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Does natural resources matter? Nexus among renewable energy policies, technological innovation, environmental protection, and economic growth

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ABSTRACT

The objective of this study is to examine the relationship among different sources of renewable energy, role of technology, environment protection and economic growth. This study uses panel annual data set of selected BRICS countries from 1997 to 2019. This study uses the Augmented Mean Group (AMG) estimator, a second-generation estimator that takes slope homogeneity and cross-sectional dependence into consideration. For robustness, the Pooled Mean Group (PMG) estimator has also been utilized. The findings show that the use of renewable energy will rise as income inequality declines. The results of the analysis demonstrate a one-way causal association between income inequality and REC. This finding confirms that a reduction in income inequality will have a major impact on the adoption of renewable energy sources.

1. Introduction

It is observed that by 2030, the 7.9 billion people who currently inhabit the planet are projected to reach 8.5 billion [1]. Whereas, Sustainable development is hampered by continued rapid population growth. Fulfilling the requirements of the present generation without depleting the resources available to following generations is what sustainable development entails. Global warming is largely caused by the enormous amount of carbon that human activity adds to the atmosphere. It develops as a consequence of the industrialization, population pressures, and urbanization that occur in economies all over the world as a result of the high reliance on fossil fuels [2].

It is noted that in between 1985 and 2016, the BRICS countries' GDP expanded rapidly, from US $2187 billion to US $16,266 billion, with a 6.5% annual growth rate on average [3]. By 2030, the BRICS nations' share of global GDP will have risen to 37.7%, significantly ahead of Europe (15.3%), and the United States (15%). The fact that the BRICS represent more than 50% of world economic growth, 40% of the global population, and nearly 20% of world trade can be used to assess the economic progress of BRICS [4]. By 2050, the BRICS economies are expected to outperform even the world's most developed economies (G7) [5]. The BRICS economies' massive energy consumption is causing global CO_2 emissions [6]. About 38% of global CO_2 emissions are attributable to these economies.

Moreover, countries are encouraged to employ more renewable energy sources and promote environmental protection as the need to reduce CO_2 emissions to prevent global climate change. Their research suggests that in low-income countries, REC is positively correlated with carbon emissions, but in high-income ones, it is negatively correlated. Lin and Zhu [7] examined variables affecting the growth of green energy technology in China. The results demonstrate that innovation is positively affected by investments in R&D and that high CO_2 emissions speed up the development of green energy technology. According to their definition of a considerable threshold impact in regard to income

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inequality, policies aimed at decreasing income disparity may also help lower CO_2 emissions [8]. Given that income inequality has been associated with a number of outcomes that may have an impact on green energy, the emphasis on income disparity is crucial.

Additionally, Bai et al. [9] specifically looked into the association between technological innovations in energy sector and discovered that innovation in energy sector is a successful strategy for coping with the sharp fluctuations in oil prices. They also discovered that government and corporate investments in new energy technology have been profitable due to the political and economic strength of the innovation system brought about by high oil prices. Their study's theoretical justification for the profitability of investments in green energy is essential given the existing dominance of traditional energy. Besides, Anser et al. [10] found the unidirectional causal relationship that the utilization of renewable energy follows technological advancement. Additionally, Cao et al. [11] discovered that technological innovation has a substantial role in reducing the use of non-renewable energy sources.

Most prior research neglected to test for CD and SH, instead relying on haphazard empirical methodologies that are likely to provide biased and inconsistent results. Hence, our study's econometric modelling approach avoids these issues for four selected BRICS countries. The study makes use of the most up-to-date panel estimation techniques to produce trustworthy and reliable results that are useful for decision-making in BRICS economies because each nation in the panel is expected to have unique features, the AMG estimator generates reliable and unbiased coefficient estimates for each economy in the panel. As a result, the obtained outcomes will be more policy-oriented. The study uses the AMG estimator to look into the effects of GDP growth, income inequality, CO_2 emissions, gross fixed capital formation, and technological innovation on REC in BRICS countries. Slope heterogeneity and cross-sectional dependence (CSD) are both taken into consideration by the AMG estimation technique to prevent the overgeneralization that impaired earlier research. The AMG provides results for the panel and for each of the BRICS economies. Consequently, more policy-oriented findings can be obtained. The empirical findings may assist policy-makers in taking measures to increase REC and develop an energy system that is both economically and environmentally sustainable.

The rest of the paper is organized as: Section 2 explains Literature review; Section 3 explores data and methodology; Section 4 describes results and their discussion; and finally conclusion is presented in Section 5.

