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Research Article

The Environmental Impact of Electricity Generation: New Evidence from BRICS Countries

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Abstract
Energy and its related services are crucial to the well-being of society. Access to clean water and sanitation is dependent on energy supply, and so is the provision of quality education and healthcare services. Of equal importance is the manner in which energy is produced and consumed, as the livelihood of future generations depends largely on this. Recently, policymakers have found themselves in a pickle, having to strike a balance between meeting the energy demands of the current generation without compromising the environmental needs of future generations. Given this context, the crux of this study was to examine the impact of renewable and non-renewable energy sources on environmental sustainability in the BRICS region. The findings revealed that non-renewable energy sources, particularly coal and natural gas, augment higher levels of carbon dioxide emissions both in the short run and long run. In contrast, renewable energy sources such as hydro, wind and solar energy were found to lessen the burden of carbon dioxide emissions on the environment. As such, this study cautions against the heavy reliance on non-renewable energy sources, as they threaten livelihoods and biodiversity.

Keywords CO_2 emissions . Environmental degradation . Renewable energy . BRICS

Introduction

The fourth industrial revolution has made it possible to harness and utilise various sources of energy which are key to economic prosperity. This has not only eased the transition to industrial and service-oriented societies but has also transformed the living conditions of citizens globally, allowing them to enjoy an unprecedented level of comfort and mobility in human history (Bildirici and Ersin, 2015). Energy and its related services are crucial to the well-being of society and economy at large. Access to clean water and sanitation is dependent on energy supply, and so is the provision of quality education and healthcare services. Without adequate energy supply, both pumping capacity and food security are adversely affected. Cheng et al., (2019) argue that, without access to clean and affordable energy, poor citizens have to resort to the inefficient combustion of solid fuels in inadequately ventilated areas which exposes them to various health illnesses. Of equal importance is the manner in which energy is produced, as

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the livelihood of future generations depends largely on this. Samour et al. (2023) noted that the heavy reliance on fossil fuels possess a global environmental threat that can potentially alter the Earth's atmosphere. Achuo et al. (2022) cautioned that current patterns in the production and use of energy are not environmentally friendly. Recently, policy makers have found themselves in a pickle, having to strike a balance between meeting the energy demands of the current generation without compromising the environmental needs of future generations.

Background

This section provides a detailed background on the composition of energy sources in BRICS countries as well as the resulting contamination of greenhouse emissions. Energy sources are measured in Terajoules (TJ) while CO2 emissions are measured as a percentage of total consumption. The information was sourced from the International Energy Agency and World Development Indicators (2023). Observations from Figure 1 indicate that the bulk of electricity consumed in Brazil is produced from a combination of renewable (i.e., biofuels) and non-renewable (i.e., oil) energy sources. The share of natural gas in the energy mix has likewise increased in the past few decades to match that of hydroelectric energy sources. Similarly, greenhouse gas emissions in Brazil are largely a result of liquid fuels and to a small degree, solid fuel and gaseous fuel. Figure 2 illustrates the composition of energy sources in Russia. Interestingly, Russia has by far the largest natural gas reserves, and this is evidenced by the share of natural gas in the energy mix, implying that the bulk of electricity consumed is produced from natural gas.

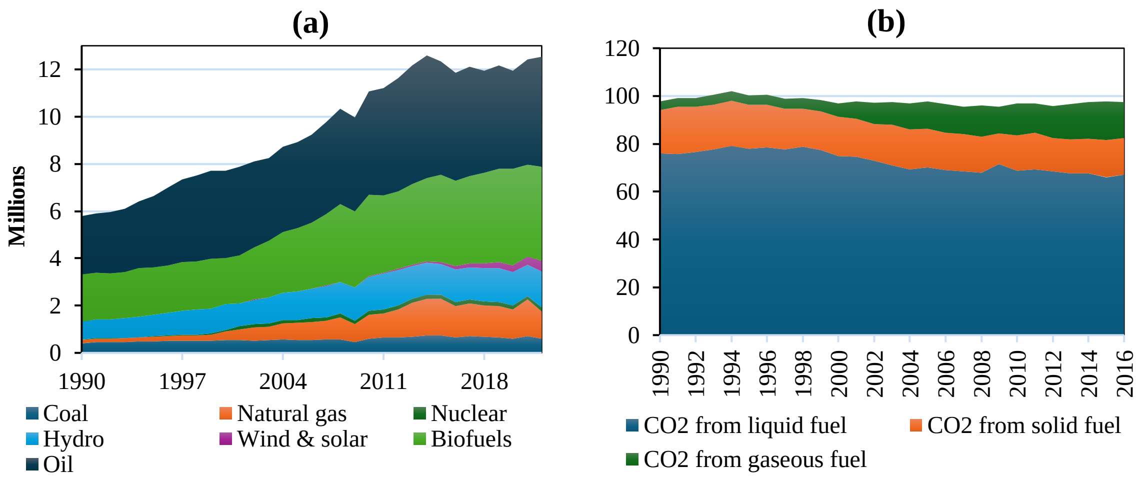

Figure 1. Composition of (a) energy sources (TJ) (b) and CO_2 emissions (% of total consumption) in Brazil

