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Effect of Renewable Energy on CO_2 Emissions in BRICS Countries

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Abstract

This paper analyzes the effect of renewable energy on carbon emissions in the BRICS countries (Brazil, Russia, India, China, and South Africa) from 1990 to 2020. Using the PMG panel ARDL approach to estimate the model. The findings indicate that renewable energy positively reduces carbon emissions in both the short and long run. However, industrialization and economic growth have a negative effect on CO2 emissions reduction in both the short and long run. These results demonstrate the positive impact of renewable energies in reducing carbon emissions in BRICS countries. The study recommends that these countries promote renewable energies to meet their energy needs and reduce carbon emissions.

Keywords: renewable energies, CO2 emissions, BRICS, and PMG Panel ARDL.

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1. Introduction

The industrial revolution has had a significant impact worldwide, especially on the environment (Bose, 2010), (Yoro & Daramola, 2020). This impact is characterized by the increase in carbon emissions due to the use of fossil fuels. Therefore, in 1997, the United Nations signed an agreement for industrialized countries called the "Kyoto Protocol" to reduce greenhouse gas emissions. In 2015, the United Nations extended this agreement by adopting the "Paris Agreement". This is an agreement for all countries, whose aim is to formulate a global warming policy and keep the average temperature increase during this period below 2 degrees Celsius (Rogelj et al., 2016). Every nation should take action to lower carbon emissions from fossil fuels to meet the target.

As a result, the world is starting a challenge against carbon emissions by using less polluting energy, called renewable energy. Using less polluting energy is a better way to ensure a greener and healthier environment as it gradually reduces global warming (Stram, 2016), (Sen & Ganguly, 2017). Therefore, many developing countries have started consuming energy from renewable sources, replacing traditional ones (Kaygusuz, 2011). Renewable energy is also an alternative solution to the rising global price of fossil fuels (Bhattarai et al., 2011). The study of the relationship between carbon emissions and renewable energy is one of the most interesting areas of research or literature today, as it allows governments to understand the interaction between carbon emissions and renewable energy. The effect of renewable energy consumption on carbon emissions is essential to achieving the Paris Agreement's goal of protecting the environment by reducing CO2 emissions.

The BRICS countries are among the highest CO2 emitters in the world (Leal-Arcas, 2013) due to their heavy reliance on energy-intensive sectors such as construction, mining, and manufacturing for economic growth and industrialization. What's more, these countries are facing rapid population growth, increasing urbanization, and changing lifestyles, all of which are driving up global energy demand and posing a real threat to the planet's environment. As a result, they rely heavily on fossil fuels to meet their energy needs, to the detriment of renewable energy sources. Most of the results of these studies have confirmed that renewable energies reduce carbon emissions (Leal-Arcas, 2013; Adebayo et al., 2023; Yuping et al., 2021). Therefore, it is important to research the relationship between renewable energy and carbon emissions by supporting previous literature by focusing on the effect of renewable energy consumption on carbon emissions in BRICS countries.

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Our research findings will be of value to policymakers, students, researchers, economists, and stakeholders to enable them to know the effect of renewable energy consumption on carbon emissions in BRICS countries and also to know how to take the right policy mix, incentives, and multi-stakeholder partnerships at national and regional levels. It will also help reduce carbon emissions globally and in the BRICS countries. However, the BRICS countries account for more than 40% of the world's greenhouse gas emissions (available online: www.rsedatanews.net, accessed on January 16, 2024) due to their dependence on fossil fuels, which poses a major threat to the environment, such as global warming and ozone depletion. The energy transition in the BRICS countries can reduce the use of fossil fuels and increase the share of energy in the mixed policies of these countries. This means an improvement in the quality of the environment in these countries. Therefore, we ask the question: Does the consumption of renewable energy impact carbon emissions?

This study aims to examine the effect of renewable energy consumption on carbon emissions in the BRICS countries (Brazil, Russia, India, China, and South Africa). To achieve the objective of this study, we used secondary data from the World Bank spanning from 1990 to 2020. We performed an ARDL panel approach to investigate the relationship between variables.

The article is structured as follows: Section 2 presents the literature review, Section 3 describes the data and empirical methodology, Section 4 presents the empirical analysis, Section 5 interprets the empirical results, and Section 6 concludes with policy recommendations and directions for future research.

2. Literature Review

Our study examines the effect of renewable energy on carbon emissions in BRICS countries, so we will focus on literature highlighting the importance of renewable energy in reducing carbon emissions. This literature review has been divided into three parts: research on energy policy regarding CO2 reduction, research on the effect of renewable energy consumption on CO2 emissions, and research on the effect of renewable energy on carbon emissions in BRICS countries.