2. Literature review

This section presents previous literature that explores the determinants of renewable energy consumption in order to justify our research gap. Meanwhile, a number of studies are dedicated to examining one or more of four widely accepted hypotheses regarding the association between GDP growth and REC. The first hypothesis also referred to as the growth hypothesis, states that there is a one-way causality linking REC and GDP growth. According to this argument, changes in REC and associated regulations will have a huge influence on economic expansion because energy is such a critical component of production. The growth hypothesis is supported empirically by studies such as [12–14]. The conservation hypothesis, which proposes a unilateral causal association between REC and GDP growth, is likewise validated by a number of studies [15,16]. Other studies that emphasize the bidirectional causal link between economic expansion and green energy support the feedback hypothesis [17–23]. Finally, number of studies supported the neutrality hypothesis, which claims no direct or indirect causal link between economic expansion and green energy usage [24–27].

It is noted that importance of research and development in fostering green technological innovation has been confirmed by numerous studies [7,28–37], and it has also been demonstrated that technological innovation has a favorable influence on REC [38]. According to Irandoust [39]; technological innovations in Denmark and Norway encourage REC, however in Sweden and Finland, the opposite is true due to the countries' differing energy systems and other factors. He et al. [40] analyzed the effects of technical innovation on RE in China. The findings show that technological research and development is one of the key variables impacting REC. The question of whether or not the introduction of new technology broadens renewable energy is examined by Shabbir et al. [41]. The findings show that the advancement of new technologies has a significant influence on REC. However, renewable energy cannot be significantly influenced by the available technology. According to Shabbir and Zeb [42]; renewable energy will drive future energy needs; hence its production must be efficient. The findings investigate how technical innovation is a crucial component of renewable development that may help resolve environmental degradation. According to Li and Shao [43]; the production of green energy has a negative effect on innovation.

Jain et al. [44] also tested the EKC hypothesis for Nigeria by using Johansen cointegration approach. The main objective of the study was to identify the association between economic growths, energy led emission in the presence of EKC hypothesis. The results of the study could not support the evidence of EKC hypothesis because quadric GDP per capita and per capita GDP growth are directly and inversely associated with carbon emission. Ali et al. [45] also could not support the evidence of EKC hypothesis for the Pakistan in short run as well as in the long run analysis. The study has taken the agricultural growth and its impact on environment because in the mid-1960s various steps have been taken by Pakistani government to improve the level of agricultural growth. The results show that inverted U shaped EKC could not found in agricultural growth-environment nexus analysis. The study tested the EKC hypothesis and also investigates the link between economic growth, energy use, urbanization and CO_2 emission [46]. This region is facing the severe environmental degradation challenges. These countries taking steps to reduce the use of nonrenewable energy sources and increases the use of renewable energy sources. The findings of this study could conclude the insignificant impact of renewable energy use policies on the environment in this region [47].

Zhang et al. [48] different countries try to examine the casual association between GDP growth and use of renewable energy sources. Recently, various studies used renewable energy as the main component of economic growth and mitigation the level of pollution. The other recent empirical studies also tested the EKC hypothesis and their findings supported the presence of EKC hypothesis. In general, the environment quality significantly increases the level of renewable energy use and the level of CO_2 emission significantly increases by the use of nonrenewable energy sources [49].

Whereas, Sikandar et al. [50] nonrenewable energy use ratio to GDP is decreasing in developed countries because developing countries exporting them pollution intensive goods. The dirty productions of goods are creating pollution in these areas where its produce, this theory is based on the "traditional production-based emission accounting approach". Therefore, this traditional theory is no longer in the context of international trade and its environmental degradation nexus. Saleem et al. [51] revealed that the production of goods in a specific country and its relationship with emission is essential for calculation of consumption-based approach. The findings of their study support the evidence of EKC hypothesis and found feedback association between CO_2 emissions, use of energy and GDP growth and bidirectional casualty also moves from trade openness to carbon emission. The study of Yang et al. [52] tested the EKC hypothesis for Malaysia and confirmed the presence of EKC hypothesis. Their findings support the short-run association between these variables and casual association found between CO_2 emission and GDP growth in the long run.

It is observed that from the above literature review that no priori study have seen to explore the impact of CO_2 emissions, capital formation, technological innovation, GDP growth and income disparity on REC in BRICS economies by using AMG estimators. This study is the first ever attempt to fulfill the research gap in our Literature.