The share of oil and coal in the energy mix is likewise significant relative to biofuels, wind and solar energy sources. This implies that Russia's energy composition is largely made up of non-renewable energy sources. Nonetheless, Figure 3 below indicates that India's production of energy increased substantially over the last three decades in line with its population growth and subsequent demand for basic government services. Non-renewable energy sources such as coal and oil make up the bulk of India's energy sources while renewable energy sources such as biofuels, hydroelectric, wind and solar make up a smaller proportion of India's energy mix. As a result of this, the bulk of emissions in India (see figure 3) emanate from solid and liquid fuels. Figure 4 shows China's energy composition as well as the resulting greenhouse gas emissions. Similar to India, China's consumption of electricity increased substantially in the last three decades in line with its population growth and subsequent demand for basic government services such as the provision of clean water and energy.

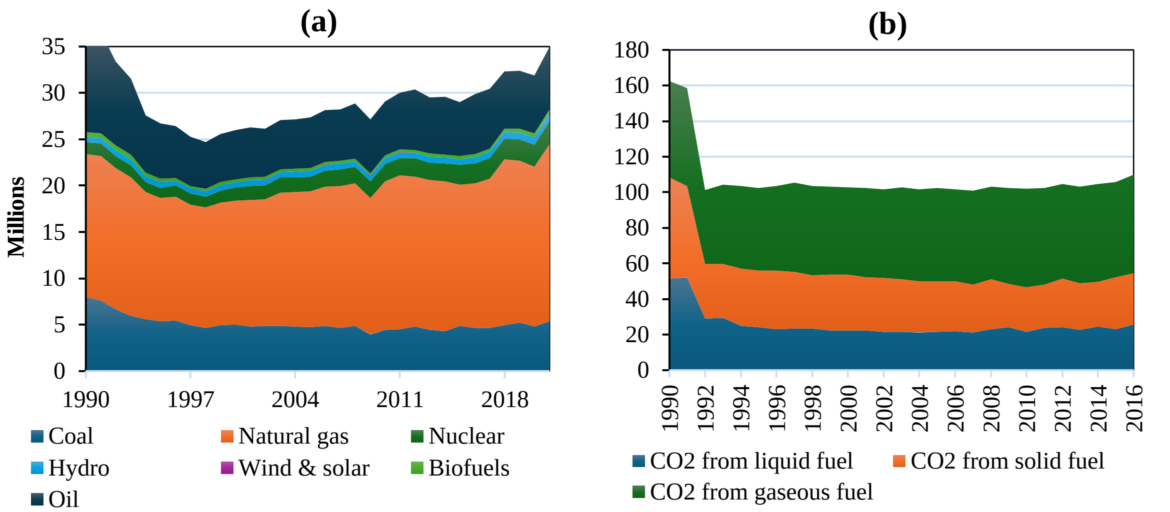

Figure 2. Composition of (a) energy sources (TJ) (b) and CO_2 emissions (% of total consumption) in Russia

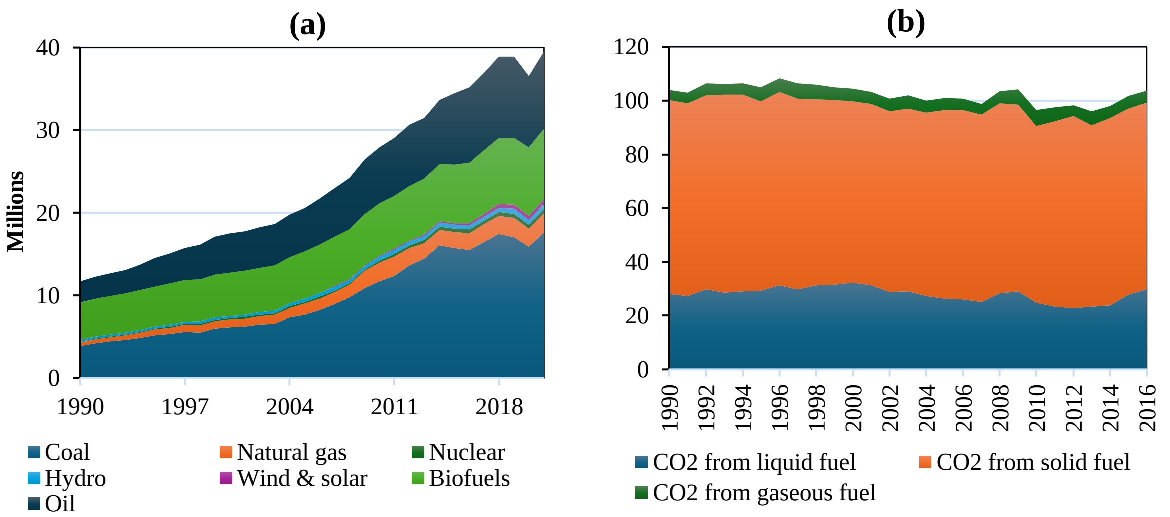

Figure 3. Composition of (a) energy sources (TJ) (b) and CO_2 emissions in (% of total consumption) India

