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Original Article

Is nuclear energy a better alternative for mitigating CO_2 emissions in BRICS countries? An empirical analysis

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ABSTRACT

Looking at the recent studies, nuclear energy and carbon dioxide (CO_2) emissions nexus shows inconclusive result. To further explain nuclear energy-pollution nexuses this study is an attempt to analyze the impact of nuclear energy on pollution reduction for BRICS countries covering data for the period from 1993 to 2017. This study conducts advanced panel techniques such as Continuously-Updated Fully-Modified (CUP-FM) and Continuously-Updated Bias-Corrected (CUP-BC) for long run estimation. Our results support the notion that nuclear energy reduce CO_2 emissions. Also, renewable energy corrects environmental pollution in BRICS countries. The magnitude of the coefficient of nuclear energy is less as compared to renewable energy, implying that nuclear is less effective in reducing environmental pollution. The findings offer significant policy understandings and suggestions not only for BRICS economies but for developing countries as well in designing suitable nuclear energy-growth-carbon policies.

1. Introduction

The BRICS (Brazil, Russia, India, China, and South Africa) countries have experienced rapid economic growth, huge foreign exchange reserves, and attracted substantial foreign direct investment. However, together all these contribute to global carbon emissions [1]. The incidence of carbon dioxide (CO_2) emission harms the worldwide atmosphere and brings climate change. Environmental degradation is the most highlighted issue that threatens the world [2]. According to the British Petroleum (BP) statistics [3], during the year 2013 CO_2 emission of BRICS countries has reached to 14,110 million tons (Mt), about two times higher as compared to the year 2000. Moreover, since 2009, BRICS countries every year have emitted more than 40% of the world's carbon [3]. Due to growing CO_2 emission, demand for clean energy has emerged. Moreover, BRICS countries plan to reduce CO_2 emission following United Nations Conference on Climate Change 2015 (COP21) in Paris which was launched to revitalize public and private actions aimed to reduce global temperature up to 2 °C. As outlined by the Intergovernmental Penal Climate (IPCC), it is committed to ensure Greenhouse gas emission (GHGs) reduction [4]. Hence, an applicable environmental strategy is required to overcome total CO_2 emission without damaging the countries developmental projects to improve energy resources and acquired ideal energy efficiency [5].

Rising concerns including environmental degradation, climate change and the need for energy justice have become key human rights issues worldwide [6]. In production process energy is the key inputs and used as capital and labour [7–9]. However, energy consumption leads countries' economic growth, but energy consumption plays a vital role in rising pollution trends; people are still anxious about environmental challenges raised due to economic growth as well [10–12]. Energy innovation measures might be helpful in pollution mitigation [2]. However, currently, electricity generation intensely depends on fossil fuels. But more electricity generation from nuclear energy may helpful in climate change

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mitigation [13]. Nuclear energy is capable to generate electricity [14] and most importantly to beat ecological issues and also help to improve and maintain environmental sustainability. Nuclear energy is suitable and well-known source for the usage of low carbon outflow [15]. However, nuclear energy has not added to relieve CO_2 emission due to the adverse environmental impact of radioactive waste and atomic accidents [16]. Nuclear energy causes to harm the environment [15] and more radioactive waste has a serious impact on humans and the environment as well [17,18].

It is observed from the earlier work (reported in Table 1) there has been a restoration of motivation for the investigation of nuclear energy and environmental pollution nexus. However, the environmental impact of nuclear energy and its implications have not been sufficiently addressed whether nuclear energy reduces environmental pollution or not. For instance, nuclear energy promotes environmental sustainability [19,20] and does not contribute to CO_2 emissions reduction [17,21]. Meanwhile, it is observed that nuclear energy releases CO_2 emission into the atmosphere and leads to environmental pollution [15,22]. Given these motivations to the prospect of nuclear energy and CO_2 emission, the current study aims to examine the relationship between nuclear energy, renewable energy, *per capita gross domestic product (GDP)* and CO_2 emission in BRICS association.

