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Balancing Growth and Sustainability: The Role of Fossil and Renewable Energy in BRICS Economies

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ABSTRACT

This study investigates the relationships between fossil fuel availability, access to renewable energy, economic growth, and CO_2 emissions in BRICS countries over the period 1990–2019. Employing FMOLS, DOLS, and Method of Moments Quantile Regression, the analysis reveals that fossil fuel availability and renewable energy access both exhibit a significant negative impact on economic growth in FMOLS and DOLS estimations, suggesting a limited role in driving growth in these countries. However, fossil fuels significantly increase CO_2 emissions, while renewable energy access significantly reduces emissions, highlighting their contrasting environmental effects. The quantile regression results further show that fossil fuel availability consistently hinders economic growth across all quantiles but raises CO_2 emissions, whereas renewable energy positively influences economic growth and lowers emissions throughout all quantile levels. These findings underscore the complex interplay between energy sources, economic development, and environmental sustainability, offering important policy implications for promoting balanced growth and emission reductions in the BRICS economies.

Keywords: The Fossil Abundance Energy, Renewable Abundance Energy, Method of Moments Quantile Regression, BRICS
JEL Classifications: Q43, Q56, C23

1. INTRODUCTION

Energy plays a crucial role in driving the global economy and fostering economic expansion. However, the heavy reliance on fossil fuels has had detrimental consequences on the environment and climate. The significant increase in carbon dioxide (CO_2) emissions caused by fossil fuel consumption remains a primary contributor to global warming. As a result, safeguarding the environment has become a top priority, necessitating responsible actions from both consumers and companies. Environmental management emerges as a strategic tool available to companies, offering effective measures to mitigate the impacts of climate change. Immediate efforts and decisive actions are required to combat climate change and counter the adverse effects of global warming (Adebayo et al., 2022; Rjoub et al., 2021). Among the recommended policies, minimizing the utilization of fossil fuels stands as a crucial step in addressing climate change, given their significant role as contributors to this pressing global issue.

As an illustration, over 80% of the world's total primary energy consumption contributes to approximately 75% of greenhouse gas (GHG) emissions. Nevertheless, this challenge can be addressed by transitioning to cleaner energy alternatives such as biomass, solar energy, and wind energy. Numerous researchers (Adebayo and Akinsola, 2021; Güngör et al., 2021) have demonstrated that adopting renewable energy sources can effectively mitigate the risks of environmental degradation by curbing GHG emissions while simultaneously promoting economic expansion.

The BRICS countries, namely Brazil, Russia, India, China, and South Africa, exhibit remarkable growth trends. According to Awosusi et al. (2022), their combined GDP reached approximately 18.82 trillion in 2017, representing around 23.31% of the global GDP. Over the years, the carbon emissions in these countries have seen a notable increase, rising from 27.35% of the world's total in 2001 to 41.3% in 2016. Additionally, they account for more than 40% of global energy consumption and contribute to 21% of the global GDP, as highlighted by He et al. (2020).

The rapid economic expansion within the BRICS countries has resulted in a substantial demand for energy to meet their growing needs. As these economies integrate, they collectively contribute to the global increase in greenhouse gas emissions. China, in particular, holds significant weight, representing 16% of the world GDP and 29% of global emissions. The country's economic progress has led to a surge in emissions, mainly due to its heavy reliance on coal, which constitutes 68% of its total primary energy supply, with fossil resources accounting for 89% in total, including 16% from oil and 5% from gas (Statista, 2021).

Similarly, India has witnessed a noteworthy increase in its share of world GDP, reaching 6% in 2016, and a 1.6-fold rise in its emissions share, accounting for 5% of global emissions. It is vital to acknowledge that the consumption of fossil energy in the BRICS countries has given rise to various environmental challenges. To ensure a healthy and sustainable environmental quality, these nations should not only focus on reducing their consumption of non-renewable energy in both production and consumption activities but also emphasize the adoption of energy-saving technologies. Restructuring and addressing political issues that might hinder rapid responses and sustainable development policies are also crucial (Akadiri and Adebayo, 2021; Dingru et al., 2021). Achieving these objectives will be instrumental in paving the way towards a more environmentally responsible and sustainable future for the BRICS countries.

China, as a conscientious advocate of international climate governance, has taken significant strides by presenting its Global Development Initiative to expedite the United Nations Agenda 2030 for Sustainable Development. Notably, climate change and green development have been identified as one of the eight key priority areas of cooperation. Moreover, China is committed to bolstering its assistance to developing countries in the realm of green energies. This concerted effort showcases China's dedication to actively address environmental challenges and foster sustainable development on a global scale.

Brazil has demonstrated its increased determination in reducing emissions by adopting a new target to cut greenhouse gas emissions by 50% in 2030 compared to 2005 levels. Additionally, the country has committed to eradicating illegal deforestation by 2028, along with a significant initiative to restore and cultivate 18 million hectares of forests by 2030. Furthermore, Brazil has launched a national program focused on reducing methane emissions.