3. Data and methodology

This study is using annual data from 1997 to 2019 for selected BRICS countries such as (China, India, Russia and South Africa). The study examines the impact of CO_2 emissions, capital formation, technological innovation, GDP growth and income disparity on REC in BRICS economies. The fact that these nations account for 37% of world energy usage, 20% of the world GDP, and 40% of world CO_2 emissions allows us to assess the sample's relevance [20,53,54]. Significant clean energy development is necessary to prevent these economies from being compelled into costly, carbon-concentrated, and unstable energy system that will harm their ability to expand economically. In order to solve this, the BRICS economies have significantly boosted their spending in sustainable energy projects as the role of green energy in the global energy supply is rapidly becoming more established. As a result, investment in green energy is rising in developing and growing countries, notably in the BRICS nations. These nations account for 36% of the world's green energy capacity, and 27% of world's non-hydro energy capacity. As green energy is the most efficient approach to protect the environment, it is crucial to look at the factors affecting REC in these countries.

$$\ln REC_{it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln CO_{2it} + \beta_3 \ln INN_{it} + \beta_4 \ln GN_{it} + \beta_5 \ln GFCF_{it} + \varepsilon_{it} \quad (1)$$

where REC stands for consumption of renewable energy. GDP, CO_2, INN, GN, and GFCF stand for economic growth, carbon emissions, technological innovation, income inequality, and gross fixed capital formation, respectively (For detail description, please see: Table A1). Finally, "t", "i", and "ε" stand for time dimension, cross-sections of countries, and the error term, respectively.

This estimator is made up of a common dynamic mechanism that reveals the main model's unobservable common factors. The AMG estimation process consists of two steps:

$$\text{Step} - 1: \Delta Y_{it} = a_i + \beta_i \Delta X_{it} + c_i f_t + \sum_{t=2}^{T} d_i \Delta D_t + e_{it} \quad (2)$$

$$\text{Step} - 2: \widehat{\beta}_{AMG} = N^{-1} \sum_{i=1}^{N} \widehat{\beta}_i \quad (3)$$

In the above equations, ΔY_{it} represents the dependent variable; ΔX_{it} denotes the explanatory variable; f_t represents the heterogeneous element; β_i represents country-specific estimation coefficients; β_{AMG} represents the mean group estimator; the coefficient of time dummies is indicated by di and the intercept and error component are denoted by a_i and e_{it}, respectively.

4. Empirical results and discussion

Further, the countries with the highest and lowest mean values of lnGFCF are South Africa (3.125) and Russia (2.413). For the BRICS panel, the average mean is highest for technological innovation (8.752), followed by economic growth (8.510), income inequality (3.712), gross fixed capital formation (3.132), REC (2.893), and carbon emissions (1.123), respectively (see Table 1).

We use the Pesaran scaled and Breusch-Pagan LM tests to examine whether the variables have CSD as mentioned in below Table 2. At the 1% level of significance, the CSD test statistics indicate that the chosen variables are cross-sectional dependent, rejecting the null hypothesis of cross-sectional independence.

To test for data stationarity, we employed first- and second-generation unit root tests, including IPS, ADF, LLC, and CIPS, and the findings are shown in Table 3. Although the findings of all unit root tests are similar (mixed order of integration), the findings of the CIPS test are

Table 2
Findings of cross-sectional dependence (CSD) tests.

Variable	Breusch-Pagan LM	Pesaran scaled LM
lnREC	72.712***	15.002***
lnGDP	214.141***	45.014***
$\ln CO_2$	80.110***	13.099***
lnINN	87.913***	16.239***
lnGN	130.152***	25.071***
lnGFCF	57.132***	11.145***
CSD for Model	106.134***	21.169***

Note: *** denotes 1% level of significance.

Table 1
Descriptive statistics.

