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Analyzing the Linkage among Economic Growth, Fossil Fuel Energy Consumption and CO_2 Emissions in BRICS. Application of Bootstrap ARDL Approach

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Abstract

Human-caused carbon emissions are primarily responsible for the increasing worldwide apprehension regarding environmental matters. Political leaders across the globe have vowed to resolve and mitigate the effects of these problems, prompting researchers to vigorously investigate their underlying causes. From 1990 to 2022, this study examines the complex interconnections among CO2 emissions, GDP growth, energy consumption, and crude prices in a group of BRICS nations. The results of the research underscore the existence of variability and cross-sectional dependence in the series being examined. As confirmed by the Westerlund-Edgerton panel bootstrap co-integration test, the variables have a long-term relationship. As per the PMG assessment, each individual element exerts a substantial and favorable influence on productivity. Moreover, a unidirectional causal relationship is identified between short-term production and the consumption of fossil fuels as an energy source. Unidirectional correlations have been observed over time between oil price, FF, and output (Y). Based on the results obtained, the research proposes the implementation of strategies that promote ecological change, including the utilization of biodiesel, hydropower, and biomass, as means to facilitate sustainable development. Moreover, because a number of BRICS nations are net importers of oil, global oil price stability is considered essential for their sustained economic prosperity.

Keywords: “Economic growth, Fossil fuel energy consumption, CO2 emissions, Oil price, Cross sectional dependence and homogeneity

1. Introduction

Energy, being an essential element of the labor and capital markets that facilitate worldwide economic expansion and progress, exerts a substantial influence on the trajectory of the global economy (Hassan et al., 2019). The availability of energy resources is of utmost importance for the industrialization and overall economic progress

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of both developed and developing nations, as it influences every facet of economic operation, ranging from production to consumption (Pao et al., 2010; Singh, 2019; Nosheen et al., 2021).

The economic development of a nation is profoundly influenced by its energy consumption (ENC) (Zahid et al., 2021). Engaging in cooperative efforts to meet the worldwide energy requirements underscores the differentiation between nonrenewable and renewable energy sources. Despite the environmental sustainability of renewable sources being acknowledged, non-renewable sources, which predominantly consist of polluting fossil fuels, continue to be indispensable for the ENC of the BRICS nations (Ummalla and Goyari, 2020). While it has been demonstrated that the utilization of fossil fuels can stimulate economic expansion in numerous nations, renewable energy presents environmental advantages but is initially unfeasible to implement (Zahid et al., 2021; Sasana and Ghozali, 2017).

The excessive consumption of coal, oil, and gas by the BRICS nations demonstrates their dependence on fossil fuels. The aforementioned dependence has led to a surge in the release of heat and greenhouse gases, which presents a significant peril to the well-being of organisms and the worldwide ecosystem (EPA, 2021). China is the largest consumer of coal and energy among the BRICS. Furthermore, it is the primary source of greenhouse gas emissions, underscoring the urgent requirement for sustainable energy alternatives (Nosheen et al., 2022). Despite increasing environmental concerns, the BRICS Energy Report (2020) predicts that fossil fuels will continue to be the predominant energy source until 2040. The excessive consumption of coal, oil, and gas by the BRICS nations demonstrates their dependence on fossil fuels. The aforementioned dependence has led to a surge in the release of heat and greenhouse gases, which presents a significant peril to the well-being of organisms and the worldwide ecosystem (EPA, 2021). China is the largest consumer of coal and energy among the BRICS. Furthermore, it is the primary source of greenhouse gas emissions, underscoring the urgent requirement for sustainable energy alternatives (Nosheen et al., 2022). Despite increasing environmental concerns, the BRICS Energy Report (2020) predicts that fossil fuels will continue to be the predominant energy source until 2040.

Rapid development and modernization in the BRICS economies will lead to a rise in ENC, which will require an escalation in energy imports. Nevertheless, this escalating pattern of energy usage presents two challenges: it could potentially lead to a surge in greenhouse gas emissions, thereby posing risks to the economic stability of the BRICS nations as well as the global environment (H Wu, Y Li, et al., 2020). At present, striking a balance between economic prosperity and environmental sustainability is of the utmost importance. In order to tackle these challenges, the BRICS economies are placing significant emphasis on the adoption of renewable energy sources. The remarkable proportion of renewable energy in the energy mixes of the BRICS nations—10% to over 30%, with India exceeding 30%—illustrates their commitment to this resource (Wu, H., Hao Yu et al., 2019). Moreover, these nations have ratified international environmental treaties, according to Zahid et al. (2021), with the intention of substantially reducing CO2 emissions by 2030. Conducting an examination of the complex interconnections among ENC, crude costs, carbon emissions, and economic expansion in the BRICS is of utmost importance from an economic and policy perspective (Hossain, 2011; Apergis and Payne, 2009). However, much contemporary research is restricted to analyses of a single nation and employs a small number of observations. Panel data studies are considered to be more dependable in addressing dependence and cross-sectional heterogeneity due to the greater number of observations they comprise (Wang et al., 2011; Arouri et al., 2012).

By constructing a time frame spanning from 1990 to 2022, this study intends to augment the existing corpus of knowledge. This study employs the bootstrap autoregressive distributed lag (ARDL) bound test to examine longitudinal cointegration connections. When compared to conventional time series or panel data analysis, the bootstrap ARDL bound test effectively handles deteriorating circumstances and provides policymakers with more accurate data.