Russia, on the other hand, is dedicated to achieving carbon neutrality by 2060. This ambition is reinforced by its efforts to implement substantial industrial and energy sector restructuring. The nation plans to promote the use of associated gas and has introduced a comprehensive program dedicated to ecological modernization and energy efficiency across all sectors. Additionally, Russia is investing in infrastructure for hydrogen production, intending to use it as a raw material and a key energy vector.

Meanwhile, India has unveiled its plans to reduce carbon intensity by 45%in 2030, demonstrating its commitment to addressing climate change. The country also aims to achieve carbon neutrality by 2070, signaling its long-term dedication to sustainable development and mitigating environmental impacts. These initiatives underscore the growing global effort among nations to combat climate change and transition towards a more sustainable and greener future.

In addition, they have initiated a groundbreaking project aimed at producing hydrogen from renewable energy sources, providing eco-friendly alternatives to fossil fuels. Furthermore, the afforestation coverage rate has been bolstered, reaching 24.62%.

Similar to its fellow BRICS nations, South Africa has taken significant strides towards a sustainable future with the implementation of a comprehensive long-term green growth strategy. Notably, the country has pledged to peak emissions a decade ahead of schedule and is actively developing detailed plans to facilitate a just transition towards a low-carbon economy and a climate-resilient society.

As part of their collective efforts, the BRICS countries will engage in information exchange across multiple levels, focusing on areas such as clean energy, low-carbon technologies, sustainable and resilient infrastructure development, carbon markets, and climate change adaptation. Collaborative endeavors will also encompass policy research on green growth, technology cooperation, and pilot projects. By advancing the transition and upgrading of energy, resource, industrial, and consumption structures, these nations are determined to foster a greener and more sustainable future for all.

Maintaining a delicate equilibrium between harnessing the potential of fossil energy for economic expansion and effectively curbing CO_2 emissions stands as a top priority for countries worldwide, with a particular focus on the BRICS nations.

The significance of energy abundance has garnered considerable attention from researchers in various fields. Existing studies predominantly focus on exploring the overall impact of energy abundance on economic expansion and CO_2 emissions, often overlooking the distinct roles played by fossil energy and renewable energy, which can yield diverse effects on economic expansion. Prolonged and excessive reliance on fossil energy has the potential to hinder sustainable economic expansion, whereas the adoption of renewable energy sources can contribute to a more sustainable, low-carbon economic trajectory. Notably, Bekun et al. (2019) have demonstrated that conventional models like the panel data model and distributed lag regression model can only estimate the medium-term impact of energy abundance on economic expansion and CO_2 emissions.

The BRICS countries exhibit heterogeneity in their economic expansion and CO_2 emission patterns, underscoring the diverse impact of energy abundance on these aspects. Moreover, significant regional disparities further contribute to the complex relationship between energy abundance, economic expansion, and CO_2 emissions. As the subject of energy abundance continues to garner interest, it is essential to delve deeper into these regional differences to better understand the intricate dynamics at play.

This article offers two notable advantages. Firstly, it carefully dissects the energy abundance in the BRICS countries, distinguishing between availability of fossil fuels and access to renewable energy sources, while thoroughly examining their respective impacts on economic expansion and CO_2 emissions. This comprehensive analysis can provide valuable support and insights to governments aiming to promote the robust development of renewable energy sources.

Secondly, the article employs the quantile regression of moments method to study the effects of these two types of energy abundance on economic expansion and CO_2 emissions. By using quantile regression models, the study can accurately assess the impact of energy abundance on dependent variables at ten different quantile points, thereby gaining a deeper understanding of how economic expansion and CO_2 emissions respond to changes in energy abundance. This nuanced approach enhances the precision and depth of the research findings, contributing to a more comprehensive and nuanced understanding of the relationship between energy abundance and its implications for these countries.

This article follows a well-structured organization, divided into several sections. The second section offers an insightful review of the relevant literature pertaining to the subject matter. In the third part, the article presents the data used and outlines the econometric model's specifications. Moving forward, the fourth section delves into the empirical findings derived from the analysis. Finally, the fifth part of the article concludes with a comprehensive summary of the results and highlights the policy implications drawn from the study.