2.1. Energy policy research on reducing CO2 emissions

Paramati et al.(2017) concerning the effects of stock market growth and renewable energy use on CO2 emissions: Evidence from G20 countries. According to them, policymakers should finance renewable energy projects using these stock markets to ensure a healthier environment. They should also reduce dependence on fossil fuels by increasing renewable energy consumption to reduce CO2 emissions. Khoshnevis Yazdi & Shakouri (2018) examined the effect of renewable energy and urbanization on CO2 emissions: A panel data for 1992-2014. They also suggest that replacing fossil fuels with renewable energy can help reduce climate change in EU member countries. According to Waheed et al. (2018) in their study concerning Forest, Agriculture, Renewable Energy, and CO2 Emission in Pakistan from 1994 to 2014. To reduce CO2 emissions, they suggest that it is preferable to increase the use of renewable energy sources (wind energy, hydropower, and solar energy) by reducing the share of fossil energy sources in the energy mix. The government should encourage investors to invest a lot in renewable energy sectors and to use renewable energy sources as energy sources. Jebli & Youssef (2017) have examined the role of renewable energy and agriculture in reducing CO2 emissions: Evidence for North African countries during 1980-2011. They also suggest that the government of North Africa should encourage the use of renewable energy (solar and wind), as this can help combat environmental deterioration by reducing carbon dioxide emissions. Cheng et al. (2019) investigated the impact of renewable energy and innovation on carbon emission: An empirical analysis for OECD countries. For them, policymakers in OECD countries should try to adapt and use renewable energy as an energy source. To do this, they should provide policy incentives to industry in the renewable energy sectors by granting subsidies and low-interest loans to electricity producers from renewable energies and facilitating the construction of renewable energy infrastructure. Aydoğan & Vardar (2020) analyzed evaluating the role of renewable energy, economic growth, and agriculture on CO2 emission in E7 countries. They recommend Governments in E7 countries should encourage and support entrepreneurs in renewable energy sectors to improve their infrastructure as these countries should continue to increase their use of renewable energy compared to fossil fuels. Aydoğan and Vardar (2020) explored the effect of the renewable energy transition on CO2 emissions of Latin American and Caribbean countries. The government should encourage investors in the renewable energy sector by encouraging private financial institutions to reduce their interest rates to combat environmental degradation. This policy aims to minimize the dependence on non-renewable energy sources damaging the environment. Saidi and Omri (2020) discuss reducing CO2 emissions in OECD countries: Do renewable and nuclear energy matter? They recommend that the best way to reduce CO2 emissions in OECD countries is to use nuclear and renewable energy, i.e., mixed energy. Namahoro et al. (2021) analyzed the impact of energy intensity, renewable energy, and economic growth on CO_2 emissions: Evidence from Africa across regions and income levels from 1980 to 2018. Governments should invest more in renewable energy projects, as they can help reduce CO_2 emissions on the African continent. Shahbaz et al. (2020) examine the effect of renewable energy consumption on economic growth: Evidence from the renewable energy country attractiveness index. They recommend that each country have a policy to encourage renewable energy investment. Using renewable energy technologies helps reduce carbon emissions and improve energy efficiency.

2.2. Research about the effect of renewable energy on CO2 emissions abroad

Nguyen and Kakinaka (2019) examined the role of renewable energy in mitigating environmental problems using panel cointegration with FMOLS and DOLS estimates for 107 countries from 1990 to 2013. They found that renewable energy consumption is positively associated with carbon emissions for poor countries, while for developed countries, renewable energy consumption is negatively associated with carbon emissions. Dogan and Ozturk (2017) used the ARDL model to analyze the influence of real income (GDP), renewable energy consumption, and non-renewable energy consumption on carbon dioxide (CO_2) emissions for the United States of America (USA) for the period 1980-2014. They found that increasing renewable energy consumption would reduce environmental degradation in the US in the long run. They suggest that the US government should increase renewable energy sources in its energy mix much more to reduce emissions. Dong et al. (2020) also examined the effect of renewable energy consumption on carbon dioxide (CO_2) emissions for a global panel of 120 countries from 1995-2015 and divided the panel into four income-based sub-panels. Applying the cross-sectional dependence and slope heterogeneity approach, they found that the influence of renewable energy consumption on CO_2 emissions was negative but not significant. The overall panel and the four sub-panels indicate the existence of mixed directionality of causality between renewable energies and CO_2 emissions, and also the significant effect of renewable energy on CO_2 emissions, and significant differences exist in the direct and indirect effects of renewable energy consumption on CO_2 emissions. Khan et al. (2019) used Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS) methods, analyzing the link between renewable energy production, CO_2 emissions, and economic growth over the period 1995 and 2016 for seven countries in the Association of Southeast Asian Nations (ASEAN). They revealed that, in the long term, renewable energy production has a significant influence on CO_2 emissions for Vietnam ($t = -2.990$), Thailand ($t = -2.505$), and Indonesia ($t = -2.515$).