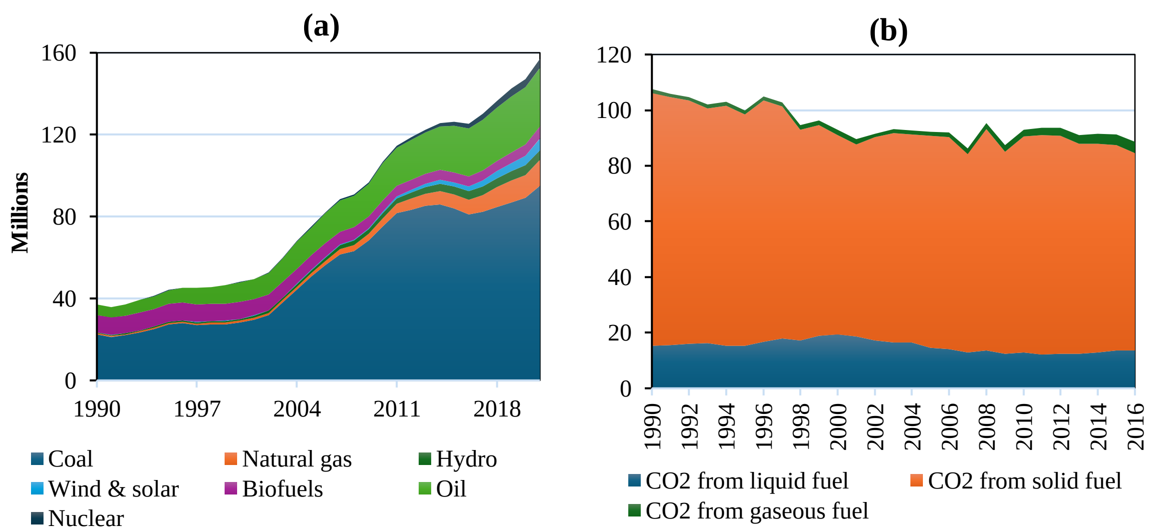

Figure 4. composition of (a) energy sources (TJ) and (b) CO_2 emissions in (% of total consumption) China

The bulk of electricity consumed in China is produced from coal followed by oil. Renewable energy sources such as hydroelectric, biofuels, wind and solar energy only make a small proportion of China's energy production. Greenhouse gas emissions largely emanate from solid fuels and to a small degree, liquid fuels and gaseous fuels. Nevertheless, observations from Figure 5 indicate that South Africa continues to produce a substantial share of electricity from non-renewable energy sources. Nearly 70% of electricity in South Africa is produced from coal. The share of oil in the energy mix is likewise relatively significant compared to biofuels, hydroelectric, wind and solar energy. Various policies such as the new Integrated Resource Plan 2023 have been put in place to foster a clean energy transition. The bulk of greenhouse gas emissions in South Africa emanate from solid fuels and to a small degree, liquid fuels.

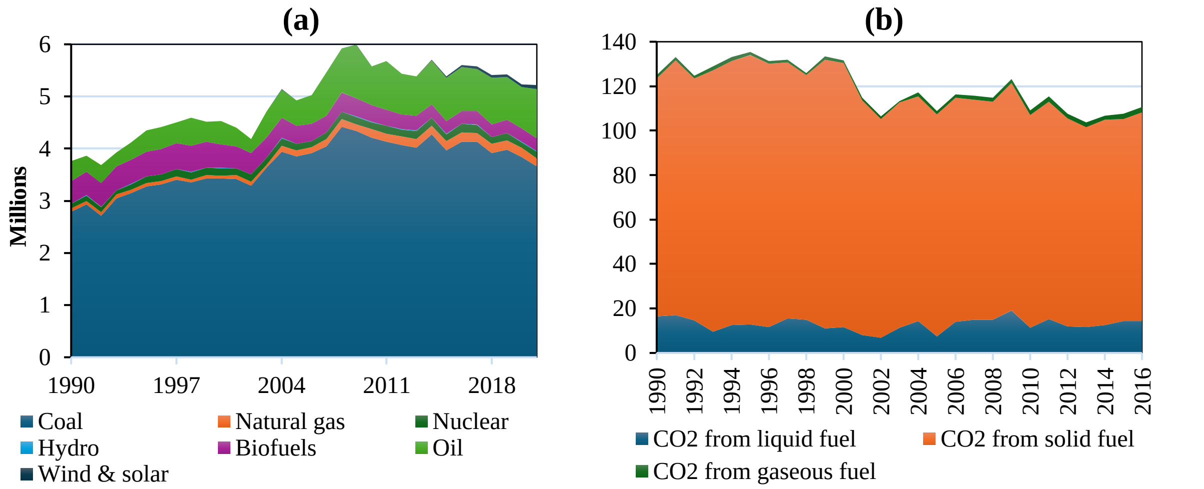

Figure 5. composition of (a) energy sources (TJ) and (b) CO_2 emissions (% of total consumption) in South Africa