Countries	Statistics	lnREC	lnGDP	$\ln CO_2$	lnINN	lnGN	lnGFCF
China	Mean	1.301	9.103	2.210	10.001	3.321	2.765
	Std. dev.	0.093	0.319	0.065	0.131	0.031	0.112
	Minimum	1.230	8.590	2.298	9.431	3.121	2.312
	Maximum	1.415	9.410	2.456	10.121	3.093	3.193
	Observations	24	24	24	24	24	24
India	Mean	3.901	6.703	0.121	8.328	3.712	3.117
	Std. dev.	0.213	0.491	0.702	0.550	0.501	0.813
	Minimum	3.612	6.910	−0.318	7.011	3.411	3.014
	Maximum	4.083	7.503	0.632	9.321	3.700	3.301
	Observations	24	24	24	24	24	24
Russia	Mean	2.790	8.981	2.231	6.413	4.130	2.413
	Std. dev.	0.013	0.403	0.780	0.212	0.038	0.321
	Minimum	2.431	8.710	2.031	4.302	4.139	2.760
	Maximum	2.821	8.012	2.315	6.210	4.140	3.125
	Observations	24	24	24	24	24	24
South Africa	Mean	3.109	7.754	1.314	11.231	3.711	3.125
	Std. dev.	0.512	0.153	0.211	1.131	0.018	0.129
	Minimum	2.502	6.538	0.630	9.190	3.315	3.321
	Maximum	3.513	8.110	2.013	13.123	3.112	3.631
	Observations	24	24	24	24	24	24
Panel	Mean	2.893	8.510	1.123	8.752	3.712	3.132
	Std. dev.	0.856	0.701	0.321	1.312	0.251	0.321
	Minimum	1.231	6.451	−0.316	4.310	3.312	2.321
	Maximum	4.053	9.210	2.543	13.521	4.109	3.652
	Observations	120	120	120	120	120	120

Table 3
Findings of 2nd generation unit root test – CIPS.

Variables	Level		1st difference		Integration order
	Intercept	Intercept & trend	Intercept	Intercept & trend	
lnREC	−2.309**	−2.129	−1.773	−1.653	I(0)
lnGDP	−1.891	−2.543*	−2.116**	−2.011	I(0)
lnCO_2	−2.009	−3.119***	−2.763***	−2.551**	I(0)
lnINN	−3.396***	−1.391	−2.213*	−2.123	I(0)
lnGN	−1.513	−2.223	−2.212**	−2.431	I(1)
lnGFCF	−1.719	−2.309	−2.096**	−2.121	I(1)

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

more significant since the CIPS test not only addresses the CSD problem but is also robust to the heterogeneity problem.

After examining the stochastic nature of the variables, several panel cointegration tests, including Pedroni, Fisher, Kao, and Westerlund (2007), are employed. The rejection of the null hypothesis in each cointegration test provided in Table 4 indicates that there is evidence of a long-term association between the variables. The long-run associations between the variables are evident in all cointegration tests, but the Westerlund [55] test is more noteworthy because it incorporates the CSD issue using the bootstrap approach.

After establishing the long-run linkage between the variables, the AMG and PMG estimators are employed to determine the direction of the relationship between the variables and the size of the long-term coefficients and the series. The findings of the AMG and PMG techniques are shown in Table 5. The direction of the predicted coefficient remains the same when using different estimators, but the size and levels of significance have changed. The findings from the AMG estimator indicate that GDP growth has a positive but insignificant impact on REC.

Table 4
Panel cointegration tests.

Pedroni (Within-Dimension)		
	Statistic	Weighted Statistic
Panel v-Statistic	1.401	0.301
Panel rho-Statistic	0.012	0.509
Panel PP-Statistic	−3.291***	−2.138***
Panel ADF-Statistic	−3.280***	−1.703***
Pedroni (Between-Dimension)	Statistic	P-value
Group rho-Statistic	1.231	0.792
Group PP-Statistic	−2.551***	0.014
Group ADF-Statistic	−2.319***	0.109
Fisher No of CE(s)	Trace test	Max-Eigen test
None	215.90***	118.10***
At most 1	121.80***	75.41***
At most 2	61.01***	35.23***
At most 3	32.01***	19.09**
At most 4	25.00***	19.03**
At most 5	22.01**	22.31**
Kao	Statistic	P-value
ADF	−2.415***	0.0041
Westerlund [55] Statistic	Value	Robust P-value
Gt	−3.491**	0.019
Ga	−3.133	0.310
Pt	−6.873**	0.029
Pa	−1.444	0.699

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

Table 5
Results of the AMG and PMG estimators.

	AMG		PMG	
Variables	Coefficient	P-value	Coefficient	P-value
lnGDP	0.031	0.791	0.149***	0.011
lnCO_2	−0.491***	0.000	−0.653***	0.003
lnINN	−0.221**	0.029	−0.051**	0.011
lnGN	−0.793***	0.007	−1.530***	0.000
lnGFCF	−0.059*	0.071	−0.175***	0.031

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

The remaining variables, including carbon emissions (CO_2), technological innovation (INN), income inequality (GN), and capital formation (GFCF), have a negative and statistically significant effect on REC, suggesting that increasing these variables reduces REC in BRICS countries. The findings indicate that REC causes a 0.491% drop in carbon emissions, demonstrating an adverse relationship between carbon emissions and REC. Also, the coefficient of capital formation is discovered to be negative and statistically significant, indicating that a 1% rise in GFCF reduces REC by 0.059%. This shows that the deployment of green energy is hindered by the current physical infrastructure asset level. This result is consistent with the findings of [56,57].