According to Albulescu et al. (2020), in their study concerning the impact of the share of renewable energies in energy production and the role of EU environmental regulations on the level of CO_2 emissions from 1990 to 2017. Using fixed and random effects, the generalized method of moments (GMM) least squares models found that the share of renewable electricity contributes to reducing CO_2 emissions, i.e., it has a significant negative effect but is marginal. Busu and Nedelcu (2021) also found that renewable energies positively and circumscribe influence on reducing CO_2 emissions, using model random effects. Rahman et al. (2022) used the Nonlinear Autoregressive Distributed Lag (NARDL) (PMG) approach in analyzing the role of contributing factors in reducing CO_2 emissions in the world's 22 most developed countries from 1990-2018. As a result, they found the importance of renewable energies in reducing CO_2 emissions. And they also discovered the bidirectional causal relationship between renewable energies and CO_2 emissions.

According to Leitão and Lorente (2020), in their analysis of the link between economic growth, renewable energies, tourist arrivals, trade openness, and CO_2 emissions in the 28 member countries of the European Union during 1995-2014 using Fully Modified Least Squares (FMOLS), Dynamic Least Squares (DOLS) and Generalized Moment System (GMM-System) methods. They discovered that renewable energies contribute to the fight against climate change and environmental degradation. Ridzuan et al. (2020) used a distributed lag autoregressive test for cointegration to examine the relationships between CO_2 emissions and economic development, renewable energy, urbanization, and agricultural subsectors in Malaysia from 1978 to 2016. They found that the reduction in CO_2 emissions is due to renewable energy consumption. Vural (2020) also found that using renewable energy reduced CO_2 emissions for eight Sub-Saharan African countries from 1980 to 2014 using second-generation panel cointegration methods.

2.3. Research about the effect of renewable energy on CO2 emissions in BRICS countries

According to (Rabia Akram et al., 2020), in their study concerning the asymmetric impacts of EE, RE, and other factors on CO_2 emissions in BRICS countries from 1990 to 2014, using the new hidden panel cointegration approach and a nonlinear panel autoregressive distributional lag model. They found that renewable energy is one of the contributing factors to reducing carbon emissions. In the long term, a 1% increase in renewable energy reduces 0.733% of CO_2 emissions in the BRICS countries. Liu et al. (2017) adopted the FMOLS and DOLS method, examining the link between renewable energy per capita, agriculture, and CO2 emissions, as well as production and non-renewable energy, in a sample of BRICS countries from 1992 to 2013. They found on their three panels that renewable energy has a negative impact on long-term CO2 emissions. They also found unidirectional causality between and CO2 emissions. Mahalik et al. (2021) employed GMM system random effect techniques to examine the role of primary and secondary education levels in reducing carbon emissions while incorporating changes in energy consumption patterns for selected BRICS countries: Brazil, India, China, and South Africa from 1990 to 2015. They discovered the positive influence of renewable energy consumption on improving environmental quality and reducing carbon emissions. They proposed to the government in the BRICS countries to encourage and incentivize companies to use renewable energy sources. Haldar and Sethi (2021) analyzed the role of institutional quality in moderating the impact of energy consumption on CO2 emissions, along with other variables for 39 developing countries from 1995-2017. They found that in the long run, the use of renewable energy has a positive influence in reducing CO2 emissions by applying the following methods: mean group (MG), augmented mean group (AMG), common correlated effects mean group estimator (CCEMG), GMM dynamic system, panel pooled mean FMOLS and panel quantile regression for empirical results. Hasanov et al. (2021) also found that renewable energy consumption reduced CO2 emissions for BRICS countries during the 1990-2017 period using integration, cointegration, cross-country interdependence, and panel data heterogeneity methods.

According to Shen et al. (2021), their work examined carbon neutrality for the BRICS economies (excluding Russia) from 1980-2018. By adopting the model, he augmented the mean group (AMG), and they found that the consumption of renewable energy has a positive impact on the reduction of CO2 emissions, i.e., the reduction of 1 unit of renewable energy consumption results in a decrease of 0.0143% of CO2 emissions.

According to Leitão et al. (2021), in their study of the links between the assumptions of the Kuznets environmental curve and economic complexity in the BRICS countries from 1990 to 2015, using panel fully modified least squares (FMOLS), panel dynamic least squares (DOLS) and fixed effects (FE) methods. They found a negative association between renewable energy and CO2 emissions, i.e., renewable energy influences carbon emissions. Chishti et al. (2021) employed the panel ordinary least squares (OLS), dynamic OLS, fully-modified OLS, and pooled mean group (PMG) panel autoregressive distributed lag (ARDL) approaches in analyzing a new model that links macroeconomic policies (fiscal and monetary), aggregate domestic consumption expenditure per capita, fossil fuel consumption and renewable energy consumption to carbon dioxide emissions in the BRICS economies from 1985 to 2014. They found that renewable energies positively impact CO2 emissions reduction, i.e., they contribute to improving atmospheric quality by reducing CO2 emissions. Hu et al. (2022) investigated the effects of renewable energy consumption on CO2 emissions under the EKC hypothesis in BRICS countries from 1990 to 2019, applying the bootstrap panel integration method. They found a significant impact of renewable energy consumption on carbon dioxide, i.e., renewable energy consumption reduces CO2 emissions. This is why they suggested that BRICS governments promote renewable energies to reduce CO2 emissions.