Our research is interesting and unique in two important manners. First, the current empirical investigation will consider the impact of nuclear energy on CO_2 emissions for BRICS countries. Henceforth; the study's scope extends the global debate on climate change and its impact on BRICS countries. For the last decade, nuclear energy has shown momentum in BRICS countries [23]. Second, no empirical studies have found to apply the Continuously Updated Fully Modified (CUP-FM) and Continuously Updated Bias Corrected (CUP-BC) techniques on the evidence of nuclear energy and CO_2 emissions. The method used for empirical estimation in this study is robust that generated reliable estimates.

2. Material and methods

Before building the model specification, we talk about the present hypothetical background of the study, which supports our empirical study to pick the explanatory variables for this research. The rise in economic growth not only expands economic structure but contributes to environmental degradation through an increase in energy demand, structural transformation; develop transportation systems and consumption habits of residents of a country. Subsequently, economic growth is influencing an individual's income, expectations for everyday comforts and buying power increases. To meet the rising energy demand the renewable energy sources are emerging as clean and environmental energy sources (renewable energy sources). Therefore, the use of renewable energy is measured to improve climate change, decrease environmental pollution and improve

Table 1
Related studies on nuclear energy and CO_2 emissions nexus.

Authors	Country	Time	Methods	Key Findings
[14]	OECD countries	1995 –2015	GMM, FMOLS	Their finding suggests that non-renewable resources increase environmental pollution but nuclear help to environmental sustainability and also EKC hypotheses confirm the presence in OECD countries.
[15]	Pakistan	1973 –2017	ARDL	Their finding summarizes that has a negative relationship with environmental pollution and also detect between bidirectional causality between nuclear energy and CO2 emission
[21]	9 developed countries	1990 –2013	Penal FMOLS, DOLS	Their results inferred that reducing nuclear energy consumption may not GDP per capita. However, there is no relation between GDP and nuclear energy but bidirectional causality is detected between labor and nuclear energy.
[19]	USA	1960 –2010	ARDL	They find that nuclear energy improves the environmental quality both long-term and short-term but renewable energy is helpful in the short-term.
[24]	OECD	1980 –2011	STIRPAT Modal	Their proof shows that non-sustainable power source builds the ecological issues however non-renewable energy has a positive relationship with CO2 emission. Furthermore, to improve sustainable development and promote energy technology to reduce non-renewable energy.
[25]	Newly industrialized countries	1971 –2011	Penal ARDL	This study indicated a non-linear relationship to show negative and positive shocks among the explanatory variables. Renewable energy has a positive shock in Africa, Mexico but the negative shock has found in India.
[26]	17 countries	1980 –2012	Bootstrap penal	In this study non-renewable energy consumption has found growth hypothesis for Mexico, China, and Colombia, conservation hypothesis has found for Egypt, Peru, and Portugal; while the feedback hypothesis has found for Turkey and neutrality hypothesis is confirmed for the 9 emerging countries.
[27]	China	1993 –2016	ARDL	Their analysis shows that EKC hypotheses exist in China. Furthermore, they summarize that nuclear and renewable energy positively contributes to CO_2 emission.
[28]	UK	–	Case study	In this find out the important facts like Uranium contribute 95% of the compound of nuclear energy in the UK. In 2018 the UK 15 nuclear reactors generated 21% of electricity which is quite helpful for sustainable development.
[29]	27 countries	–	Case study and sampling	Their exploratory study demonstrated that to improve sustainability, energy strategies, and to start nuclear energy production.
[17]	30 countries	1980 –2014	Penal Analysis	In this study, the causality test indicated that nuclear energy cannot contribute to CO_2 emission, so it emphasizes the expansion of renewable except nuclear energy, renewable energy is essential to control global warming.
[30]	42 develop countries	2002 –2011	GMM	Their results suggest that non-renewable energy consumption is negatively affecting GDP for developing countries. Moreover, they find renewable energy consumption increase the GDP.
[31]	G7 countries.	1980 –2009	Penal ARDL	Their main finding summarizes that long-run results of renewable and non-renewable energy consumption increase the GDP and production function.
[32]	Asian countries	1995 –2016	FMOLS, DOLS	Their analysis revealed that ASEAN nations must execute economic development and energy-saving related policies. Moreover, ASEAN countries should take steps to reduce their dependence on fossil fuels for accomplishing these targets.
[33]	11 developed countries	1990 –2012	STIRPAT	Renewable energy has a negative impact while the GDP has a positive significant contribution.
[34]	Pakistan	1990 –2016	NARDL	Their main purpose to check the asymmetric impact of both nuclear and renewable energy. Their analysis shows that GDP, oil prices, oil consumption, and CO_2 emission are contributing to nuclear and renewable energy.
[35]	South Korea	–	Query Analysis	This empirical result shows that, depending on the type of incident and accident, several incidents and accidents related to nuclear energy have a consistent or temporary impact on the attitudes and ratios of statements.
[36]	80 countries	1990 –2007	Penal Analysis	Their study demonstrated that there is little distinction to estimate renewable energy consumption. Moreover, this study detected there exists bidirectional causality between renewable and non-renewable consumption.