2. Literature Review

Energy is essential for sustaining economic growth due to the fact that it powers industry and partially substitutes labor and capital inputs (Ozturk, 2010; Ito, 2017). The correlation between energy and economic growth is a multifaceted phenomenon that varies across nations (Alper and Oguz, 2016). While certain research studies (Ho & Siu, 2007; Lee and Chang, 2005; Karanfil, 2008) demonstrate a one-way correlation between economic expansion and ENC, others (Zhang and Cheng, 2009; Ang, 2008) establish a unidirectional causal relationship between energy and economic growth. Moreover, contrary to the findings of some studies (Ohler and Fetters, 2014; Polemis and Dagoumas, 2013), which suggest that economic growth and ENC are inversely related, others (Menyah and Wolde-Rufael, 2010; Payne, 2009) find no significant correlation between the two variables. While Nosheen, M., Iqbal, J., & Ahmad, S. (2023); Nosheen, M., Iqbal, J., & Khan, H. U. (2021); Nosheen, M., Iqbal, J., & Abbasi, M. A. (2021); Nosheen, M., Iqbal, J., & Hassan, S. A. (2019).

Numerous studies have examined the correlation between gross domestic product and ENC. The effects of renewable energy, natural gas, and nuclear energy on CO2 emissions and costs were examined by (Azam et al. in 2020; Nosheen, M., Iqbal, J., & Ahmad, S. 2023; Nosheen, M., Abbasi, M. A., & Iqbal, J. 2020 and Zafar, A., Majeed, M. T., Nosheen, M., & Iqbal, J. (2021); They emphasized the potential for nuclear and renewable energy to coexist in a manner that promotes economic growth and reduces carbon emissions. Abbas et al. (2020) emphasized the significance of renewable energy in Belt and Road countries for promoting environmentally sustainable conditions without impeding economic growth. The 2021 study by Magazzino et al. utilized machine learning techniques to predict forthcoming CO2 fluctuations in China, India, and the United States, with a particular focus on the contribution of renewable energy sources to the reduction of CO2 emissions.

Al-Mulali and Sab (2012) corroborated the results reported by Shahbaz and Lean (2012), wherein they identified an enduring correlation between ENC and economic progress. A study conducted by Heidari et al. (2015) encompassing five ASEAN countries revealed a nonlinear correlation between ENC and economic growth. A unidirectional, positive, and statistically significant correlation was established by Saidi and Hammami (2015) between ENC and economic development. A bidirectional and transient correlation was identified by Al-Mulali between ENC and economic development. Granger established sustained economic welfare growth (ISEW), as ENC was used as a proxy for GDP by

Menegaki and Tugcu (2016). Sbia et al. (2017) posit that an inverse U-shaped relationship exists between ENC and economic advancement.

Grossman and Krueger (1991) were pioneers in the modeling of the correlation that existed between economic development and environmental quality. A negative correlation was identified between environmental degradation and per capita GDP (Managi, 2006). The concept of an EKC has been supported by a number of studies that have examined the correlation between environmental contamination and economic growth, such as Markandya et al. (2006) and Song et al. (2008).

With varying degrees of success, numerous studies have been conducted on the correlation between CO2 emissions and economic development. The discovery of Govindaraju and Tang (2013) regarding a substantial unidirectional correlation between CO2 emissions and economic development was corroborated by Menyah and Wolde-Rufael (2010). Conversely, Ghosh (2010) identified a reciprocal relationship between India's economic growth and CO2 emissions over the short term. The bidirectional relationship between CO2 and economic growth was confirmed by Yang and Zhao (2014), who built upon the research conducted by Govindaraju and Tang (2013). By including urbanization, Farhani et al. (2014) enhanced the outcomes of their model for eleven Middle Eastern and North African (MENA) countries. Similar connections were discovered by Magazzino (2021), Chang (2010), Cai et al. (2018), and Heidari et al. (2015) between ENC, CO2 emissions, and economic development. Halicioglu (2009) and Pao and Tsai (2011) found that income exerted a more substantial influence on CO2 emissions in the contexts of Brazil and Turkey, respectively, as opposed to ENC. Lean and Smyth (2010) found that ENC and CO2 emissions significantly impacted the economic growth of ASEAN nations. Ozturk and Acaravci (2010) assert that Jafari et al. (2015) provided validation for the immediate and enduring impacts of carbon dioxide (CO2) on the economic expansion of Turkey. Pao and Tsai (2011) and Menyah and Wolde-Rufael (2010) provided evidence for a long-term unidirectional causal relationship between energy use, CO2 emissions, and economic development in South Africa. Many studies have explored the matter of environmental quality from both time series and panel perspectives, for example (Najibullah, Iqbal, J., & Nosheen, M. 2021 and Najibullah, Iqbal, J., Nosheen, M., Khan, M. W., Raja, E. U. H., & Jasim, M. (2021).

3. Methodology

3.1. Theoretical framework

The study employs the Solow growth model, a neoclassical approach, to examine the interconnections among oil price, output, carbon emissions, and ENC. The Cobb-Douglas production function, which can be expressed as follows, serves as its foundation.