2. LITERATURE REVIEW

The relationship between energy abundance, both fossil and renewable, and economic expansion as well as environmental impact has been extensively studied with often contrasting results depending on the regional and economic context. Several studies have identified a negative impact of fossil fuel abundance on economic growth. For instance, Wang et al. (2019), Inal et al. (2022), and Liu et al. (2021) showed that in China and African oil-producing countries, the availability of fossil fuels tends to hinder economic expansion. On the other hand, other research highlights a positive effect of fossil fuel abundance on economic development. Rahman et al. (2020) and Dong et al. (2019) provide evidence of fossil energy promoting employment and economic growth in China and various regions. Similarly, Sinaga et al. (2019) found a positive correlation between natural gas extraction and growth in Indonesia, and Okorie and Manu (2016) reported a beneficial relationship between electric power generation and economic expansion in Nigeria. Studies on the MENA and OPEC regions (Matallah, 2020; Yuzbashkandi and Sadi, 2020) also indicate that oil extraction and exports significantly contribute to economic growth. More recent findings suggest that in Gulf Cooperation Council countries, high energy intensity and CO_2 emissions may actually hinder growth, highlighting the environmental costs of fossil fuel dependence (Al Malki and Selim, 2024). In OECD economies, fossil fuel efficiency and green finance have also been found to moderate the growth–energy nexus, making development more sustainable (Ullah et al., 2024). These divergent findings underscore the complex and context-dependent nature of the link between fossil fuel abundance and economic expansion.

Regarding environmental impacts, most literature agrees that fossil fuel abundance significantly increases CO_2 emissions. Akhmetov (2015), Yan et al. (2016), and Chen et al. (2018) demonstrate a strong causal link between fossil fuel use and rising carbon emissions in Kazakhstan and other countries. Research by Wu et al. (2017), Balsalobre-Lorente et al. (2019b), and Kwakwa et al. (2018) further confirms that natural resource exploitation drives higher CO_2 emissions in the EU, Ghana, and other regions. However, some studies provide mixed or diminishing effects of fossil fuel abundance on emissions. Nathaniel et al. (2020) suggest that fossil fuels' impact on CO_2 emissions may be decreasing, while Danish et al. (2019) show varying effects within BRICS countries, where fossil fuels decrease emissions in Russia but increase them in South Africa. Liu et al. (2021) also report a negative relationship between fossil fuel abundance and emissions, emphasizing the complexity of these interactions. At a global scale, Al Mamun and Ehsanullah (2025) further highlight that, despite international agreements such as the Paris Accord, energy consumption continues to exert upward pressure on CO_2 emissions in middle-income economies.

In contrast, the abundance of renewable energy is generally linked to positive economic outcomes. Gozgor et al. (2018), Sohag et al. (2019), and Piłatowska et al. (2020) all found that renewable energy fosters economic growth in OECD countries and beyond. Studies on African countries (Maji and Sulaiman, 2019; Zallé, 2019), G7 nations (Cai et al., 2018), and emerging markets (Destek, 2016; Paramati et al., 2018) further confirm the beneficial role of renewables. Specific analyses of China and India reveal nuanced relationships, with Ummalla and Samal (2019) finding causality from renewables to growth in India but not China, while Danish et al. (2019) report bidirectional causality in BRICS. Nevertheless, some research challenges this view, indicating weak or negative effects of renewables on growth in developing countries (Liu et al., 2020; de Bayar and Gavriletea, 2019; Polat, 2018), with Paramati et al. (2017) extending these findings to G20 and Next-11 countries. Ali et al. (2020) introduce political context as a key moderator, showing that renewables boost growth in countries with free political systems but may hinder it in unfree regimes. Recent evidence from Aouini et al. (2023) also suggests that renewable deployment substantially reduces pollution and strengthens the sustainability of growth, especially when advanced econometric methods are employed.

Renewable energy abundance is also largely associated with reductions in CO_2 emissions. Ummalla and Goyari (2020) documented significant decreases in emissions in BRICS countries, while Altinoz and Dogan (2021) confirmed this negative effect of renewables on carbon emissions across 82 countries. Country-level studies in Turkey (Altarhouni et al., 2021; Qashou et al., 2022) and cross-country analyses (Dong et al., 2020; Razmjoo et al., 2020) support the important role of renewables in mitigating environmental degradation. However, some studies report opposing results, with Dong et al. (2018) and Aziz et al. (2021) finding increased emissions linked to renewable consumption in MINT countries. Jebli and Kahia (2020), Saidi and Omri (2020), Cai et al. (2018), and Baloch et al. (2019) also highlight country-specific variability and short-term dynamics, underscoring the complexity of renewables' environmental impacts and the need for context-sensitive policies. Additional insights from the MENA region further indicate that renewable energy, when combined with economic diversification, plays a crucial role in curbing emissions (Kalyoncu and Kalyoncu, 2023).

3. MODEL SPECIFICATION AND DATA

3.1. Model Specification

Model 1: economic expansion model

Based on the empirical models proposed by Liu et al. (2021), Bui et al. (2021), and Aydin (2019), we formulate our own empirical model as follows:

In our model, the variables are denoted as follows: GDP signifies economic expansion, FEA represents availability of fossil fuels, and REA denotes access to renewable energy sources.

Equation (1) is formulated as follows:

$$GDP_{it} = f(FEA_{it}, REA_{it}) \tag{1}$$

In our model, the variables are denoted as follows: GDP signifies economic growth, FEA represents fossil energy abundance, and REA denotes renewable energy abundance.