human wellbeing and quality of life improve [37]. Similarly, nuclear energy contributes to a clean environment, increase energy supply, control of CO_2 emission, and lead to sustainable development [14]. However, the role of nuclear energy in CO_2 emission is unclear. In this sense, the decision-making process is more complicated so that's why we examine the influence of nuclear energy, renewable energy, and *per capita GDP* on CO_2 emission which can be expressed as:

$$\ln(CO_{2it}) = \alpha_0 + \alpha_1 \ln(Y_{it}) + \alpha_2 \ln(NE_{it}) + \alpha_3 \ln(RE_{it}) + \mu_{it} \quad (1)$$

where CO_2 is carbon dioxide emission; Y is the *income per capita*; NE shows nuclear energy, and RE means renewable energy in time *t* from 1993 to 2017 for *i* cross-section. Finally, μ it represents an error term.

The study uses panel data for BRICS countries and based on available data empirical estimation techniques are employed. The cross-sectional dependence (CSD) test among the panel countries is very common owning to overflow impact, financial crisis, and trade agreement [38]. Recently the CSD investigation in panel data analysis becomes popular in energy-environment studies [39,40]. This study also use panel data which may confront the homogeneity, correlation and cross-section dependence issues. To solve the above-mentioned problem, this empirical study uses advanced penal methods that are capable to handle the endogeneity issue. Our research begins by investigating cross-sectional dependence (CSD) across sample countries since there may prompt the issue of the dependencies between cross-section elements in panel data [41,42] and CSD test by Ref. [44] is utilized for the purpose to detect the CSD issue. The next step is to check the stationary level of the data weather indicated variables hold unit root or not. Avoiding the stationary level may lead to biased results. For this purpose, our study relies on CIPS panel unit root tests by Pesaran (2007) to resolve the cross-section dependence issue that might exist in panel data. After successfully resolving these issues the next step is to assess the level of the relationship among the investigated variables in the study. At this stage, the LM bootstrap panel cointegration approach created by Ref. [45], is employed. For long-run results, we use continuously updated fully modified (CUP-FM) and continuously updated (CUP-BC) develop by Ref. [46] which produces robustness estimates. The estimation process is continuously updated till to the convergence happening for robust estimation, this methodology is known as continuously updated fully modified (CUP-FM). Similarly, asymptotic bias is additionally assessed and revised in this process which is named (CUP-BC) estimation. The equation of the (CUP-FM and CUP-BC) is can be expressed of the below:

$$\widehat{\beta}_{cup} = \left[\sum_{i=1}^{N} \left(\sum_{t=1}^{T} \widehat{y}_{it} + (\widehat{\beta}_{cup}) \times (x_{i,t} - \overline{X}_i) - T\left(\lambda_i^{'} (\widehat{\beta}_{cup}) \widehat{\Delta}_{F\varepsilon i} + (\widehat{\beta}_{cup}) + \Delta\mu\varepsilon\dot{i} + (\widehat{\beta}_{cup}) \right) \right) \right] \times \left[\sum_{i=1}^{N} \sum_{t=1}^{T} (x_{i,t} - \overline{X}_i)(x_{i,t} - \overline{X}_i)^{'} \right]^{-1} \quad (2)$$