$Q\ it = A_{it} b K_{it} c L_{it}$ (1)

An integral component of neoclassical growth models, the Solow growth model is utilized in this study to examine the relationships among oil price, carbon emissions, ENC, and production growth (Qit). The Cobb-Douglas production function serves as the foundation for this model, which Solow introduced in 1956. In this model, output growth is denoted by Qit, technical development is denoted by Ai, and labor and capital are represented by K and L, respectively. It is noteworthy to mention that while the Cobb-Douglas formula adequately considers conventional inputs like labor and capital, it fails to account for energy. The expression for the Cobb-Douglas formula is as follows:

$$Q_{it} = A_{it} K_{it}^{b} L_{it}^{c} \qquad (2)$$

where b and c denote the elasticity of the output with respect to the inputs. On the contrary, more recent growth studies (Kato (2005), Bentsen et al. (2017), Boopen and Vinesh (2011), and Asafu-Adjaye et al. 2016) have incorporated energy consumption, CO2 emissions, and crude prices as independent variables, in contrast to the conventional Cobb-Douglas paradigm. Thus, the five independent variables of our model are oil prices, labor, capital, energy consumption, and carbon emissions. Consequently, Equation 2 is represented as follows:

$$Q_{it} = A_{it} K_{it}^{b} L_{it}^{c} FE_{it}^{d} COE_{it}^{e} OLP_{it}^{f} \qquad (3)$$

where FEit, COEit, and OLPit denote energy use from fossil fuels, carbon emissions, and oil prices, respectively, in the equation (3). The respective elasticities of output with respect to fossil fuel consumption, greenhouse gas emissions, and oil prices are denoted by d, e, and f in this equation.

The following production function is obtained by applying the natural logarithm to Equation 3 in order to resolve the heteroskedasticity issue:

$$lnYit = lnAit + blnKit + clnLit + dlnFEit + elnCOEit + flnOLPit \quad (4)$$

where lnAit = ao +εit with ao is used to measure efficiency level over time and across individual units. So, we can write equation 4 as

$$lnYit = ao + blnKit + clnLit + dlnFEit + elnCOE2it + flnOLPit + \varepsilon it \quad (5)$$

Actual output is denoted as Yit in Equation 5. The independent variables Kit, Lit, FEit, COEit, and OLPit represent labor, capital stock, ENC from fossil fuels, carbon emissions, and oil price, respectively. The economic significance of coefficients b, c, d, e, and f is associated with the growth elasticities pertaining to various inputs.

Owing to the fact that CO2 emissions result from industrial production and energy utilization, it is vital to emphasize the potentially significant correlation between output growth and CO2 emissions. The BRICS nations' substantial dependence on natural resources renders environmental quality an evidently vital element of industry. It is anticipated that a decline in environmental quality will put an end to the expansion of output. Moreover, there is a tendency for the ENC and production of these nations to increase concurrently. Environmentally sustainable industrial practices are more likely to be adopted by nations during periods of substantial output growth. Concerns of endogeneity and collinearity emerge due to the strengthened correlation among carbon emissions, ENC, and GDP.

There is evidence that ENC is a factor influencing production growth. Four hypotheses are presented in the literature review regarding the correlation between ENC and output growth. Energy is initially regarded as a critical element of production that significantly enhances efficiency. Furthermore, heightened energy demand stimulates output expansion, which subsequently requires increased ENC. Likewise, oil is recognized as a significant catalyst for output expansion in the BRICS region, primarily attributable to escalating demand. Particularly among the BRICS, a considerable proportion of the GDP of numerous developing nations is correlated with energy prices. It is anticipated that a surge in oil prices will result in elevated transportation and manufacturing expenses for a diverse range of industrial commodities, ultimately impeding economic expansion.The inclusion of ENC, CO2 emissions, and crude price as explanatory variables in the development functions of the BRICS countries is justified by these numerous factors.

3.2. Econometric Method

Initial consideration is given to homogeneity and cross-sectional dependence in order to facilitate the choice of a suitable econometric method. Utilized are the Pesaran Yamagata (2008) homogeneity test and Pesaran's (2004) Cross-sectional Dependence (CSD) test. To evaluate stationarity, the CIPS and CADF unit root tests, which were devised by Pesaran (2007), are utilized. The research subsequently employs the Bootstrap co-integration test, which was designed by Westerlund-Edgerton (2007).

The study employs the Autoregressive Distributed Lag (ARDL) and Panel Mean Group (PMG) methodologies to calculate the coefficients for the Long Run (LR) and Short Run (SR), respectively. The ARDL method concurrently anticipates the LR and SR outcomes and is applicable in any scenario, irrespective of the integration order (0 or 1). SR results and LR equilibrium are computed utilizing the Panel Vector Error Correction method in order to further assess the validity of PMG results. The Batsman probability test is ultimately employed to evaluate the suitability and credibility of the selected econometric method.

$$Y_{it} = \sum_{j=1}^{m} \gamma_{ij} y_{i,t-1} + \sum_{j=1}^{n} \acute{\delta_{\imath\jmath}}\, x_{i,t-j} + \epsilon_{i,j} \qquad (6)$$

Where $x_{i,t-j}$ is k*1 explanatory variables vector y_{it} is endogenous variable. δ_{ij}shows k*1 vector having independent variables coefficients γ_{ij} is scalar factor and $\in_{i,j}$ is error terms, I = 1,

2,…...,N denotes cross sections, and t = 1,2,…..,T represents time period. So, we have the "error-correction model".

$$\Delta Y_{it} = \emptyset_i y_{i,t-1} + \acute{\alpha}_i x_{it} + \sum_{j=0}^{m-1} \dot{\gamma}_{ij} \Delta y_{i,t-1} + \sum_{j=0}^{m-1} \acute{\dot{\delta}}_{ij} \Delta x_{i,t-j} + \in_{i,j} \qquad (7)$$