Further, it is discovered that income inequality has a negative and significant long-term effect on REC, suggesting that more fair income distribution will lead to higher usage of renewable energy. This result is backed by Refs. [58–65]. The favorable effect of fairer income distribution on REC can be explained in several ways. First off, by easing people's financial worries, the lowering of income disparity can raise ecological consciousness. Environmental demands may rise as a result of ecological issues. Reduced individuality and higher communal consciousness may significantly contribute to the promotion of RES due to fairer income distribution. Governments can encourage green energy projects using incentive mechanisms like tax concessions and financing facilities in the context of people's need for a high-quality environment. As Apergis [66] suggested, private efforts should also shoulder responsibilities for assisting the shift to renewable energy in order to reduce manufacturing costs. Reduced expenses will enable medium-sized and small businesses to use green energy at a lower cost, which is anticipated to reduce income disparity.

5. Conclusion and policy implications

In order to attain the study's objective, we adopt the PMG and AMG estimators for the BRICS economies over the period 1997 to 2019. According to the estimation outcomes from both methodologies, REC is negatively and statistically significantly associated with technical innovation, CO_2 emissions, gross fixed capital formation, and income inequality. Using the PMG estimator, the influence of GDP growth on REC is favorable and significant. Moreover, according to the AMG estimator, the long-run elasticity for technological advancement, CO_2 emissions, gross fixed capital formation, and income disparity are −0.221%, −0.491%, −0.059%, and −0.793%, respectively.

The following policy implications could be implemented based on the study's findings to further enhance the quality of the environment in BRICS economies. In addition, in order to increase the usage of renewable energy, it is crucial to remove the economic and legal obstacles that prevent businesses and individuals from making investments in RES. Moreover, strategies that promote the use of RES, including placing a heavy tax burden on the consumption of non-renewables, will lessen income disparity and boost environmental quality. This implies that continuous investment support is essential to maintain the speed of the green energy transition. So, for instance, financial subsidies for sustainable energy projects will help governments reduce inequality.

These financing plans may raise distributional issues for (effective) carbon pricing because high carbon costs can not only result in decreased profitability for the non-renewable energy sector but also in a loss of purchasing power for middle- and low-income families. With the broad use of renewable technology, energy costs, particularly for low-income populations, are stabilized, which will help reduce poverty.

Future studies could analyze the impact of other factors on REC, such as government clean energy subsidies and institutional efficiency. Future research could also take into account the quantile-level analysis and spatial dimensions of multilateral trade and clean energy production. Besides, given that renewable energy generation comes from several sources, future research may examine the influence of disaggregated RECs on GDP growth. Such research will aid in determining which renewable energy sources have the greatest positive effects on economic development and, consequently, will aid in identifying the sources that are economically more advantageous for the deployment of such renewables. It is also possible to look at how various inequality indices, including wealth disparity, income inequality among the top 1%, and wage inequality, affect the use of RES and environmental deterioration. This will improve the body of empirical literature and evaluate how reliable the findings of earlier research.

CRediT authorship contribution statement

Dr Xinxin Yan conceptualized the work, Dr Alaa Amin Idea development, Dr Guohua Zhu wrote Introduction part, Dr Yeter Demir wrote Literature Review, Dr Malik Shahzad worked on the Methodology section, Dr Mady Mohamed data analysis and interpreted the results, Dr Taseer Muhammad wrote conclusion and proof read the paper.

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Declaration of competing interest

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Data availability

Data will be made available on request.

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Appendix

Table A1
Variables and source description

Variable	Variable Description	Source	Expected Sign
CO_2	CO_2 emissions taken as CO2 emissions (kt)	WDI	(−)
GFCF	gross fixed capital formation taken as Gross fixed capital formation (constant 2015 US$)	WDI	(−)
GN	income disparity taken as GINI coefficient	OECD Statistics	(−)
INN	Technological innovation taken as Share of environment-related patent applications in the total number of patents from 2000 to 2017 (in %).	OECD	(−)
GDP	Economic Growth taken as GDP (current US$)	WDI	(+)

Source: Author's Construction

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