where $\Delta F_{\varepsilon i}$ & are estimated one-sided covariance. The (CUP-FM and CUP-BC) techniques are efficient estimators in the core of exogenous variables. Similarly, the (CUP-FM and CUP-BC) estimators are appropriate for the occurrence of mixed order of integration such as I(1)/I(0) and generate robust estimation within sight of endogeneity [46]. Owning these advantages, accurate size and small data sample, the (CUP-FM) and (CUP-BC) are the most appropriate selection for current empirical investigation. Besides, these methods are widely used for long-run estimation [40,47,48].

The selections of countries are a crucial phase in panel data analysis and one should be careful in choosing a panel of countries. Hence, yearly data of nuclear energy, renewable energy, *gross domestic product (GDP)*, and CO_2 emission are acquired from 1993 to 2017 for BRICS countries. The data of CO_2 emission is measured in metric tons per capita. Both renewable energy and nuclear energy are measured in kiloton oil equivalent (ktoe) and converted into per capita by dividing the total population. The data on CO_2, renewable energy and nuclear energy is retrieved from BP statistics [49]. The *per capita GDP* constant 2010 US dollar is collected from World Database Indicator [50].

3. Results

The empirical part begins with the investigation of the CSD of panel data and analyzed results have appeared in Table 2. The results show that the null hypothesis of independence among the panel data is rejected at a 1% significance level. In short, CSD is found among the study regressors, and shocks happening in one sample country may spill over to other sample countries. After confirmation of the CSD, the CIPS panel unit root test is used for the stationary check which helps in the selection of the proper estimation approach in the existence of CSD. The result of CIPS is noted down in Table 2 which shows that the unit-root of all the variables is not integrated at level, but they become stationary at the first-order of integration I(1).

Having found out the order of integration now we determine the cointegrated relationship among indicated variables of the study. The LM bootstrap cointegration results are indicated in Table 3 and the analyzed results show that the rejection of null hypothesis of cointegration among the indicated variables are not rejected. So, we do not rejected the null hypothesis and found cointegration among indicated variables. Thus, there is strong evidence for the long-run relationship that exists among the CO_2 emission, (nuclear energy) NE, (renewable energy (RE), and income per capita (Y).

The results of CUP-FM and CUP-BC estimators have appeared in Table 4. the evidence indicates that *per capita GDP* (Y) has a positive and significant impact on CO_2 emission. Keeping other things constant a 1% increase in *per capita GDP* will increase CO_2 emission by 0.054% and 0.055%.

Concerning the role of nuclear energy, from Table 4 it can be seen that a rise in a 1% increase in nuclear energy consumption reduces CO_2 emissions. It clearly shows that the environmental pollution reduce by nuclear energy consumption in BRICS countries. In other words, nuclear energy works as a clean source of energy in BRICS countries which is indicated by Lau et al. (2020) as well. Notably, BRICS has been pursuing nuclear energy infrastructure development-related projects for the last three years [15]. Nuclear energy can be served as an alternative for conventional energy sources to certify better environmental quality [14]. However, it relies on the economic classification and socioeconomic factors of the country that help to implement the energy storage for sustainable development [51]. Nuclear energy has prodigious market potential and it is also cost-effective. Nuclear energy development ensures energy security, stimulate economic growth. Taking into account the encouraging role of nuclear energy in clean environment, the constant increase in pollution in BRICS can be lessened via conversion toward nuclear energy [40].

Also, renewable energy significantly contributes to CO_2 emission by (0.006% & 0.007%) to increase environmental sustainability and economic development. Our finding differs from the existing study [30,52,53]. More investment in clean energy technologies is required which might be compatible with the environment. For instance, the cost of incorporating renewable energy is higher than

Table 2
Results of cross-sectional dependence and CIPS panel unit root test.