It is evident from the above analysis that the composition of energy sources differs significantly across BRICS countries although non-renewable energy sources remain dominant. The crux of this study is to examine the impact of renewable and non-renewable energy sources on environmental sustainability measured by carbon dioxide emissions. Unlike earlier studies, this study makes use of robust estimators such as the panel Autoregressive Distributed Lag technique to account for the slope heterogeneity between groups. The rest of the study is organised as follows: the first section introduces the research topic and contribution of the study. Section 2 provides a detailed background on the composition of energy sources and emissions in BRICS countries. The third section tackles the literature review while the fourth section describes the methods employed to estimate the impact of energy sources on environmental degradation. The fifth section provides a summary of findings while the last section concludes the study in short.

Literature review

The year 2015 marked a significant shift in global public policy as numerous countries adopted the global treaty on climate change (United Nations, 2015). Through the "Paris Agreement", countries made several commitments to reduce greenhouse gas emissions and mitigate climate change and its impact on the environment. Following this, countries have been in pursuit for an optimal energy mix. An optimal energy mix is one that encompasses elements of energy efficiency, security, cleanliness and cost-effectiveness (Ahmed & Shimada, 2019). Although 91.4% of the world's population have access to basic electricity services, access to clean and affordable electricity remains a major global crisis. For instance, during the covid19 pandemic, global electricity prices reached an all-time record high as the demand for electricity skyrocketed. In South Africa, electricity prices increased by 25% on average in the last three years alone (Labuschagne, 2020). In order to realize net zero emissions as per the Paris Agreement, there is a strong need for nations to transition from fossil-based systems of energy production and consumption to modern renewable-energy based systems. Non-renewable energy sources comprise of nuclear, coal, oil and natural gas while renewable energy sources include hydroelectric, bioenergy, wind and solar energy. A key distinction between renewable and non-renewable energy sources lies in the manner in which they are processed and the resulting impact on the environment (Dong et al., 2018).

Renewable energy, often referred to as clean energy, comes from natural sources or processes that are constantly replenished. Magazzino et al. (2022) argue that the use of renewable energy sources has resulted in a sharp decline in greenhouse gas emissions. Their study examined the nexus between GDP, greenhouse gas emissions and renewable energy consumption in a panel of five Scandinavian countries. The study found that the adoption of renewable energy sources has significantly reduced CO_2 emissions in Scandinavian countries without adversely affecting economic growth. The study concluded that the deployment of renewable energy sources augments higher levels of energy efficiency and economic growth. Khan et al. (2021) investigated whether technological advancement and institutional quality mediate the association between energy usage and environmental degradation in a panel of 188 countries. The study employed several econometric techniques including system Generalised Methods of Moments, Panel Ordinary Least Squares and fixed effects technique. The study established that renewable energy consumption contributes positively to environmental sustainability. Further, several control variables such as institutional quality and technological advancements were found to mediate the association between renewable energy use and environmental sustainability.

A similar study by Achuo et al. (2022) analysed the impact of both renewable and non-renewable energy consumption on environmental degradation in a panel of 173 countries over the period 1996 – 2020. The fixed effects technique was employed, and the findings were two-fold. The findings indicated that renewable energy consumption has a positive impact on environmental quality while non-renewable energy consumption adversely impacts environmental sustainability. The findings further revealed that the environmentally friendly-ness of renewable energy consumption is higher in developed countries while the environmental degradation of non-renewable energy consumption is higher in developing countries. Alola et al. (2024) determined whether the combination of several sources of energy improves environmental sustainability. The study found that several energy sources such as coal, oil and natural gas contribute positively to environmental degradation. The study however argued that innovations in environmental patents help reduce the adverse effects of non-renewable energy sources such as coal, oil and natural gas. Tariq & Tania (2019) explored the nexus between environmental degradation, water withdrawal and renewable energy in a panel of 166 countries using dynamic panel data spanning from 1990 to 2017. The study employed several dynamic panel data estimators such as the Panel OLS, fixed effects, random effects and 2 Stage Least Squares in order to account for the heterogeneity among countries. The study finds that renewable energy consumption contributes positively to environmental mitigation while water withdrawal has an adverse effect on environmental sustainability through emissions. Owusu et al. (2016) investigated some of the factors that hinder the adoption of renewable energy sources. The study finds that several factors including access to raw materials, carbon footprint, market failures and inadequate information are among the factors that hinder the sustainability of renewable energy sources. Panwar et al. (2011) reviewed the role of renewable energy sources in mitigating environmental degradation. The authors concluded that the use of clean energy sources such as solar and hydro power can help mitigate climate change through reductions in greenhouse gas emissions. Balat (2005) assessed the environmental impact of global energy sources. The study argued that the production of electricity through various energy sources has two major implications, that is, the extensive use of limited natural resources and the stressed caused by environmental pollution.

