of causality
$REC \neq CO_2GR$	1.005	No causality
$CO_2GR \neq REC$	0.850	
$lnTECH \neq CO_2GR$	3.462**	$lnTECH \rightarrow CO_2GR$
$CO_2GR \neq lnTECH$	1.749	
$FDI \neq CO_2GR$	7.990***	$FDI \rightarrow CO_2GR$
$CO_2GR \neq FDI$	1.421	
$URB \neq CO_2GR$	2.992***	$URB \rightarrow CO_2GR$
$CO_2GR \neq URB$	0.679	
$INSTQ \neq CO_2GR$	2.929***	$INSTQ \rightarrow CO_2GR$
$CO_2GR \neq INSTQ$	1.068	

The symbol "≠" indicates being not Granger caused

***Statistical significance at 1%

**Statistical significance at 5%

reducing corruption for driving the RET process so that a sustainable environment can be established in the future.

Furthermore, to check the robustness of the outcomes displayed in Table 6, both Models 1 and 2 are re-estimated using per capita CO_2 emission growth rates as the outcome variable. The robustness test results are presented in Table 7. In this regard, based on the similarity of the predicted signs, the robustness of the results is established across alternative indicators of environmental sustainability (i.e., total CO_2 emission and per capita CO_2 emission growth rates). Next, the outcomes derived from the causality analysis are presented in Table 8 and discussed accordingly. It is apparent that there is the existence of unidirectional causalities running from technological innovation, FDI receipts, urbanization, and institutional quality improvement to CO_2 emission growth rates while no causal association between renewable energy and CO_2 emission growth rates can be identified. Hence, these causal relationships corroborate the corresponding regression outcomes to further establish the overall robustness of the findings.

Conclusions and policy recommendations

Attaining environmental sustainability in line with the objective of SDG-13 has become an utmost important issue across the globe. However, the global economies, amidst predominant fossil fuel dependence worldwide, are believed to bottleneck the prospects of achieving the targets enlisted under SDG-13. In this regard, the BRICS countries are no exception as these nations have recorded noteworthy economic performances while becoming more fossil fuel–dependent over time. Consequently, unless fossil fuel reliance is withdrawn, the possibility of the members of the BRICS bloc to attain SDG-13 appears to be slim. Accordingly, this study explored whether undergoing the RET can, directly and indirectly, contain the yearly carbon emission growth figures in the BRICS by controlling for their levels of technological innovation, FDI receipts, urbanization, and institutional quality. Based on data spanning from 1996 to 2021 and considering analytical outcomes generated using advanced panel data estimators, the results highlight that the yearly rates of CO_2 emission growth are (a) unaffected by undergoing the RET on its own; (b) positively impacted by technological innovation, FDI receipts, and urbanization; and (c) negatively impacted by improving institutional quality by controlling the spread of corruption. More importantly, the results verified the role of institutional quality improvement as a mediator between the RET and CO_2 emission growth rate nexus. Regarding this issue, the results certified that simultaneously undergoing the RET and improving institutional quality is possible for the BRICS nations to contain their annual CO_2 emission growth rates in the long run.

Based on the core findings mentioned earlier, a set of CO_2 emission growth rate–mitigating policies can be prescribed to the concerned governments of the BRICS countries. First, considering the environmental impacts exerted by renewable energy and institutional quality improvement, it is important for the BRICS nations to substantially raise the share of renewables in their respective final energy consumption profiles. This is relevant because a nominal rise in this share is not likely to be effective in containing the emission growth figures. Accordingly, identifying the factors bottlenecking the RET process in the BRICS countries is also important. Thus, it is imperative to scale investment in renewable energy development projects so that the renewable energy penetration rates in the respective energy sectors of the BRICS countries can be significantly improved. At the same time, efficient measures should be adopted to control the spread of corruption in a better manner so that good quality institutions, especially the ones related to governing energy employment and protecting the environment, can prevent fossil fuel employment and stimulate renewable energy adoption as an energy option alternative. In this regard, setting up anti-corruption bureaus is critically important while making these bureaus free from state interventions and pressures is equally relevant. Consequently, under less corrupt institutions, the BRICS countries can be expected to undergo the RET process in full swing and, in the process, effectively contain their emission growth rates in order to establish environmental sustainability.

Second, regarding the environmental quality–degrading impacts associated with technological innovation, it is now imperative for the BRICS nations to green their technological development projects because the traditional technologies developed in these countries are more likely to be pro-economic growth but detrimental to the environment. Hence, the development of green technologies, especially those associated with the RET process, is of paramount importance for the BRICS nations. These technologies would not only help these nations achieve the targets related to SDG-13 but also enable them to achieve environmental sustainability in line with the SDG-7-related targets. In this regard, though investment in research and development programs is deemed essential for innovating technologies, the BRICS nations should be careful in ensuring that such investments are made for synthesizing green technologies that can facilitate clean energy employment and boost energy efficiency rates within the economic output production processes. Third, adopting clean FDI is also needed for the BRICS nations to not turn into pollution havens. Accordingly, cleaning mechanisms for globalizing financially is important which would ensure that pollution-intensive FDI no longer flows into the BRICS economies. Rather, it is ideal for these emerging market economies to facilitate the influx of less pollution-intensive FDI so that the carbon emission growth rate–surging impact of financial globalization can be reduced over time. Lastly, the BRICS nations should also emphasize the adoption of green urbanization policies so that higher urban population growth rates do not lead to surges in their respective emission growth rates. In this context, manufacturing industries that are located in urban areas across the BRICS nations should be made less intensive in the use of energy resources so that energy consumption–based emissions are significantly contained.

Limitations and research directions

This study is focused on identifying the determinants of CO_2 emission growth rates in developing countries but does not explore the factors influencing emission growth rates in developed countries. Thus, future studies can address this limitation by conducting counterfactual analyses using data from a set of developed nations. Besides, this study considers corruption control as the only indicator of institutional quality. Thus, there is scope for future studies to incorporate data regarding other institutional quality indicators for assessing whether these factors can also contribute to the objective of reducing emission growth rates in the BRICS countries and beyond. Furthermore, evaluating the determinants of growth rates of other indicators of environmental sustainability can also be considered for assessing the robustness of this study's findings further.

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Author contribution MMA and AH conducted the econometric analysis and analyzed the findings. SP and MAD conceptualized the study, wrote the original draft, compiled the literature review, conducted the econometric analysis, analyzed the findings, provided visualization, and reviewed and edited the final draft. KK and DK compiled the literature review and generated the graphical illustrations.

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