3. Data and Methodology

3.1. Data

In the previous study by the researchers concerning the factors that impact carbon emissions, we can note that renewable energy contributes to reducing carbon emissions. Following this observation, we chose the following variables for our study: CO2 emissions, renewable energy consumption, economic growth, industrialization, and direct foreign investment. Our variables are secondary data taken from the World Bank's database, and the research concerns the BRICS countries' data panel from 1990 to 2020 due to the availability of relevant data in our study. The description of variables shown on Table 1.

3.2. Model Specification

The main objective of our study is to examine the effect of renewable energy on carbon emissions in the case of BRICS countries. Based on the contribution of Chandran and Tang (2013), we will specify our model as follows:

$$CO_2E_{it} = (RE_{it}, IND_{it}, FDI_{it}, GDP_{it}) \tag{1}$$

We transform our model into logarithmic and level to minimize the problems of heterogeneity of our variables, and we obtain:

$$lnCO_2E_{it} = \beta_0 + \beta_1 RE_{it} + \beta_2 IND_{it} + \beta_3 FDI_{it} + \beta_4 GDP_{it} + \varepsilon_{it} \tag{2}$$

In the present model, *CO_2E, RE, IND, FDI, and GDP* represent the variables CO2 emissions, renewable energy consumption, industrialization, foreign direct investment, and economic growth. The β_0, β_1, β_2, β_3, and β_4 represent, respectively, the elasticity of CO2 emission per renewable energy consumption, industrialization, foreign direct investment, and GDP per capita. And ε represents the error term.

Table 1. Description of variables

Categories de variables	Measured by	Definition
CO2 emissions (CO2E) (Dependent variable)	Metric tons per capita	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.
Renewable energy consumption (RE) (Independent variable)	% of total final energy consumption	Renewable energy consumption is the share of renewable energy in total final energy consumption.
(Controls variables) Industrialization (IND)	Industry (including construction), value added (% of GDP)	Industry (including construction) comprises mining, construction, electricity, water, and gas value added. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources.
Foreign direct investment (FDS)	foreign direct investment, net inflows (%GDP)	Foreign direct investment is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital, as shown in the balance of payments. This series shows net inflows (new investment inflows less disinvestment) in the reporting economy from foreign investors and is divided by GDP.
Economic growth	GDP per capita (constant 2015 US$)	GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products.

3.3. Methodology

In this work, we performed several tests, such as descriptive statistics and correlation tests, panel unit root tests, cointegration, human tests, and the PMG model.

– The panel unit root test

To specify an appropriate model, it is essential to analyze and examine the order of integration of each variable to exclude spurious regression in data analysis. The Augmented Dickey-Fuller (ADF) unit root test is not satisfying when the number of observations in a time series study is less than 50 (Ramirez, 2007). Applying the unit root test in panel data can remedy this problem, as it was carried out based on individual and combined effects. According to Levin et al. (2002), Breitung (2001), and Im et al. (2003), the panel unit root test gives the most reliable result compared to the time series unit root test.

– Panel Cointegration

As with the Panel ARDL approach, testing for variable cointegration is not mandatory, as the Panel ARDL approach can solve the cointegration problem between variables using the error correction term. Cointegration is defined as two or more variables having the same long-run movement (Kao et al., 1999). Many tests have been developed using panels, including the absence of cointegration test proposed by (Pedroni, 2004), which is similar to the residual test proposed by Engle Engel and Granger (1987) in the case of time series. This test takes into account the heterogeneity of the individual cross sections in the country panel. The null hypothesis of this test is the absence of cointegration, which allows for panel-specific cointegrating vectors.

3.4. Panel estimation

Before estimating the estimator in a model, it is first necessary to select the optimal lag using the Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC) to know the number of model lags considered. Among the three estimators, Pooled Mean Group (PMG), Mean Group (MG), and Dynamic Fixed Effect (DFE), the PMG estimator has a great advantage over the other estimators (Pesaran et al., 2000). It can estimate the heterogeneity of the intercept, the parameters, and the short-run error variance. The MG estimator is also superior to the others in that it allows a separate regression for each individual under consideration. It is the complete opposite of PMG, not limited to estimation procedures. It can generate different and heterogeneous coefficients for each individual in the long and short run. Finally, the DFE estimator is similar to the PMG estimator in that it has the same characteristics. The vector cointegration coefficient is the same for all long-run panels. In addition, it limits the speed of adjustment, and the short-run coefficient is the same.