Where$\emptyset_i = -1 + \sum_{j-1}^{m} \gamma_{ij}$;$\sigma_i = \sum_{j-0}^{n} \dot{\delta}_{ij}$; $\dot{\gamma}_{ij} = \sum_{p-j+1}^{m} \gamma_{ip}$,j=1,2,…,m-1 and $\dot{\delta}_{ij} = \sum_{p-j+1}^{n} \delta_{ip}$

$$\Delta Y_{it} = \emptyset_i \left(y_{i,t-1} + \acute{\alpha}_i x_{it} \right) + \sum_{j=0}^{m-1} \dot{\gamma}_{ij} \Delta y_{i,t-1} \sum_{j=0}^{m-1} \acute{\dot{\delta}}_{ij} \Delta x_{i,t-j} + \in_{i,j} \qquad (8)$$

$\emptyset_i$

α_i denotes LR relationship between endogenous and exogenous variables $\dot{\delta}_{ij}$stands for short run parameters." $\emptyset_i$s are error-correction terms." To confirm LR relationship, these terms should be negative and significant. So, our revised neoclassical Solow growth model in ARDL format is given as.

$$\Delta y_{i,t} = \alpha_0 + \emptyset_{1,i} \left[y_{i,t-1} - \theta_{1,j} (COE_{i,j} + FF_{it} \dot{+} K_{it} + L_{it} + OLP_{it}) \right] + \sum_{j=0}^{m-1} \acute{\vartheta}_{it} \Delta y_{i,t-j}$$
$$+ \sum_{j=0}^{m-1} \acute{\vartheta}_{it} \Delta COE_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it} \Delta FF_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it} \Delta K_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it} \Delta L_{i,t-j}$$
$$+ \sum_{j=0}^{m-1} \acute{\vartheta}_{it} \Delta OLP_{i,t-j} + \in_{i,t} \qquad (9)$$

To notice causal association among variables, the remaining equations are written as follows;

$$\Delta COE_{i,t} = \alpha_0 + \emptyset_{2,i}\left[COE_{i,t-1} - \theta_{1,j}(\, y_{\iota,t} + FF_{\iota t} + \grave{K}_{\iota t} + L_{\iota t} + OLP_{\iota t})\right] + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta y_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta COE_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta FF_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta K_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta L_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta OLP_{i,t-j} + \epsilon_{i,t} \qquad (10)$$

$$\Delta FF_{i,t} = \alpha_0 + \emptyset_{3,i}\left[FF_{i,t-1} - \theta_{1,j}(\, y_{\iota,t} + COE_{\iota t} \grave{+} K_{\iota t} + L_{\iota t} + OLP_{\iota t})\right] + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta y_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta COE_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta FF_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta K_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta L_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta OLP_{i,t-j} + \epsilon_{i,t} \qquad (11)$$

$$\Delta K_{i,t} = \alpha_0 + \emptyset_{4,i}\left[K_{i,t-1} - \theta_{1,j}(\, y_{\iota,t} + COE_{\iota t} + \grave{F}F_{\iota t} + L_{\iota t} + OLP_{\iota t})\right] + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta y_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta COE_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta FF_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta K_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta L_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{\iota t}\,\Delta OLP_{i,t-j} + \epsilon_{i,t} \qquad (12)$$

$$\Delta L_{i,t} = \alpha_0 + \emptyset_{5,i}\left[L_{i,t-1} - \theta_{1,j}(\,y_{i,t} + COE_{it} + FF_{it} + K_{it} + OLP_{it})\right] + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta y_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta COE_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta FF_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta K_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta L_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta OLP_{i,t-j} + \in_{i,t} \quad (13)$$

$$\Delta OLP_{i,t} = \alpha_0 + \emptyset_{6,i}\left[OLP_{i,t-1} - \theta_{1,j}(\,y_{i,t} + COE_{it} + FF_{it} + K_{it} + L_{it})\right] + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta y_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta COE_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta FF_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta K_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta L_{i,t-j} + \sum_{j=0}^{m-1} \acute{\vartheta}_{it}\,\Delta OLP_{i,t-j} + \in_{i,t} \quad (14)$$

4. Empirical Findings

The research utilizes data obtained from a cohort of BRICS economies over the course of the years 1990 to 2022. A comprehensive inventory of all variables utilized in the inquiry is presented in Table 1.

The study incorporates various indicators, including the labor force, GDP expressed in constant 2010 USD, energy use (calculated as a percentage of total fossil fuel use), and CO2 emissions. The Organization of Petroleum Exporting Countries (OPEC) provides the crucial data on oil prices denominated in USD, while the World Development Indicators (WDI) provides information on ENC, labor force, GDP, and gross capital formation. These vital statistics are obtained from reputable databases. To facilitate the estimation of elasticities, a natural logarithmic transformation was applied to the data.

Five well-known nations, or BRICS (Brazil, Russia, India, China, and South Africa), are the subject of scrutiny. The selection of these nations was predicated on their significance in the global economy and their ability to exemplify a range of economic attributes unique to the BRICS countries. 1990 to 2020 comprises the study's temporal scope, which was deliberately selected to encompass significant economic developments and patterns over the past three decades.