Equation (1) is formulated as follows:

$$GDP_{it} = FEA_{it}^{\beta_1} REA_{it}^{\beta_2} e^{\varepsilon_{it}} \tag{2}$$

all the data is transformed into its natural logarithm. Consequently, the model (2) can be expressed in log-linear form as follows:

$$LGDP_{it} = \beta_0 + \beta_1 FEA_{it} + \beta_2 REA_{it} + \varepsilon_{it} \tag{3}$$

Equation (3) comprises several components, with β_0 representing the constant term, while β_1 and β_2 symbolize the parameters that require estimation. The error term is denoted as ε_{it}. In this equation, countries are indicated by the variable "i," and periods are identified by the variable "t."

Model 2: CO_2 emission model

Drawing from relevant literature (Liu et al., 2021; Zuo et al., 2021; Danish, 2019), we formulate our model as follows:

$$CO_{2it} = f(FEA_{it},) \tag{4}$$

The variable CO_2 signifies CO_2 emissions, while FEA and REA are defined as per Equation (1). To maintain consistency and facilitate analysis, all data is subjected to natural logarithm transformation, resulting in the following model:

$$LCO_{2it} = \beta_0 + \beta_1 LFEA_{it} + \beta_2 LREA_{it} + \varepsilon_{it} \tag{5}$$

3.2. Data Description

Our article aims to analyze the influence of availability of fossil fuels and access to renewable energy sources on economic expansion and carbon dioxide (CO_2) emissions in the BRIC countries during the period 2000-2019. For The present research, economic expansion is represented by GDP per capita (constant 2010 US Dollar), while availability of fossil fuels is denoted by FEA. To measure FEA, we employ the consumption of coal, oil, and natural gas as proxies. Renewable energy consumption, denoted as REA, is measured by the share of renewable energy in total final energy consumption. CO_2 emissions per capita serve as an indicator of environmental pollution.

The data for all variables were sourced primarily from the World Bank database (World Bank, 2020), with the exception of CO_2 emissions, which were obtained from the BP statistical review (BP, 2020). This comprehensive dataset enables us to examine the intricate relationships between energy abundance, economic expansion, and environmental impact across the BRIC countries during the specified timeframe.

Table 1 displays the definitions of the variables utilized in the present research, while Table 2 presents the statistical description of all the economic variables.

The descriptive statistics reveal significant heterogeneity in the data, emphasizing the need for employing the panel quantile

Table 1: Definition of variables

Variable	Abbreviation	Explanation	Data source
Economic growth	GDP	GDP per capita (constant 2010$)	World Development Indicators
Carbon dioxide emissions	CO_2	Metric tons	British Petroleum database
Fossil energy abundance	FEA	Consumption of coal, oil, and natural gas	World Development Indicators
Renewable energy abundance	REA	Share of renewable energy in total final energy consumption	World Development Indicators

Table 2: Statistical description of economic variables

Statistic/ Variable	LFEA	LREA	LGDP	LCO_2
Mean	1.829820	2.880156	8.435370	12.36887
Median	2.897708	3.421926	8.852974	12.72715
Maximum	3.489400	3.948519	9.382252	13.11934
Minimum	−1.021146	1.157038	6.630246	10.83289
Std. Dev.	1.679295	1.065273	0.887685	0.832420

regression method to obtain reliable and robust empirical results (Table 2).

4. THE ECONOMETRIC METHOD

4.1. Cross-sectional Dependence Test

Given that our study focuses on countries with similar economic characteristics, there exists a relationship between the cross-sectional units in the panel data models. Neglecting these relationships may lead to misleading results; therefore, we conducted cross-sectional dependency tests as a preliminary step. Furthermore, we employed the classic statistic proposed by Breusch and Pagan (1980) to address this issue.

The formula for the CD statistic is as follows:

$$CD_{BP} = \sqrt{\frac{1}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\hat{\rho}_{ij}^{2}-1\right)\right)} \tag{6}$$

This statistic is calculated as the sum of various correlations between the residuals of each section. The term preceding the summation of correlations serves as a standardization factor. In the asymptotic case of N, this statistic follows a standard normal distribution (N(0,1)). As a result, when the absolute value of the CD statistic is notably large, the null hypothesis of independence is rejected. At a 95% confidence level, we reject the null hypothesis for absolute values exceeding 1.96.

An advantage highlighted by Pesaran (2004) is that this statistic does not rely on a priori assumptions about a spatial dependence matrix (weight matrix). In certain situations, when relevant information is available, assumptions about time and/or space dependence between observations can be made. For instance, if individuals represent subjects sampled from different locations, spatial correlation may be present. In such cases, a weight matrix can be utilized in modeling the residuals. However, Pesaran (2004) seeks to establish a method that is independent of this spatial dependence and does not require such a priori assumptions.