The long-run equation for the PMG and DFE models is as follows:

$$lnCO_2E_{it} = u_i + \sum_{j=1}^{p} \lambda_{ij} ln\, CO_2E_{i,t-j} + \sum_{j=1}^{q} \delta_{ij} RE_{i,t-j} + \sum_{j=1}^{q} \delta_{ij}\, IND_{i,t-j} + \sum_{j=1}^{q} \delta_{ij}\, FDI_{i,t-j} + \sum\nolimits_{j=1}^{q} \delta_{ij}\, GDP_{i,t-j} + \varepsilon_{it} \quad (3)$$

Where i=1 to 5 represent countries, t is the year (1990 to 2020), j is the optimal time lag, and u is a fixed effect.

The short-run equation of the PMG and DFE models takes the following form:

$$\Delta lnCO_2E_{it} = u_i + \varphi_i(\ln CO_2E_{i,t-j} - \lambda_1 RE_{it} - \lambda_2 IND_{it} - \lambda_3 FDI_{it} - \lambda_4 GDP_{it}) + \sum\nolimits_{j=1}^{p} \lambda_{ij} ln\, CO_2E_{i,t-j} + \sum\nolimits_{j=1}^{p} \delta_{ij} RE_{i,t-j} + \sum\nolimits_{j=1}^{p} \delta_{ij}\, IND_{i,t-j} + \sum\nolimits_{j=1}^{p} \delta_{ij}\, FDI_{i,t-j} + \sum\nolimits_{j=1}^{p} \delta_{ij}\, GDP_{i,t-j} + \varepsilon_{it} \quad (4)$$

While the long-run models of MG are written as follows:

$$lnCO_2E_{it} = \theta_i + \delta_{0i} \ln CO_2E_{t-1} + \delta_{1i} RE_{it} + \delta_{2i} IND_{it} + \delta_{3i} FDI_{it} + \delta_{4i} GDP_{it} + u_{it} \quad (5)$$

– Hausman Test

The Hausman test is important in the model estimation because it helps us to select or choose one of the three estimators (PMG, MG, and DFE) most appropriate for the ARDL panel, and the p-value of the Hausman test allows us to say whether it is statistically insignificant, which allowed us to choose the PMG estimator. Specifically, we use the PMG if the probability p is greater than 5%. This hypothesis is valid for the Hausman test between PMG and MG and PMG and DFE.

4. Empirical Findings and Discussions

Table 2 presents the descriptive statistical analysis results of the variables: CO2 emissions, renewable energy consumption, industrialization, foreign direct investment, and GDP per capita. The variables were transformed into standard form, and the table displays the number of observations, mean, standard deviation, maximum, and minimum values. The table indicates that our study includes 155 observations. The mean value of carbon emissions is 1.294425, with a minimum of -0.4347117 and a maximum of 2.682492. Renewable energy consumption has a mean of 25.03819, with a minimum of 3.18 and a maximum of 52.95. Industrialization has a maximum value of 47.5574, a minimum value of 18.1885, and an average value of 31.29571. Foreign Direct Investment has an average of 1.981133, a minimum of -

0.0600742, and a maximum of 5.98719. On the other hand, the average GDP per capita is 5786.9, with a minimum of 528.898 and a maximum of 9958.47.

Table 2. Descriptive statistics

	lnCO2E	RE	IND	FDI	GDP
Obs	155	155	155	155	155
Mean	1.294425	25.03819	31.29571	1.981133	5786.9
Std. Dev.	0.9140647	17.39454	8.097226	1.451761	2761.962
Minimum	-0.4347117	3.18	18.1885	-0.0600742	528.898
Maximum	2.682492	52.95	47.5574	5.98719	9958.47

Table 3. Correlation test

Variables	lnCO2E	RE	IND	FDI	GDP
lnCO2E	1				
RE	-0.9624	1			
IND	0.2459	-0.3240	1		
FDI	-0.0260	0.0782	0.1877	1	
GDP	0.5885	-0.4134	0.1730	0.4244	1

Analyzing the correlation matrix of variables is a crucial step in our study. It helps us understand the variables' relationship and detect multicollinearity issues among independent variables. If the correlation coefficients of independent variables exceed 0.8 or 0.9, it indicates a serious collinearity problem between the variables (Midi et al., 2010). As shown in Table 3, all coefficients between the independent variables are less than 0.8. Therefore, collinearity does not affect our analysis in the present study, as confirmed by this table.