	LOG CO_2	LOG Y	LOG NE	LOG RE
LM Test	43.580* [0.0000]	24.565*[0.0000]	69.260 [0.0000]*	61.428* [0.0000]
CD test	4.9773*[0.0000]	10.807* [0.0000]	7.3973 *[0.0000]	4.9458* [0.0000]
CIPS Panel unit root test				
At Level	−3.107	−2.702	−2.678	0.786
First Difference	−3.719	−4.010	−3.592	−4.140

Note: *denote significance level at 1%.

Table 3
Results from the LM bootstrap panel cointegration test.

Test	Constant		Constant & trend	
	Test statistic	Bootstrap p-value	Test statistic	Bootstrap p-value
LM bootstrap	3.073	0.921	−0.639	0.999

Note: The bootstrap test statistic is calculated by using 1000 replications.

Table 4
Results of CUP-FM and CUP-BC

Dependent variable = CO_2 emission				
Regressor	CUP-FM		CUP-BC	
	Coefficient	t-value	Coefficient	t-value
LOG Y	0.054	133.97	0.055	118.284
LOG NE	−0.001	27.489	−0.001	24.851
LOG RE	−0.006	52.331	−0.007	48.977

Note: *, **, *** denote significance level at 1% 5% and 10%, respectively.

non-renewable technologies. Therefore, the BRICS countries should start the stage-wise transformation from fossil fuel (oil, gas, coal) to green energy implying in household use, industrial and commercial sectors. Energy innovation measures are suggested that reduce environmental pollution [6,54–56]. Furthermore, the BRICS countries need to promote nuclear energy-related investment. For a better understanding, BRICS countries should bring reforms to reduce the use the fossil fuel consumption through intensification of nuclear energy and renewable resources. Regarding the strategy and policy execution between income level and pollution, implementing energy conservation measures are suggested, and according to the neutrality hypothesis, neither energy supply nor energy conservation affect economic growth [57,58].

4. Conclusion and future prospective

This study investigates the long-run relationship between nuclear energy, renewable energy, *per capita GDP*, and CO_2 emissions in the context of the BRICS for the period from 1993 to 2017. For this purpose CSD test and CIPS unit root test are applied to check the dependencies across countries and stationary levels respectively. We employ the LM-bootstrap Panel cointegration test for the level of relationship among indicated variables. For long-run estimation results, we use CUP- FM and CUP- BC estimators. Our results show: (i) The CSD test confirmed there exists dependencies across sample countries. (ii) LM bootstrap co-integration confirmed the level of relationship among variables under consideration . (iii) The CUP-FM and CUP-BC estimation result confirmed nuclear energy consumption reduce CO_2 emission and renewable energy consumption plays a significant role in climate change mitigation.

In the light of the study's findings hypothetically probable relation is affirmed between the investigated variables. Nuclear energy can contribute to energy production. Execution of carbon pricing instruments in the manufacturing sector across the countries and inside the economic activities would be useful to control pollution. Moreover, it is not only an environmental concern but also a social perspective that has generated a strong interest in nuclear energy consumption. Nuclear energy plays a significant role in ensuring energy security and improves environmental pollution if the scientist and policy analyst of BRICS countries should take serious measures especially. No doubt nuclear energy-related technology will continue to maintain the status of country and significance for alternative power supply sources not only to contribute economic growth but also contribute to social and sustainable environmental improvement. Due to less expensive and ensuring energy security, the nuclear power supply generation has a positive role in the environment through reducing air pollution and ozone-depleting which come from fossil-based energy production. Innovative technology based on nuclear energy can be an attractive choice for economic, social, and environmental purposes.

This study attempts to observe fronts or challenges on the BRICS's CO_2 emission considering the influence of nuclear energy on environmental pollution, however, some limitations still exists. Future research ought to analyze the the role of nuclear energy in climate change mitigation in the presence of globalization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.net.2020.05.016.

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