4.2. Panel Unit Root Test

Panel techniques rely on a fundamental assumption: the stationarity of the various variables. Failing to consider this condition may lead to the problem of dummy regression in panels. The first panel unit root test was introduced by Levin and Lin (1992) and further refined through the contributions of Levin et al. (2002). Taking inspiration from the temporal root tests of Dickey and Fuller (1979), the Levin, Lin, and Chu (LLC) test (2002) incorporates the Dickey and Fuller Augmented ADF test into a panel context. The general model is expressed as follows:

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{it-1} + \sum_{j=1}^{pi}\rho_{ij}\Delta y_{i,t-j} + e_{it} \qquad i = 1,\ldots\ldots N \quad et\, t = 1,\ldots\ldots T \tag{7}$$

4.3. Panel Cointegration Test

To avoid encountering a spurious regression, it is crucial to determine the presence or absence of a long-term relationship between non-stationary variables through cointegration tests. The most commonly employed cointegration tests in panel contexts are the tests developed by Pedroni (2004) and Kao (1999). These tests are residual-based, drawing inspiration from the tests proposed by Engle and Granger (1987) in the context of time series. The execution of cointegration tests involves estimating the long-term relationship expressed as follows:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{M}\beta_{i,t}^{k}x_{i,t}^{k} + \varepsilon_{i,t} \tag{8}$$

Pedroni (2004) introduced a range of tests designed to explore cointegration relationships while considering the heterogeneity among individuals. In this context, each country exhibits a distinct cointegration relationship with parameters that vary based on the composition of the panel.

4.4. Panel Longrun Estimation

After establishing the existence of a cointegration link among the variables mentioned earlier, it becomes essential to estimate this long-term relationship using an appropriate technique for non-stationary dynamic panels. The literature commonly suggests two main estimators when cointegration is present: the Fully Modified Ordinary Least Square (FMOLS) proposed by Pedroni (2000) and the Dynamic Ordinary Least Square (DOLS) proposed by Kao and Chiang (2001). These estimators aim to correct the standard OLS estimator, which faces two common issues in long-term relationships: series correlation and regressor endogeneity. A comparative analysis of various OLS estimators conducted by Chen et al. (1999) revealed that the alternative estimators FMOLS and DOLS outperform the OLS estimator when estimating cointegrated panels.

The specifications of these estimators are provided below:

$$\beta^{FMOLS} = \left[N^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T}\left(p^{it}-\bar{p}^{i}\right)^{2}\right]^{-1} \times \left[\sum_{t=1}^{T}\left(p_{it}-\bar{p}_{i}\right)S_{it} - T\Delta_{\varepsilon u}\right] \tag{9}$$

$$\beta_{DOLS} = \left[N^{-1}\sum_{i=1}^{N}\left\{\sum_{t=1}^{T}Z_{it}Z'_{it}\right\}^{-1}\left\{\sum_{t=1}^{T}Z_{it}\right\}\right] \tag{10}$$

The extensive literature on quantile regressions offers various approaches. For our study, we adopt the estimator introduced by Machado and Silva (2019), which constitutes a scale and location function estimation model. This approach presents a significant advantage as it enables the utilization of methods typically restricted to estimating conditional means, such as differentiating individual effects in panel data models, while also providing valuable insights into how the regressors impact the entire conditional distribution. Our chosen estimator allows for the control of country-specific heterogeneity.

The proposed estimator by Machado and Silva (2019) takes the form of the following equation:

$$y_{it} = \gamma_i + X_{it}'\delta + \lfloor \lceil \mu_i(\tau) + Z_{it}'w(\tau) \rceil \rfloor \square_{it} \quad (11)$$

5. RESULTS AND DISCUSSIONS

5.1. Cross-sectional Dependence and Panel Unit Root Test Results

Table 3 displays the outcomes of the CD tests. Based on both the CD and CD_{BP} tests, the null hypothesis of no cross-sectional dependence is rejected. Consequently, it is evident that there exists a transversal dependence among the variables under investigation.

The Im, Pesaran and Shin (IPS) unit root test was conducted to examine the stationarity properties of the panel data variables. The results are presented in the Table 4. At levels, all variables fail to reject the null hypothesis of a unit root, indicating that they are non-stationary. However, after first differencing, all variables become stationary at the 1% or 5% significance levels, as indicated by the W-statistics and corresponding significance marks (* and **). Thus, all variables are integrated of order one, i.e., I(1), and are suitable for further analysis such as cointegration testing and long-run estimation.