Table 4. Panel unit root test

Variables	Test	Levels	p-value	Difference	p-value	Decision
		t=--2.7203				
lnCO2E	LLC	t*= -1.6665	0.0478**			I_0
	IPS	t=- -0.9104	0.1813	-2.1105	0.0174**	I_1
		-2.9400				
RE	LLC	-1.5909	0.0558***			I_0
	IPS	-0.1989	0.4212	-1.8092	0.0352**	I_1
		-4.7966				
IND	LLC	-2.5080	0.0061*			I_0
	IPS	-1.2132	0.1125	-4.8669	0.0000*	I_1
		-5.0664				
FDI	LLC	-2.2535	0.0121**			I_0
	IPS	-2.0688	0.0193**			I_0
		-3.8135				
GDP	LLC	-2.1307	0.0166**			I_0
	IPS	-0.1575	0.4374	-2.0739	0.0190**	I_1

Note: *, ** and *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively

Table 4 presents the results of the unit root tests. The Levin, Lin, and Chu (LLC) and Im, Pesaran, and Shin (IPS) tests were used to check for simultaneity among the variables (lnC02E, RE, IND, FDI, and GDP) in our study. This test is important to determine the degree of integration of each variable considered in the study. The table indicates that the LLC test confirms the stationarity of all variables in level (CO2E, RE, IND, FDI, GDP), while the IPS test shows that four variables are stationary in the first difference (CO2E, RE, IND, GDP) and FDI is stationary. It is important to note the distinction between the two types of stationarity. In summary, the variables in the IPS test are integrated of mixed order I_0 and I_1, while in the LLC test, they are integrated of order I_0. Therefore, we applied the panel ARDL approach to our study.

Table 5 shows that the p-values associated with the coefficients of all the test statistics are significant and reject the null hypothesis (absence of cointegration) in both the Kao and Pedroni tests. The evidence of long-run cointegration is verified for all indicators and will support a long-run relationship between CO2E and the independent variables. It is important to remember that these two tests show the presence of cointegration between the variables. The estimation of our model will also be able to confirm the existence of this cointegration since the ARDL panel model has the advantage of studying the existence of cointegration between variables in the long run, using the Error Correction Time (ECT).(Dong, Kangyin, Renjin Sun, 2017).

Table 5. Panel cointegration

Pedroni test	Statistic	p-value
Modified variance ratio	-2.4075	0.0080***
Modified Phillips-Perron t	2.3065	0.0105**
Phillips-Perron t	3.0671	0.0011*
Augmented Dickey-Fuller t	3.1250	0.0009*
Kao test	Statistic	p-value
Modified Dickey-Fuller t	1.5913	0.0558***
Dickey-Fuller t	2.1962	0.0140**
Augmented Dickey-Fuller t	2.1992	0.0139**
Unadjusted modified Dickey-Fuller t	1.2939	0.0978***
Unadjusted Dickey-Fuller t	1.7076	0.0439**

Note: *, ** and *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively

Table 6. Hausman test

	(b) pmg	**(B) DFE**	**(b-B) Difference**	**sqrt(diag(V_b-V_B)) S.E**
RE L1.	-0.033445	-0.04924	0.015799	0.23748
IND	0.020933	0.017631	0.003312	0.313928
FDI	0.0179096	-0.14838	0.166294	0.81769
GDP	0.0000353	0.000186	-0.00015	0.000799
b=	consistent under Ho and Ha; obtained from xtpmg			
B=	inconsistent under Ha, efficient under Ho; obtained from xtpmg			
Test:	Ho: Difference in coefficients not systematic chi2(4)=(b-B)'[(V_b-V_B)^(-1)](b-B)=0.11			
	Prob>chi2=0.9986			
	(b) mg	**(B) pmg**	**(b-B) Difference**	**Sqrt(diag(V_b-V_B)) S.E**
RE L1.	-0.1656578	-0.0334451	0.1322127	-0.1445068
IND	-0.0384727	0.0209433	0.0594161	0.068117
FDI	0.0540257	0.0179096	0.0361161	0.0686385
GDP	0.0000824	0.0000353	0.0000472	0.0000543
b=	consistent under Ho and Ha; obtained from xtpmg			
B	inconsistent under Ha, efficient under Ho; obtained from xtpmg			
Test:	Ho: Difference in coefficients not systematic chi2(4)=(b-B)'[(V_b-V_B)^(-1)](b-B)=5.64			
	Prob>chi2 =0.2280			

Before estimating our model, we must determine the optimal lag using the Bayesian Information Criterion (BIC) method. We need to identify the most common lag among the countries to choose the optimal lag. The test results indicate that (1 0 1 0 0) is the optimal lag for our ARDL model. After estimating the three estimators of our model (PMG, MG, and DFE), we performed a Hausman test to determine the best estimator. The results of this test showed that the p-values were greater than 5% (refer to Table 6). Therefore, we retained the PMG estimator to discuss and interpret our results.