Deciding upon the chronology, variables, and inclusion of these specific nations was contingent upon the accessibility and reliability of the data. Thorough care has been taken to ensure the accuracy and relevance of the data, which forms the foundation for insightful and consequential assessments. Tables 1 and 2, which contain comprehensive data summaries and descriptive statistics, offer a profound examination of the characteristics and trends inherent in the chosen variables. This establishes the foundation for an in-depth examination of the interconnections among these economic metrics within the framework of the BRICS.

Between 1990 and 2020, Table 2 provides a comprehensive analysis of the summary data for the selected variables for the BRICS nations. It is imperative to recognize that the data has undergone a logarithmic transformation, thereby enhancing its suitability for advanced statistical investigations. The statistical findings offer valuable insights into the fundamental patterns and distributions of the significant economic indicators.

The mean value of GDP growth is 27.81, with a standard deviation of 0.90. The mean economic growth rate for all BRICS countries over the specified time period is denoted as such. Upon conducting additional analysis on particular variables, it is observed that the mean values and standard deviations for the following are provided: capital (K), oil prices (OLP), fossil fuel consumption (FE), CO2 emissions (CO2), and labor (L): (19.37, 0.98), 3.63, 0.67, 4.31, 0.20, and 26.01, 1.33, respectively.

The evaluation of skewness and kurtosis is crucial in ascertaining the shape of the data distribution in the case of a normal distribution. Zero and three are the optimal values of skewness and kurtosis, respectively, for a distribution that is perfectly normal. Despite the fact that a number of values in the examined series approach the suggested standards, the investigated series fall short of precisely matching this ideal. The distributions of labor (L), CO2 emissions (COE), and fossil fuel consumption (FF) exhibit negative skewness, which indicates that the former has a larger tail than the latter. Conversely, the remaining series exhibit a conspicuous positive skewness.

In consideration of kurtosis, a metric that assesses the behavior of the tail of the distribution, values near 3 also indicate mesokurtic distributions. It is noteworthy that the kurtosis values for capital (K), GDP growth (Q), and CO2 emissions (COE) are in proximity to 3, indicating a distribution that closely resembles the normal distribution. Conversely, the series representing fossil fuel consumption (FE), labor (L), and oil prices (OLP) exhibit values below 3, indicating platykurtic distributions characterized by flatter tails.

In order to validate these observations, the Jarque Bera test is applied. Consistent skewness and kurtosis values indicate that the observed data deviates from a perfectly normal distribution. The statistical findings presented herein serve as the cornerstone for a more intricate understanding of the underlying characteristics and behaviors of the selected variables within the economies of the BRICS.

The assessment of multicollinearity, which occurs when independent variables in a regression model are highly correlated and introduce instability into the estimation of coefficients, is an essential procedure for guaranteeing the reliability of econometric analysis. Tolerance and the Variance Inflation Factor (VIF) are indispensable diagnostic instruments in this pursuit.

Table 3 contains comprehensive details regarding the Tolerance and VIF values for each variable. This information is critical in determining the presence of multicollinearity. The utmost VIF value documented was 8.33, while the range of tolerance values spans from a minimum of 0.12 to an unspecified maximum. A critical understanding of the degree of correlation among the explanatory factors is contingent upon the interpretation of these results. Multicollinearity is typically a matter of concern when the VIF value exceeds 10 or when the Tolerance value approaches zero. The reported results of the analysis, which vary between 0.12 and 8.33, suggest that the presence of significant multicollinearity issues is unlikely.

Furthermore, to enhance the understanding of variable correlations, Pearson product-moment correlation analysis is implemented in Table 4. The results confirm significant correlations between GDP and both crude prices (OLP) and capital (K). This indicates that fluctuations in crude and capital prices are significantly correlated with changes in GDP, suggesting the existence of additional research-worthy relationships.

An additional indication of the interdependence among labor (L), capital (K), and fossil fuel use (FE) is the substantial and positive correlation between CO2 emissions (COE) and the aforementioned factors. This suggests that variations in capital, labor force, and the utilization of fossil fuels exert a substantial influence on fluctuations in carbon dioxide emissions. These interconnections underscore the intricate dynamics that are present within the economic system and emphasize the need for a more comprehensive examination of these interactions.

Additional substantiation for the interplay between labor dynamics and crucial economic indicators is provided by the robust and positive correlations observed among capital (K), CO2 emissions (COE), and fossil fuel consumption (FE). These connections shed light on the potential effects of labor-related disparities on capital, fossil fuel consumption, and CO2 emissions.

Essentially, the results of the Pearson correlation analysis, the Tolerance and VIF analysis, and additional analyses validate the robustness of the selected variables in the econometric model. Subsequent studies assessing the effects of these factors on economic growth are credibly supported by the absence of significant multicollinearity issues and the existence of robust correlations among key economic indicators.

The homogeneity test, illustrated in Table 5, is a critical procedure utilized to ascertain the degree of consistency in the distribution of slope coefficients across the sampled panels. The null hypothesis of homogeneous slope coefficients is refuted at a significance level of one percent on account of the results, which highlight the importance of delta and adjusted delta. This rejection indicates that the variables comprising the sampled panels differ. It is crucial to consider the implications of heterogeneity, especially when integrating external impacts and policy perspectives into the econometric framework, as

Phillips and Sul (2003) state. Understanding the potential complications associated with cross-sectional dependency is an imperative concern when conducting panel data analysis. Unit root tests of the second iteration of panels are utilized to circumvent this issue. In this instance, the Common Correlated Effects (CCE) procedure is implemented, which employs the CADF and CIPS tests. These evaluations are of the utmost importance in identifying and resolving the challenges that arise from cross-sectional dependence, thereby ensuring the reliability of subsequent econometric research.