A study by Bongers (2021) considered the environmental impact of both renewable and non-renewable energy sources. The study found evidence of a positive aggregate productivity shock that increases energy consumption and emissions but reduces energy intensity and emissions per unit of output as renewable energy consumption increases. Safdar (2020) explored the long-run relationship between environmental degradation, macroeconomic performance and energy consumption in a panel of 50 developing countries between 1990 and 2016. The Pedroni panel cointegration test was employed in order to establish the long run relationship among the variables while the Homogenous panel causality test was employed to estimate the causal relationship among the variables. The findings revealed the presence of a long run relationship amongst the variables as well as the presence of cross-sectional dependency, implying that the instability in one country would presumably spillover to other countries.

Rafindadi & Ozturk (2017) investigated the impact of renewable energy sources on economic growth in Germany using quarterly time series data spanning from 1971 Quarter1 to 2013 Quarter4. The study made use of the ARDL bounds test and Vector Error Correction Model (VECM) in order to observe the long run relationship among renewable energy sources and economic growth. The findings revealed the presence of a long run relationship among renewable energy sources and economic growth. The study finds that an investment in renewable energy boosts economic growth by as much as 1%. However, this is conditional on other macroeconomic variables such as fixed investment and labour productivity. A similar study by Salari et al. (2021) observed the relationship between economic growth, energy consumption and greenhouse gas emissions in the United States using annual macroeconomic data ranging from 1997–2016. The study found that energy consumption and greenhouse gas emissions are cointegrated. Further. The study revealed that non-renewable energy sources used for industrial and residential activities contributes positively to greenhouse gas emissions while renewable energy sources have a negative impact on greenhouse gas emissions.

Methods

The study employed annual panel data spanning from 1990 to 2020. The choice of period was largely based on the availability of reliable data. The data was sourced from several reliable sources such as the International Energy Agency (IEA) and World Development Indicators (WDI) published by the World Bank. Our model specification was guided by earlier studies including Irandoust (2018), Nosheen et al. (2021), and Sheng et al. (2023). The model can be expressed mathematically as follows:

$$CO_2 = f(coal, oil, natural\ gas, nuclear, biofuel, hydro, wind, solar) \quad (1)$$

CO_2 is the dependent variable represented by carbon dioxide emissions. In this regard, CO_2 is a function of energy sources which include coal, oil, natural gas, nuclear, biofuel, hydro, wind and solar energy. All variables were considered in log form. Descriptive analysis was conducted to show and explain the characteristics of each variable in the model. Following this, the panel unit root analysis was executed in order to assess the order of integration of the variables as well as to ascertain that no variable is integrated of order 2. The Phillips-Perron Fisher unit root test was employed in this regard. Given the order of integration, the panel Autoregressive Distributed Lag (ARDL) technique was found to be the most suitable estimator. Noteworthy to mention that earlier studies (i.e., Zhang, 2021) made use of the ARDL technique. Naape & Matlasedi (2020) assert that the ARDL technique is more efficient when one has a combination of variables that are stationary at level I(0) and at first difference I(1). The re-parameterized form of equation (1) can be formulated as follows:

$$\Delta CO2_{it} = \theta_i\left(CO2_{i,t-1} - \beta_i X_{i,t-j}\right) + \sum_{j=1}^{p-1} \gamma_j^i \Delta\, CO2_{i,t-j} + \sum_{j=0}^{q-1} \delta\, \Delta(X_i)_{t-j} + \mu_i + \varepsilon_{it} \quad (2)$$

Where CO_2 is carbon dioxide emissions, X is a set of regressors comprising of sources of energy production and consumption, δ and γ represent the short-run coefficients of dependent and independent variables, respectively. The symbol i represents the individual countries, t refers to the periods of the respective countries and θ is the coefficient of speed of adjustment to the long run status. βi refers to the projected long run residuals, u incorporates the country-specific fixed effects and ε_{it} is the error correction term. Equation (2) can be estimated using either the Mean Group (MG), Dynamic Fixed Effects (DFE) or Pooled Mean Group (PMG) estimator by Pesaran et al. (1999).

The PMG is an intermediator between the MG and DFE estimators. The PMG estimator involves both pooling and averaging and allows both the intercepts, short run coefficients and error variances to differ freely across groups while constraining the long run coefficients to be the same (Eberhardt & Teal, 2011). Its advantage lies in its ability to generate consistent estimates of the mean of short run coefficients by taking the simple averaging of individual units coefficients. In contrast, the MG estimator assumes that the error variances, short run and long coefficients vary across groups while the DFE estimator assumes that the error variances, short run and long run coefficients are homogenous across groups. As such, the PMG estimator is based on a lower degree of heterogeneity. A major requirement of the PMG estimator is the assumption of long-run slope homogeneity (Garidzirai & Muzindutsi, 2020). Noteworthy to mention that BRICS countries comprise of emerging market economies that share similar economic and environmental characteristics. A complete description of variables is provided in Table 1.