Following the pre-testing stages, we concluded that the Panel ARDL (PMG) approach suits our study. Thus, we solely concentrate on the outcome produced by this model, specifically the dependent variable of CO2 emissions. Table 7 shows the long-run result, while Table 8 shows the short-run result of our estimation. Therefore, it is imperative to discuss our findings to previous studies relevant to our research.

Table 7. Results for the Long-Run

The dependent variable is lnCO2E; No of observation=150; Average=29; log Likelihood=340.9014; Cross Section Included=5				
Variables	Coefficients	Standard error	t-Statistics	p-Value
RE	-0.0334451	0.0031579	-10.59	0.000*
IND				
L1.	0.0209433	0.0041889	5.00	0.000*
FDI	0.0179096	0.011163	1.60	0.109
GDP	0.0000353	0.000011	3.22	0.001 *

Note: *, ** and *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively

The results indicate that RE, IND, and GDP variables are significant at a 1% level, and FDI is not significant.

Table 7 displays that the coefficient of RE is -0.033, indicating that a 1 unit increase in RE in BRICS countries reduces CO2E by almost 0.033%, holding all other variables constant. The impact of RE on CO2E in BRICS countries is significant. These findings demonstrate that RE has a significant impact on the environment. The results indicate that due to strong economic growth and increasing energy demand, BRICS countries consume a large portion of their energy from non-renewable sources, increasing CO2 emissions. While they aim to limit carbon emissions using renewable energy, their resources are insufficient to meet all energy demands. As shown in the table, an increase in RE leads to a decrease in CO2E. Utilizing this resource can help limit or reduce CO2 emissions, thereby aiding BRICS countries in protecting the environment and reducing emissions. This conclusion is supported by previous studies (Dong et al., 2017), (Khattak & Ahmad, 2021) (Haldar & Sethi, 2021), and (Bhat, 2018). The data indicates that renewable energy consumption effectively limits carbon emissions in BRICS countries.

On the other hand, IND has a positive impact on CO2E with a coefficient of 0.02. A 1 unit increase in IND causes a 0.02% increase in CO2E in the BRICS country, holding all other variables constant. IND is a driving sector that favors the emission of CO2E, degrading the environment in the BRICS countries. As previously stated, the BRICS countries are industrialized and heavily reliant on fossil fuels to power their industries, resulting in significant environmental damage. Our findings indicate that as industrialization increases, so do carbon dioxide emissions, making industry a major contributor to environmental degradation in these countries. The positive contribution of IND to CO2E is also confirmed by (Ghazouani, 2022), (Akinsola et al., 2022), and (Sikder et al., 2022).

In the BRICS countries, it was found that GDP positively affects CO2 emissions. Specifically, 1 unit of GDP would increase by about 0.000035% of CO2E, holding all other variables constant. Although the impact of GDP on CO2E is small, its presence is still detrimental to the environment. Improving the performance of BRICS countries to achieve a better standard of living may lead to a deterioration of the environment. Economic growth requires sustained increases in production over time, which in turn requires high energy consumption. This increased production or improved GDP, coupled with the fact that BRICS countries still rely on fossil fuels, leads to environmental pollution and increased carbon emissions. These findings are supported by previous studies (Zakarya et al., 2015), (Zhao et al., 2021), (Begum et al., 2015) and (Mitić et al., 2017).

Table 8 shows that RE, IND, and GDP are significant in the short run.

The RE significantly cntributes to reducing carbon emissions in the BRICS countries with a coefficient of -0.021. This means that an increase of 1 unit of RE reduces 0.020% of CO2E. Therefore, RE can limit carbon emissions and contribute to environmental protection. These results are confirmed by previous studies by (Attiaoui et al., 2017) (Sinha & Shahbaz, 2018). On the other hand, the IND significantly impacts carbon emissions in the BRICS countries. Specifically, when the IND increases by one unit, CO2 emissions rise by 0.005%, with other variables remaining constant. This relationship highlights the dependence of industries on fossil fuels. Based on these results, the BRICS countries have not taken adequate measures to protect the environment. The positive impact of the IND on CO2 emissions is also supported by research from (Ahmed et al., 2022) and (Rahman & Kashem, 2017).

On the other hand, GDP increases CO2E emissions with a coefficient of 0.00013, i.e., a 1% increase in GDP accounts for 0.00013% of the increase in CO2E in the BRICS countries. Thus, our result shows that GDP is environmentally destructive and contributes significantly to the increase in C02E in the BRICS countries. The BRICS countries are developing countries experiencing rapid economic growth, all of which require energy from non-renewable sources. The study also confirms the positive effect of GDP on CO2E in the short run (Hakimi & Hamdi, 2016; Zubair et al., 2020).