Following this, we examine Table 7, which displays the results of the panel unit root test when both trend and constant components are considered. As indicated by the estimation, the null hypothesis (H0) regarding the non-stationarity of the variables under investigation for the panel at the level is not rejected. At the first difference, however, the null hypothesis is refuted, indicating that the variables become stationary. This signifies a fundamental characteristic of the panel data: stationarity at the first difference, a prerequisite for proceeding with the co-integration analysis.

The groundwork is prepared to examine the enduring associations between variables through the application of co-integration analysis, ensuring stationarity at the first difference. Co-integration, a fundamental concept in econometrics, posits that certain economic variables exhibit simultaneous motion over time in order to establish equilibrium connections. It is a critical component in elucidating the interconnections among economic matters and grasping the manner in which they interact to influence economic expansion.

In conclusion, the assessment of stationarity and cross-sectional dependence through panel unit root tests, followed by the homogeneity test, are pivotal phases in ensuring the dependability and resilience of the econometric investigation. The meticulous diagnostic methodologies establish a solid groundwork for delving into the intricate dynamics of co-integration among significant economic factors. The results not only contribute to the scientific rigor of the study, but also pave the way for crucial understandings of the enduring connections that impact the economic environment of the panels included in the sample.

As shown in Table 8, the outcome of the Westerlund-Edgerton bootstrap panel cointegration test is crucial for identifying the long-term relationships between the variables under consideration. When GDP (Yit) is used as the dependent variable, the results indicate strong cointegration, as indicated by the probability values associated with the statistics Gt, Gf, and Pt. By rejecting the no-cointegration hypothesis, the existence of a long-term relationship between the main economic variables under investigation is highlighted.

Once the co-integration of the variables being examined has been established, the research proceeds to calculate long-run (LR) and short-run (SR) relationships for every BRICS nation. The Panel Mean Group (PMG) estimate results, which reveal the LR and SR elasticities of output with respect to the independent variables, are presented in Table 10.

The coefficients of the PMG estimate provide insights into the impact that individual independent variables have on the growth of output. It is worth noting that the coefficients of all the independent variables—COE, FE, K, L, and OPL—are both significant and positive. The extent to which these coefficients influence production growth is denoted by their magnitudes. The respective coefficients for COE, FE, K, L, and OPL are 1.58, 3.36, 0.41, 2.94, and 0.23. This implies that a one-unit increase in each of these variables results in an equivalent increase in production growth, denoted by the magnitude of the coefficients, over an extended period of time.

In addition to examining the LR and SR elasticities, the study delves into the examination of causal relationships. The SR establishes a unidirectional causal relationship, which proceeds from output to COE (carbon emissions). This implies that fluctuations in production growth have an immediate causal impact on carbon emissions. In a similar vein, the LR establishes a unidirectional causal relationship between COE and oil prices (OLP), indicating that oil prices exert a sustained influence on carbon emissions. It is noteworthy that the SR does not identify any correlation between oil prices (OLP) and GDP, indicating that oil prices do not impact production growth in the BRICS states in the short term. Conversely, the LR establishes a unidirectional causal relationship, suggesting that oil prices exert a positive long-term impact on economic development.

Moreover, the research demonstrates a reciprocal relationship between GDP and capital stock (K) in both the immediate and extended periods. This implies a bidirectional relationship in both temporal dimensions, whereby alterations in capital stock influence expansion of output and conversely. The thorough examination of the co-integration outcomes and the subsequent calculation of the SR and LR relationships offer a holistic comprehension of the complex mechanisms that govern the economies of the BRICS. The results of this study not only enhance the empirical depth of the research but also provide significant knowledge for policymakers and scholars attempting to understand the intricate dynamics that influence the economic paths of these developing countries.

The results of this study are consistent with a wide range of prior scholarly works that examine the complex correlation between ENC and economic expansion. Consistent with previous research (Zhang and Cheng, 2009; Ang, 2008), this study provides further evidence in favor of the hypothesis that economic expansion is accompanied by a unidirectional rise in ENC. Moreover, the results of this research are consistent with those of Ho and Siu (2007), Lee and Chang (2005), and Karanfil (2008), which indicate that energy and economic growth have a unidirectional causal relationship.

Recognizing the intricate nature of this correlation, the present study also acknowledges the existence of bidirectional connections between ENC and economic expansion, as postulated by Ohler and Fetters (2014) and Polemis and Dagoumas (2013). Furthermore, the potential absence of a substantial correlation between ENC and economic development, as Menyah and Wolde-Rufael (2010) and Payne (2009) have noted, is recognized. This contributes to a more nuanced comprehension of these interdependencies.

Within the realm of renewable energy, this research aligns with the conclusions drawn by Azam et al. (2020), Abbas et al. (2020), and Magazzino et al. (2021), underscoring the potential congruence between nuclear energy and renewable energy in terms of bolstering economic expansion and reducing carbon dioxide emissions. The significance of sustainable energy sources in promoting economic development while ensuring environmental sustainability is highlighted by these congruent results.

The identification of a sustained correlation between ENC and economic progress, as noted by Al-Mulali and Sab (2012) and Shahbaz and Lean (2012), is a significant finding consistent with the ongoing investigation. Moreover, the discovery of a nonlinear correlation between ENC and economic advancement, which mirrors the results reported by Heidari et al. (2015), contributes to the scholarly comprehension of the ways in which energy influences the dynamics of the economy.