Table 1. Description of variable

Variables	**Description**	**Unit**	**Symbols**	**Sources**
CO_2 Emissions	Carbon dioxide emission	Kt	CO_2	WDI
Electricity produced from Oil	Total production	TJ	EPOil	IEA
Electricity produced from Natural Gas	Total production	TJ	EPGas	IEA
Electricity produced from Coal	Total production	TJ	EPCoal	IEA
Electricity produced from biofuels	Total production	TJ	EPBio	IEA
Electricity produced from hydro	Total production	TJ	EPHydro	IEA
Electricity produced from nuclear	Total production	TJ	EPNuc	IEA
Electricity produced from wind and solar	Total production	TJ	EPWS	IEA

Findings and discussions

This section provides a summary of findings and discussions. The first step of analysis involved conducting the descriptive analysis. The purpose of descriptive analysis is to demonstrate and explain the characteristics of the variables (Naape & Qeqe, 2022). The results are provided in Table 2 below. Carbon dioxide emissions averaged 1.9 million kilotons (kt) between 1990 and 2020 while electricity produced from biofuels and natural gas averaged 4.8 million Terajoule (TJ) and 4.1 million TJ, respectively. On average, the bulk of electricity produced in the BRICS region was sourced from coal between 1990 and 2020. In contrast, nuclear and hydro energy are among the least contributors to electricity consumption and production in the BRICS region. Nevertheless, the total number of observations amounts to 155 across all variables.

The second step of analysis involved examining the order of integration of the variables. As previously mentioned, the panel ARDL technique is more efficient when one has a combination of variables that are stationary at level I(0) and at first difference I(1). However, this does not include variables that are integrated of order 2. Therefore, it became imperative to conduct the panel unit root test in order to ascertain that no variable is integrated of order 2. The ADF panel unit root test was employed in this regard and the results are illustrated in Table 3 below.

Table 2. Descriptive statistics

	CO_2	EPBio	EPCoal	EPHydro	EPGas	EPNuc	EPOil	EPWS
Mean	1981573	4813239	14362443	622635.3	4133489	826228.5	3374687	1475609
Median	1136466	2664627	4787566	533990	1081466	193963	3649122	103169
Maximum	10944686	27833352	89100774	4553712.	17922712	4758343.	11043845	8585232.
Minimum	197897.4	243112.0	404905.0	525.00	45196.00	600.00	0.10	436.00
Std. Dev.	2607265	6136336	22830431	721932.9	5807305	1068083	2863003.	2783846
Skewness	2.21	2.00	2.23	2.60	1.27	1.78	0.39	1.69
Kurtosis	7.03	6.69	6.80	12.46	2.87	5.85	2.35	4.17
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Sum	3.07E+08	7.46E+08	2.23E+09	96508477	6.41E+08	1.28E+08	5.23E+08	2.29E+08
Observations	155	155	155	155	155	155	155	155

Table 3. Unit root test

Variable	Level		First difference		Outcome
	Intercept	Trend	Intercept	Trend	
EPBio	6.71	1.74	-7.49*	-13.78*	I(1)
CO_2	0.52	1.43	-3.99*	-2.39*	I(1)
EPCoal	-1.62*	-1.40*	-6.39*	-5.54*	I(0)
EPHydro	3.56	2.11	-7.12*	-8.95*	I(1)
EPGas	4.89	2.51	-6.28*	-6.65*	I(1)
EPNuc	3.09	-0.29	-8.21*	-8.12*	I(1)
EPOil	3.56	1.54	-2.49*	-1.73*	I(1)
EPWS	6.77	4.70	-2.14*	-1.47*	I(1)

* Statistical significance at 1%

The majority of variables including biofuel, carbon dioxide emissions, hydro energy, natural gas, nuclear power, oil, solar and wind energy were found to be stationary after first differencing I(1). In contrast, coal was found to be stationary at level I(0). Notably, none of the variables were found to be integrated of order 2. The combination of I(0) and I(1) variables implies that the panel ARDL technique is the most appropriate procedure. A crucial step in utilizing the panel ARDL technique is the determination of an optimal lag length. For this purpose, the unrestricted vector autoregressive technique was employed, and the results are summarized in Table 4. To avoid the loss in degrees of freedom, the information criterion with a relatively lower lag length was chosen. The Schwarz Information criterion revealed an optimal lag length of 1, being the lowest compared to Hannan–Quinn (3) and Akaike (8) information criterions.

The last step of analysis involved conducting the panel ARDL technique by means of the PMG estimator. The underlying factors for the choice of estimator are briefly explained in section 4. Nonetheless, the long run coefficients from the PMG estimator are provided in Table

5. Non-renewable energy sources including coal, natural gas, oil and nuclear power were found to augment higher levels of carbon dioxide emissions in the long run. Also, their contribution to greenhouse emissions was found to be statistically significant. Coal in particular, increases carbon dioxide emissions by as much as 48%, followed by nuclear power (9%) and natural gas (7%). These findings are in line with Ahmed and Shimada (2019) who established that non-renewable energy consumption is the largest contributor to greenhouse gas emissions at least in Caribbean countries. With regard to non-renewable energy sources, oil is among the least contributors to greenhouse gas emissions in the BRICS region. Similarly, renewable energy sources such as biofuel, hydro, wind and solar energy contribute positively to carbon dioxide emissions although by a relative smaller percentage. For instance, hydro energy increases greenhouse gas emissions by as little as 3% while wind and solar energy raise greenhouse gas emissions by as little as 5% in the long run. The contribution of renewable energy sources to greenhouse gas emissions was found to be statistically significant with the exception of biofuel. Earlier findings by Arouri et al., (2012) also revealed that both renewable and non-renewable energy sources contribute to carbon dioxide emissions in the long run although by relative margins.