Table 8. Results for the short-run

The dependent variable is lnCO2E; No of observation=150; Average=29; log Likelihood=340.9014; Cross Section Included=5				
Variables	Coefficients	Standard error	t-Statistics	p-Value
ECT	-0.1675058	0.101307	-1.65	0.098***
RE				
D1	-0.0201501	0.005086	-3.24	0.001*
IND				
D1.	0.0055638	0.0028565	1.95	0.051***
FDI				
D1	0.0012827	0.0019342	-0.66	0.507
GDP				
D1	0.0001313	0.0000487	2.70	0.007*
_cons	0.2585822	0.1562266	1.66	0.098***

Note:*, ** and *** indicate statistical significance at the1%, 5%, and 10% levels, respectively

The error correction term (ECT) confirms the model's stability and dynamic nature, indicating cointegration among the variables under study. It is important that the ECT is negative, significant, and falls within the range of 0 to 1 (A. Asongu, 2014). The negative sign of the ECT confirms the existence of cointegration among the variables. Table 8 shows that the error correction term (ECT) coefficient is -0.1675 and significant at 10%, indicating the speed at which short-run deviations return to their long-run equilibrium following an exogenous shock. The estimated model indicates an annual adjustment effect of 16.75%, meaning that any short-term mismatch is gradually corrected over 5.97 years.

5. Conclusions, policy implications and limitations

Renewable energy is seen as the most effective solution to the problem of rising carbon emissions worldwide. However, it is important to consider the factors contributing to carbon emissions. This study analyzes the correlation between carbon emissions, renewable energy consumption, industrialization, foreign direct investment, and economic growth in the five BRICS countries (Brazil, Russia, India, China, and South Africa) from 1991 to 2020 using the panel ARDL model. The data analysis began with descriptive and correlation statistics, the panel unit root test, the Pedroni and Kao cointegration test, and the Hausman test. Based on the previous test steps, the document selects the PMG approach.

The results indicate that increasing renewable energy consumption positively impacts reducing carbon emissions in both the short and long term. Therefore, to reduce carbon emissions, increasing renewable energy consumption and vice versa is necessary. The negative impact of fossil fuels can drive renewable energy consumption in this region. Increased use of renewable energy reduces the carbon emissions associated with fossil fuels. It is important to reduce the use of fossil fuels because of their significant contribution to carbon emissions. In addition, the study revealed that industrialization has a significant and positive impact on carbon emissions in the long term, as it leads to increased emissions. BRICS countries, whether emerging or industrialized, have an industrial surplus. As renewable energy sources are scarce in this region, industry must consume significant energy from fossil fuels.

Additionally, the study found that industrialization significantly and positively impacts carbon emissions in the long run, leading to increased emissions. The BRICS countries, being both emerging and industrialized, have a surplus of industry. As renewable energy sources are scarce in this region, industry needs to consume a significant amount of energy from fossil fuels. Higher GDP means higher CO2 emissions in both the long and short term. The BRICS are much more dependent on non-renewable energy sources than on renewable ones, which require a lot of energy to increase production. Our study confirms that renewable energies can effectively reduce carbon emissions in the BRICS. Our model shows that of the four explanatory variables, only renewable energy consumption can reduce carbon emissions.

The policy implications of our research are based on these results and should prioritize renewable energy. BRICS governments should promote renewable energy by increasing the share of renewable energy sources in their countries' energy policies. This can be achieved by reducing dependence on fossil fuels through increased taxes. Additionally, industrialization significantly contributes to these countries' environmental damage, specifically carbon emissions. In light of this, policymakers should promote renewable energy sources by implementing environmental regulations, promoting industrial structural reform, and encouraging technological innovation.

Additionally, BRICS governments should facilitate setting up companies to encourage foreign entrepreneurs to invest in the renewable energy sector within their territories. Fourth, as economic growth contributes to rising carbon emissions, BRICS governments should invest in renewable energy sources to meet industry's energy needs. Governments should also encourage domestic investors to invest in the renewable energy sector by providing subsidies to renewable energy companies to support economic growth in their countries. These subsidies can be low-interest loans and tax reductions or exemptions.

Our study has some limitations. Firstly, our model does not include the variable of environmental regulation, which has been confirmed by many previous studies as important in reducing carbon emissions (Wang & Zhang, 2022),(Neves et al., 2020). Secondly, our research does not consider the data from the last three (3) years, as the available data on carbon emissions and renewable energy consumption only goes up to 2020. Finally, regarding our results, we used the PMG ARDL to make our model more robust; one or more methods should verify it.

Due to the limitations of our study, we suggest future research consider the impact of environmental regulations on carbon emissions. Additionally, future research could investigate any significant changes in our findings over the past three (3) years. Finally, future research could verify our results by applying other models to our model.

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