Consistent with previous research (Al-Mulali 2016), the present study establishes a reciprocal association between economic expansion and ENC, incorporating both immediate and enduring effects. The acknowledgment of an inverse U-shaped correlation between ENC and economic growth, similar to the results reported by Sbia et al. (2017), contributes depth to the comprehension of the intricacies that regulate ENC and economic growth.

The research is consistent with the Environmental Kuznets Curve (EKC) theory, which was first proposed by Grossman and Krueger in 1991 and has since been investigated in greater depth by Managi (2006), Markandya et al. (2006), and Song et al. (2008). This correlation highlights the congruence between economic expansion and diminished environmental degradation, offering valuable perspectives on the dynamic interplay between environmental issues and economic development.

Consistent with the findings of Govindaraju and Tang (2013), Menyah and Wolde-Rufael (2010), Ghosh (2010), Yang and Zhao (2014), Farhani et al. (2014), Chang (2010), Magazzino (2021), Heidari et al. (2015), and Cai et al. (2018), the present study corroborates various associations between economic growth and CO_2 emissions. Additionally, the research supports the notion that income exerts a substantial influence on carbon dioxide (CO_2) emissions, as proposed by Halicioglu (2009) and Pao and Tsai (2011).

Furthermore, the present research places considerable consensus on the effects of power consumption and CO_2 emissions on economic growth, as investigated by Lean and Smyth (2010). Furthermore, the research is consistent with the concept that ENC, CO_2 emissions, and economic development have a long-term, unidirectional causal relationship, as Menyah and Wolde-Rufael (2010b) and Pao and Tsai (2011) have noted. The aforementioned alignments enhance the present research's credibility and pertinence in the wider body of literature concerning energy, environmental sustainability, and economic growth.

5. Conclusions and Recommendations

The research examined the interconnections among crude prices, GDP growth, CO_2 emissions, and fossil fuel energy consumption in the BRICS economies over the period of 1990 to 2022. Here, the significant findings are presented. The results of the Yamagata homogeneity test and Pesaran CD test, when applied to the panel time series, suggest that the variables under investigation exhibit heterogeneity and cross-sectional dependence. Furthermore, the investigated series exhibit non-stationarity at the level but transition to stationarity at the first difference, as demonstrated by the CADF and CIPS tests. The third step involved examining the long-run relationships between the variables using the Westerlund-Edgerton panel bootstrap co-integration test. Furthermore, according to the PMG estimation results, every output-influencing independent variable has a statistically significant and positive effect. Furthermore, the study demonstrates a one-way causal relationship between short-term fossil fuel production and usage, along with long-term unidirectional correlations between crude prices, GDP, and fossil fuel consumption. A multitude of policy concerns are affected by these findings. Generally, a surge in energy consumption coincides with a rise in economic expansion. Consequently, irrational economic development or oil-producing status as a country aside, safeguarding a nation's energy requirements should be the primary focus when formulating energy management strategies. While implementing energy-saving measures, careful attention must be given to mitigating any adverse consequences in order to guarantee their efficacy. In addition, the correlation between economic expansion, rising energy consumption, and emissions underscores the criticality of implementing policies that promote sustainable development. Environmental change can be aided by initiatives such as the promotion of biodiesel, hydropower, and biogas, which can also foster sustainable economic expansion. In addition, the achievement of sustained growth in the international energy market becomes imperative for a number of BRICS nations, which are net importers of oil.

Conflict of interest

The authors declare that there is no conflict of interest.

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Appendix

Table 1: Variables and Data Source

Variable	Description	Source
Y_{it}	GDP (constant 2010 US $)	WDI
COE_{it}	Carbon emissions (kt)	WDI
FF_{it}	Energy use (fossil fuel) (% of total)	WDI
K_{it}	Gross capital formation (current US $)	WDI
L_{it}	Labor force, total	WDI
OLP_{it}	Oil prices (per barrel USD)	OPEC

Table 2: Descriptive Statistics

Statistic	K_{it}	Q_{it}	L_{it}	$CO2_{it}$	OLP_{it}	FE_{it}
Mean	25.98	28.00	19.34	12.34	3.63	4.31
Median	26.00	27.95	19.84	14.00	3.63	4.43
Maximum	29.42	30.01	21.48	15.90	4.65	4.53
Minimum	23.65	25.09	17.90	5.67	2.56	3.93
Std. Dev.	1.33	0.90	0.98	3.21	0.67	0.20
Skewness	0.51	0.02	-0.30	-1.24	0.11	-0.62
Kurtosis	3.04	2.85	1.27	2.45	1.54	1.78
Jarque-Bera	6.371416	0.14	20.08	38.46	12.93	17.99
Probability	0.041349	0.93	0.00004	0.000	0.001466	0.00010
Sum	3771.875	4133.13	2705.14	1873.24	528.6009	626.129
Sum Sq. Dev.	256.3964	117.84	138.77	1640.11	66.07525	5.7929
Observations	148	148	148	148	148	148

Note: Authors' calculations, based on the WDI dataset.

Table 3: Multicollinearity

Model	Tolerance	VIF
Energy consumption (Fossil fuel)	0.33	3.22
Carbon emissions	0.37	2.53
Labor force	0.30	3.34
Capital stock	0.13	8.23
Oil Price	0.15	6.77

Note: Authors' calculations, based on the WDI dataset.