Table 3: Cross-sectional dependency test results

Variables	CD	CD_{BP}
LGDP	97.61252*	9.870638*
LFEA	58.38063*	3.282722*
LFEA	58.38063*	3.282722*
LCO_2	76.28285*	3.262261*

Table 4: Unit root test

Variables	Level	First differences
LGDP	0.05575	1.83895*
LTP	0.99913	3.73134*
LCI	0.58696	4.01221**
LLI	1.92913	0.49181*
LEA	1.32858	1.38650**
LIN	1.27684	4.86482**
LREA	0.57789	5.28543*
LCO_2	2.05246	2.73441**
LPOP	0.14440	1.20352*

5.2. Panel Cointegration

To examine the long-run equilibrium relationship between energy variables and economic outcomes, we employed the Westerlund panel cointegration test using both within-dimension (panel statistics) and between-dimension (group statistics) approaches. The results are presented separately for economic growth and CO_2 emissions as the dependent variables (Table 5).

For economic growth, the majority of the test statistics (Panel v-Stat, Panel rho-Stat, Panel PP-Stat, Panel ADF-Stat, and all group statistics) are statistically significant at the 1% level, indicating the existence of a long-run cointegrating relationship among the variables. This implies that fossil and renewable energy variables, along with other controls, move together with economic growth in the long run.

Regarding CO_2 emissions, the panel v-Stat and group statistics (Group rho-Stat and Group PP-Stat) are also significant at the 1% level, confirming the presence of cointegration among the variables. These results provide strong support for a stable long-term relationship between energy variables and environmental outcomes in BRICS countries.

The Westerlund panel cointegration test was applied to examine the long-run equilibrium relationship between the variables. The results are presented separately for the dependent variables: economic growth and CO_2 emissions, under both the within-dimension (common AR coefficients) and between-dimension (individual AR coefficients) frameworks.

5.2.1. Result of FMOLS and DOLS for economic expansion

The results depicted in Table 6 demonstrate a significant and negative impact of the FEA and REA variables on the economic expansion of the BRIC countries. Specifically, a 1% increase in the FEA variable leads to a decline in economic expansion by 0.508% (FMOLS) and 0.64% (DOLS). Similarly, a 1% increase in REA results in a reduction of economic expansion by 0.659% (FMOLS) and 0.415% (DOLS). These findings align with the research conducted by Bayar and Gavriletea (2019), who also established the negative effect of the REA variable on the economic expansion of emerging countries. Maji and Sulaiman (2019) have similarly

Table 5: Pedroni panel cointegration test

Test	Statistic	Probability	Group statistic	Group probability
Panel v-Stat	0.607086*	(0.0000)	Group rho-Stat	3.040998* (0.0000)
Panel rho-Stat	2.150759	(0.9843)	Group PP-Stat	1.175371* (0.0000)
Panel PP-Stat	−1.147543*	(0.0000)	Group ADF-Stat	1.700569* (0.0000)
Panel ADF-Stat	−2.102538*	(0.0000)		
Panel v-Stat	−0.728866	(0.0000)	Group rho-Stat	3.057340* (0.0000)
Panel rho-Stat	2.197131	(0.9978)	Group PP-Stat	1.238818 (0.3767)
Panel PP-Stat	1.191923*	(0.0000)	Group ADF-Stat	−0.493648* (0.0000)
Panel ADF-Stat	0.360667	(0.0000)		

(*) indicates significance at the 1% level. Compilation: Authors asserted the negative impact of REA on the economic expansion of African countries. Moreover, Akram et al. (2021) and Umella and Goyari (2020) have found that REA has a negative effect on the economic expansion of BRICS countries. Additionally, Aziz et al. (2021) concluded that REA does not contribute significantly to the economic expansion of MINT countries.

The long-term estimations for CO_2 emissions reveal interesting findings. A 1% increase in FEA leads to a 0.26% and 0.40% rise in CO_2 emissions, as per FMOLS and DOLS models, respectively. Conversely, REA demonstrates a CO_2 reduction of 0.37% and 0.56% in FMOLS and DOLS, respectively. These results indicate that FEA has a positive and significant impact on CO_2 emissions, while REA exerts a negative and significant influence on CO_2. These outcomes align with previous empirical studies conducted by Zafar et al. (2019), Anwar et al. (2021), Aziz et al. (2021), and Baskaya et al. (2022). The transition to clean and renewable energy sources is crucial for mitigating carbon emissions and fostering economic expansion. Our findings corroborate the idea that environmental sustainability relies on the adoption of clean and renewable energy in consumption and production practices. As evident from the results, the BRICS countries' significant reliance on conventional coal-based energy contributes to higher CO_2 output. To tackle this challenge, subsidizing renewable energy and imposing taxes on fossil fuels should be considered as effective measures to mitigate emissions and promote sustainable environmental practices in the BRICS countries.

5.2.2. Quantile regression results of economic expansion

Table 7 presents the results of the quantile regression of economic expansion. Interestingly, all the coefficients of FEA are negative, indicating that the production and consumption of fossil energy do not contribute to economic expansion. On the contrary, the regression coefficients of the abundance of renewable energies in all quantile provinces are positive, signifying that the current production of renewable energy has played a crucial role in promoting economic expansion.