Table 4. Optimal lag length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-988.92	NA	0.01	17.34	17.53	17.42
1	609.75	2947.11	1.20e-14	-9.35	-7.63*	-8.65
2	699.61	153.15	7.78e-15	-9.80	-6.56	-8.48
3	817.23	184.11	3.18e-15	-10.73	-5.96	-8.79*
4	913.69	137.56	1.95e-15	-11.29	-4.99	-8.74
5	987.64	95.17	1.87e-15	-11.47	-3.64	-8.29
6	1051.55	73.36	2.29e-15	-11.47	-2.11	-7.67
7	1157.57	106.93	1.49e-15	-12.20	-1.32	-7.78
8	1269.74	97.54*	1.00e-15*	-13.04*	-0.63	-8.00

* Recommended number of lags

Table 5. Long run coefficients

Variable	Coefficient	Std. Error	t-Statistic	Probability
EPBio	0.04	0.04	1.05	0.29
EPCoal	0.49	0.11	4.55	0.00*
EPHydro	0.03	0.02	1.82	0.07***
EPGas	0.08	0.04	1.91	0.05**
EPNuc	0.09	0.03	2.85	0.00*
EPOil	0.02	0.00	7.28	0.00*
EPWS	0.05	0.02	2.38	0.01*

*, **, *** statistical significance at 1%, 5% and 10% respectively

Table 6-10 provide a summary of group specific short run coefficients. The findings in Table 6 indicate that in Brazil, renewable energy sources reduce greenhouse gas emissions by a range of [1-2]% while, in contrast, non-renewable energy sources such as natural gas, coal, oil and nuclear power raise greenhouse gas emissions by a range of [1-72]%. A study by Belaïd & Zrelli (2019) also revealed that non-renewable electricity consumption supplements CO_2 emissions in Southern and Northern Mediterranean countries, while renewable electricity reduces them. Oil is the largest contributor to greenhouse gas emissions, followed by coal, natural gas and nuclear power. It is sufficient to note that the contribution of various sources of energy to greenhouse gas emissions depends on the composition of the energy mix.

Nonetheless, all variables were found to be statistically significant in explaining variations in carbon dioxide emissions.

In Russia, natural gas increases greenhouse gas emissions by as much 43% in the short run followed by coal (17%). Although hydro energy reduces greenhouse gas emissions, its association with carbon dioxide emissions was found to be statistically insignificant. Nevertheless, renewable energy sources, specifically biofuel, wind and solar energy were found to be the least contributors to carbon dioxide emissions in the short run. The speed of adjustment was found to be negative and statically significant, as expected. The coefficient value of -0.07 implies that about 7% of departures from long run equilibrium is correct each period. Also, because the coefficient is negative and statistically significant, we can conclude that the variables are cointegrated. These findings are consistent with earlier studies such as Ang (2007) who established that sources of energy consumption and carbon dioxide emissions have a long run relationship.

Table 6. Short run coefficients (Brazil)

Variable	Coefficient	Std. Error	t-Statistic	Probability
ECM(-1)	-0.02	0.00	-47.18	0.00*
D(EPBio)	-0.02	0.00	-6.90	0.00*
D(EPCoal)	0.15	0.00	135.84	0.00*
D(EPHydro)	-0.00	0.00	-2.84	0.06***
D(EPGas)	0.11	0.00	185.07	0.00*
D(EPNuc)	0.00	5.90E-06	622.47	0.00*
D(EPOil)	0.73	0.00	256.11	0.00*
D(EPWS)	-0.02	0.00	-49.63	0.00*
C	0.06	0.00	24.09	0.00*

*, *** Statistical significance at 1% and 10% respectively

Table 7. Short run coefficients (Russia)

Variable	Coefficient	Std. Error	t-Statistic	Probability
ECM(-1)	-0.07	0.01	-14.03	0.00*
D(EPBio)	0.02	0.00	13.23	0.00*
D(EPCoal)	0.17	0.01	35.36	0.00*
D(EPHydro)	-0.01	0.01	-0.71	0.53
D(EPGas)	0.44	0.01	52.20	0.00*
D(EPNuc)	0.06	0.01	8.39	0.00*
D(EPOil)	0.06	0.00	13.63	0.00*
D(EPWS)	0.00	7.85E-05	22.08	0.00*
C	0.16	0.02	6.56	0.00*

* Statistical significance at 1%

Carbon dioxide emissions in India are largely driven by a combination of both renewable and non-renewable energy sources. For instance, coal raises greenhouse gas emissions by as much as 52%, followed by biofuels (36%) and oil (31%). In contrast, solar and wind energy reduce greenhouse gas emissions by as little as 1%. Other energy sources including nuclear power, natural gas and hydro energy are among the least contributors to greenhouse gas emissions. Notably, all variables were found to be statistically significant in explaining variables in carbon dioxide emission in the short run. The error correction coefficient stood at -0.22, implying that the variables converge to long run equilibrium at a rate of 23%. The coefficient was likewise found to be negative and statically significant, implying that the variables are cointegrated.