Table 4: Pearson Correlation analysis of BRICS countries

Pearson Correlation analysis							
	Variables	CO_{Eit}	OLP_{it}	FF_{it}	K_{it}	Y_{it}	LF_{it}
CO_{Eit}	Pearson corr. Sig.(2-tailed)	1.00	0.07	0.77***	0.23***	0.04	0.52***
		-----	0.43	0.00	0.003	0.56	0.00
OLP_{it}	Pearson corr. Sig.(2-tailed)		1.00	0.13*	0.53***	0.38***	0.09
			-----	0.08	0.00	0.00	0.32
FF_{it}	Pearson corr. Sig.(2-tailed)			1.00	0.58**	-0.08	0.31***
				-----	0.04	0.22	0.0005
K_{it}	Pearson corr. Sig.(2-tailed)				1.00	0.17**	0.93***
					-----	0.03	0.00
Y_{it}	Pearson corr. Sig.(2-tailed)					1.00	-0.05
						-----	0.47
LF_{it}	Pearson corr. Sig.(2-tailed)						1.00

Note: ***, **, * show 1 %, 5 % and 10% significance level.

Table 5: Pesaran yamagata's Homogeneity test

Test	Statistic	P value
Δ	9.750***	0.000
Δadj	12.309***	0.000

Note: ***, **, * show 1 %, 5 % and 10% significance level.

Table 6: Cross sectional dependency test

	$CO2_{it}$	OP_{it}	FE_{it}	Y_{it}	K_{it}	LF_{it}
CD Test value	10.28***	17.12***	11.29***	15.49***	14.86***	12.13***
P value	0.000	0.000	0.000	0.000	0.000	0.000

Note: ***, **, * show 1 %, 5 % and 10% significance level.

Table 7: Panel unit root tests

Group	$CO2_{it}$		OP_{it}		FE_{it}		Q_{it}		K_{it}		LF_{it}	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ
CADF	-3.85***	-3.53***	2.65	-3.63***	-1.37	-3.23***	-3.12***	-2.88***	-1.67	-2.80***	-1.88	-2.44**
CIPS	-3.59***	-4.81***	2.61	-1.80*	-1.82	-4.07***	-2.82***	-2.57***	-1.82	-4.64***	-0.50	-4.05***

Note: ***, **, * show 1 %, 5 % and 10% significance level.

Table 8: Bootstrap Panel cointegration test (Westelund and Edgerton (2007) test)

G_r		G_a		P_t		P_a	
Value	Robust P value	Value	Robust P value	Value	Robust P value	Value	Robust P value
-4.07	0.01	-11.32	0.06	-8.53	0.06	-13.51	0.02

Note: ***, **, * show 1 %, 5 % and 10% significance level.

Table 9: Short and long run causality

Short run causality	Long run causality
$K_{it} \rightarrow CO2_{it}$	$OP_{it} \rightarrow CO2_{it}$
$K_{it} \rightarrow OP_{it}$	$CO2_{it} \leftrightarrow LFit$
$K_{it} \rightarrow FE_{it}$	$OP_{it} \rightarrow FE_{it}$
$K_{it} \leftrightarrow Yit$	$OP_{it} \rightarrow K_{it}$
$K_{it} \leftrightarrow LFit$	$OP_{it} \rightarrow Y_{it}$
$Y_{it} \rightarrow CO2_{it}$	$OP_{it} \leftrightarrow LFit$
$Y_{it} \rightarrow FE_{it}$	$FE_{it} \leftrightarrow LFit$
$Y_{it} \leftrightarrow LF_{it}$	$Y_{it} \leftrightarrow Kit$
$LF_{it} \rightarrow CO2_{it}$	$LF_{it} \rightarrow K_{it}$
	$K_{it} \rightarrow LF_{it}$
	$LF_{it} \rightarrow Y_{it}$

Table 10: PMG estimation of BRICS countries

Dependent var	Q_{it}	$CO2_{it}$	FE_{it}	K_{it}	LF_{it}	OP_{it}
Long run coeff.						
Q_{it}		-0.23**	0.09	0.36*	0.98***	0.12
$CO2_{it}$	1.573***		0.18***	0.47***	-0.32***	-0.07
FE_{it}	3.371***	2.21***		1.52	-0.07	-2.46**
K_{it}	0.427***	0.56***	0.09***		-0.23***	0.58***
LF_{it}	2.956***	-0.69**	0.28*	-0.64**		2.02***
OP_{it}	0.212**	0.027	-0.02**	0.46***	0.0***	
ECT	-0.05	-0.272***	-0.35*	-0.58**	-0.0***	-0.57***
Short run Coeff						
ΔQ_{it}		-0.252	0.07*	1.53	-0.07*	2.91
$\Delta CO2_{it}$	-0.004		0.01	-0.14	-0.01	0.42
ΔFE_{it}	-0.080	0.133	-0.21	-5.47**	0.01	-3.14
ΔK_{it}	0.032***	0.025	0.02		-0.01	0.23
ΔLF_{it}	0.595**	0.394	0.14	-2.71		-1.16
ΔOP_{it}	0.010	-0.015	0.001	0.19***	-0.01	
Hausman test value	1.30	0.08	6.14	0.06	6.12	0.01
P value	0.96	0.72	0.28	0.88	0.13	0.79

Note: ***, **,* show 1 %, 5 % and 10% significance level.

Figure 1: Causality test of BRICS countries