Table 4: Result of FMOLS and DOLS

FMLOS				DOLS
	Explained variable: economic growth			
Variables	Coefficient	Probabilty	Coefficient	Probability
LFEA	-0.508060**	0.0031	-0.640305*	0.0139
LREA	-0.659975*	0.0240	-0.451506**	0.0022
	Explained variable:CO2 emissions			
Variables	Coefficient	Probability	Coefficient	Probability
LFEA	0.267592**	0.0004	0.404675**	0.0001
LREA	-0.377591**	0.0031	-0.564018**	0.0002

note: *, **, means significance of the tested variables at 5%, 1% levels, respectively

These findings align with previous research by Umella and Goyari (2020) for the BRICS countries, Liu et al. (2021) for China, Ali et al. (2018) for ASEAN countries, and Bilgili and Ozturk (2015) for G7 countries. However, they diverge from the conclusions of Aydin (2019) for BRICS countries and the results of Destek (2017) for Finland, India, Japan, the United Kingdom, and the United States. These contrasting outcomes highlight the nuanced relationship between energy sources and economic expansion, emphasizing the importance of considering various factors specific to each country when analyzing the impact of energy abundance on economic performance.

Based on the findings, it can be deduced that the impact of renewable energy production and consumption on economic growth exhibits a gradual increase from low quantile levels to high quantile levels. In high-income countries such as China, the contribution of renewable energy consumption to economic expansion is more pronounced. This could be attributed to technological advancements and improved labor efficiency, making the production of renewable energy economically more efficient compared to fossil energy production and consumption. The results suggest that as countries progress economically, the adoption of renewable energy sources becomes increasingly beneficial for fostering sustainable and robust economic expansion.

The results obtained from the quantile regression of CO_2 emissions, as shown in Table 7, reveal interesting patterns. The regression coefficients associated with the abundance of fossil energy are consistently positive across all quantile levels, indicating a positive relationship between availability of fossil fuels and CO_2 emissions. At the lower quantiles, this effect appears to be relatively weaker, aligning with previous findings by Balsalobre-Lorente et al. (2018) and Shahabadi and Feyzi (2020). This suggests that in countries with lower pollution levels, the impact of fossil fuel abundance on CO_2 emissions is not as significant due to a relatively low coefficient. However, the relationship gains strength at the middle and upper quantile levels, as observed in the study by Bekun, Alola, and Sarkodie (2019). In these countries with medium to high pollution levels, the prevalence of primary resource consumption driven by industrialization and increased reliance on fossil fuels plays a substantial role in escalating CO_2 emissions. This highlights the importance of addressing the increasing fossil energy extraction activities in these nations to effectively curb CO_2 emissions.

The findings from the quantile regression analysis demonstrate the consistent and significant impact of renewable energy consumption on reducing CO_2 emissions across all quantile levels. These results

Table 7: Quantile regression result

Variables	Quantile								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Quantile regression results of economic growth									
LFEA	−1.226**	−1.18**	−1.15**	−2.23**	−2.37*	−2.18**	−1.78**	−1.54*	−1.71**
LREA	1.07**	1.09**	1.13**	2.24**	2.57**	3.15**	3.19**	3.42**	3.47**
Quantile regression results of CO_2 emissions									
LFEA	1.12*	1.11**	1.12*	1.23**	1.28*	1.38*	1.53**	1.73**	2.25**
LREA	−1.02**	−1.02**	−1.031**	−1.187**	−1.279**	−1.432**	−1.709**	−2.054**	−2.10**

align with the studies conducted by Anwar et al. (2021) for ASEAN countries, Baskaya et al. (2022) for BRICS countries, Aziz et al. (2021) for MINT countries, and Qamruzzam (2022) for Russia and India. Moreover, the analysis reveals that the emission reduction effect of renewable energy becomes more pronounced as we move up the quantile levels. This indicates that the contribution of renewable energy consumption in mitigating CO_2 emissions increases with the level of pollution in a country. Countries with lower pollution levels experience a comparatively smaller emission reduction effect from renewable energy consumption, while those with higher pollution levels benefit significantly from the reduction of emissions. Consequently, increasing the share of renewable energy sources in a country's energy mix leads to substantial improvements in environmental quality, emphasizing the vital role of transitioning to renewable energy to combat climate change and foster sustainable development.

From a political perspective, it becomes imperative to establish a conducive policy framework that incentivizes the utilization and advancement of renewable energies, while also attracting increased investments in this sector. Encouraging active participation of private investors in the expansive domain of renewable energy is crucial. Promoting public-private partnerships and addressing barriers to investment in renewable energy are essential steps in this direction.

The achievement of sustainable development objectives necessitates a continued shift towards renewable energies, leading to a surge in investments within this sector. Consequently, this transition will play a pivotal role in promoting economic expansion and reducing CO_2 emissions.