Table 8. Short run coefficients (India)

Variable	Coefficient	Std. Error	t-Statistic	Probability
ECM(-1)	-0.23	0.01	-20.74	0.00*
D(EPBio)	0.36	0.03	13.45	0.00*
D(EPCoal)	0.53	0.01	89.07	0.00*
D(EPHydro)	0.02	0.00	81.98	0.00*
D(EPGas)	0.01	0.00	26.34	0.00*
D(EPNuc)	0.00	0.00	4.00	0.02**
D(EPOil)	0.32	0.00	232.15	0.00*
D(EPWS)	-0.01	0.00	-75.83	0.00*
C	0.45	0.03	13.28	0.00*

*, ** Statistical significance at 1% and 5% respectively

In China, renewable energy sources such as wind and solar energy reduce greenhouse gas emissions by as much as 10%. In contrast, the production of electricity by means of coal increases greenhouse gas emissions by as much as 74% in the short run. Oil, nuclear power and hydro energy are among the least contributors to carbon dioxide emissions in China. The speed of adjustment was found to be negative and statically significant, as expected. The coefficient value of -0.018 implies that about 2% of departures from long run equilibrium are correct each period. Also, because the coefficient is negative and statistically significant, we can conclude that the variables are cointegrated.

Table 9. Short run coefficients (China)

Variable	Coefficient	Std. Error	t-Statistic	Probability
ECM(-1)	-0.02	0.00	-10.43	0.00*
D(EPBio)	0.04	0.01	7.16	0.00*
D(EPCoal)	0.75	0.01	156.44	0.00*
D(EPHydro)	0.02	0.00	186.38	0.00*
D(EPGas)	0.05	0.00	12.34	0.00*
D(EPNuc)	0.01	0.00	5.77	0.01*
D(EPOil)	0.00	1.80E-06	976.39	0.00*
D(EPWS)	-0.10	0.01	-8.59	0.00*
C	0.04	0.01	4.87	0.02*

* Statistical significance at 1%

The bulk of electricity production in South Africa emanates from coal resources. Similarly, coal is the largest contributor of greenhouse gas emissions in South Africa, raising greenhouse gas emissions by as much as 20% in the short term. In contrast, renewable energy sources such as biofuels, hydro, wind and solar energy reduce carbon dioxide emissions by a range of [2-18]%. Interestingly, other forms of non-renewable energy sources such as natural gas and oil were found to influence reductions in greenhouse gas emissions. All variables were found to be statistically significant in explaining variations in carbon dioxide emissions. Additionally, the speed of adjustment to equilibrium was found to be relatively high compared to Brazil, Russia, India and China. The coefficient value of -0.82 implies that about 82% of departures from long run equilibrium are correct each period.

Table 10. Short run coefficients (South Africa)

Variable	Coefficient	Std. Error	t-Statistic	Probability
ECM(-1)	-0.82	0.03	-26.50	0.00*
D(EPBio)	-0.02	0.00	-15.98	0.00*
D(EPCoal)	0.21	0.03	7.74	0.00*
D(EPHydro)	-0.02	8.16E-05	-209.99	0.00*
D(EPGas)	-0.02	0.00	-24.22	0.00*
D(EPNuc)	0.02	0.00	9.35	0.00*
D(EPOil)	-0.00	2.28E-05	-112.98	0.00*
D(EPWS)	-0.19	0.01	-17.88	0.00*
C	1.43	0.65	2.21	0.11

* Statistical significance at 1%

Generally, the group specific short run coefficients indicate that different sources of energy contribute differently to greenhouse gas emissions across countries. However, most non-renewable energy sources were found to augment higher levels of greenhouse gas emissions while renewable energy sources, particularly, wind and solar energy, were found to reduce greenhouse gas emissions by a considerable amount.

Conclusion

The aim of this study was to investigate the impact of renewable and now renewable energy sources on environmental sustainability in the BRICS regions. The study employed several statistical techniques including descriptive analysis, unit root analysis and regression analysis. The contribution of energy sources to greenhouse gas emissions was measured by means of the PMG estimator based on the characteristics of the variables. Overall, the findings reveal that non-renewable energy sources augment higher levels of carbon dioxide emissions compared to renewable energy sources. At the regional level, coal and nuclear power were found to increase carbon dioxide emissions by as much as 48% and 7%, respectively. Country specific coefficients revealed that hydro, wind and solar energy lessen the burden of carbon dioxide emissions in the short run. In light of these findings, this study cautions against the heavily reliance on non-renewable energy sources given their threat to human health and biodiversity.

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