6. CONCLUSION AND POLICY IMPLICATIONS

The present research focuses on investigating the impact of availability of fossil fuels and renewable energy abundance on economic expansion and CO_2 emissions in the BRICS countries. Specifically, the aim is to understand how the variables FEA and REA influence GDP and CO_2 emissions in these countries using a novel approach called method of moments quantile regression (MMQR). The analysis covers the period from 1990 to 2019, providing insights into the relationship between energy abundance, economic expansion, and environmental sustainability in the BRICS nations. By employing MMQR, this research seeks to offer a comprehensive understanding of the varying effects of energy abundance across different quantile levels, shedding light on the nuances of this relationship and its implications for policy and sustainable development.

The present research adopts a comprehensive approach by applying various panel sensitive and preliminary tests to describe the dataset and ensure the reliability of the analysis. The results of the Cross-sectional dependence (CD) tests indicate the presence of cross-sectional dependence in the studied variables, while the unit root tests confirm that all series are stationary at first differences, signifying an integrated of the first order I(1) nature. Furthermore, the application of Pedroni's panel cointegration tests supports the existence of long-term relationships between availability of fossil fuels, access to renewable energy sources, economic expansion, and CO_2 emissions. These empirical findings shed light on the interconnectedness between energy abundance and key economic and environmental indicators, providing valuable insights for policymakers and researchers. The robustness of the results is further confirmed through several panel estimation techniques, ensuring the reliability of the conclusions drawn from The present research.

The empirical findings from the FMOLS and DOLS methods concerning economic expansion reveal that a 1% increase in FEA leads to a decrease in economic expansion by 0.508% (FMOLS) and 0.64% (DOLS), while a 1% increase in REA results in a decrease in economic expansion by 0.659% (FMOLS) and 0.415% (DOLS). On the other hand, the results obtained from the FMOLS and DOLS for CO_2 emissions indicate a significant positive impact of FEA on CO_2, while REA has a negative impact on CO_2. These outcomes highlight the contrasting effects of availability of fossil fuels and access to renewable energy sources on economic expansion and CO_2 emissions in the BRIC countries, emphasizing the importance of considering both factors in formulating sustainable energy and environmental policies.

The long-term estimates for CO_2 emissions show that a 1% increase in FEA leads to a rise in CO_2 emissions by 0.26% and 0.40% in the FMOLS and DOLS models, respectively. Conversely, REA contributes to a reduction in CO_2 emissions by 0.37% and 0.56% in the FMOLS and DOLS models, respectively. These results indicate that availability of fossil fuels positively affects CO_2 emissions, while access to renewable energy sources plays a crucial role in mitigating and reducing CO_2 emissions in the BRICS countries. Such findings underscore the significance of transitioning towards renewable energy sources to combat climate change and foster sustainable development.

In the quantile regression analysis of economic expansion, the coefficients of FEA are consistently negative, suggesting that the production and consumption of fossil energy do not contribute to economic expansion. On the other hand, the coefficients of access to renewable energy sources are positive across all quantile levels, indicating that the current production of renewable energy has played a significant role in fostering economic growth. These results emphasize the importance of transitioning towards renewable energy sources to promote sustainable economic development in the BRIC countries.

The results of the quantile regression analysis for CO_2 emissions are presented in Table 7. The coefficients of availability of fossil fuels in all quantile levels are found to be positive, while the coefficients of access to renewable energy sources are negative across all quantile provinces.

Based on these findings, our study proposes several policy directions for the BRICS countries. To address the challenges posed by increasing demand for fossil fuels and mitigate CO_2 emissions, the BRICS countries should prioritize the transition to renewable energies. Renewable energy sources offer significant potential to achieve a balanced approach to social, economic, and environmental goals. Emphasizing the shift towards renewable energies would require increased investments in this sector, making it an attractive opportunity from both economic and social perspectives.

Furthermore, the adoption of renewable energy sources can play a vital role in reducing carbon emissions while supporting economic development in these countries. Increasing the utilization of renewable energy sources can lead to positive economic impacts, fostering sustainable and environmentally friendly economic expansion. By embracing renewable energies, the BRIC countries can move towards a greener and more sustainable future.

Hence, it becomes imperative for governments to implement comprehensive measures that encourage the widespread adoption of renewable energies. These measures could encompass initiatives aimed at fostering human and institutional capacities, establishing research and development infrastructures, and creating a conducive investment environment. Overcoming the financing challenges for renewable energy projects in African countries is particularly crucial in integrating them into the existing energy mix. The primary source of external financing in these economies is the banking sector, which can pose a disadvantage for renewable energy projects. Developing robust financial institutions is key to securing the necessary funding for these projects. Local governments should focus on enhancing their financing capabilities, with a vital step being the improvement of domestic financial markets to enhance domestic funding capacities. By taking these actions, governments can pave the way for a successful transition towards a renewable energy-driven future.

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