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The Role of Disaggregated Level Natural Resources Rents in Economic Growth and Environmental Degradation of BRICS Economies

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Abstract

This study investigates the pollution halo and natural resources blessing phenomenon in Brazil, Russia, India, China, and South Africa (BRICS) economies at the disaggregated level over 1995–2018. The study applies panel techniques useful in endogeneity, autocorrelation, heteroscedasticity, and crossectional dependence. Our study's results partially supported the natural resources curse phenomena and resource blessing for BRICS countries. The empirical results further substantiated that total natural resource rents help decrease CO_2 emissions, while the mineral, forest, and oil rents substantially increase CO_2 emissions of the BRICS economies. The causality results further indicated that fossil fuels, economic growth, and CO_2 emissions have feedback effects. Similarly, mineral resources have bidirectional causal impacts on CO_2 emissions and fossil fuel consumption. The unilateral causal linkages are also found to forest resources from all the chosen variables. Finally, a significant causal relationship originates from GDP, fossil fuel to natural resource rents, and the BRICS economies' oil rents. Since the study outcomes are unique, it has reliable policies for the theory and practice of the BRICS economies.

Graphical Abstract
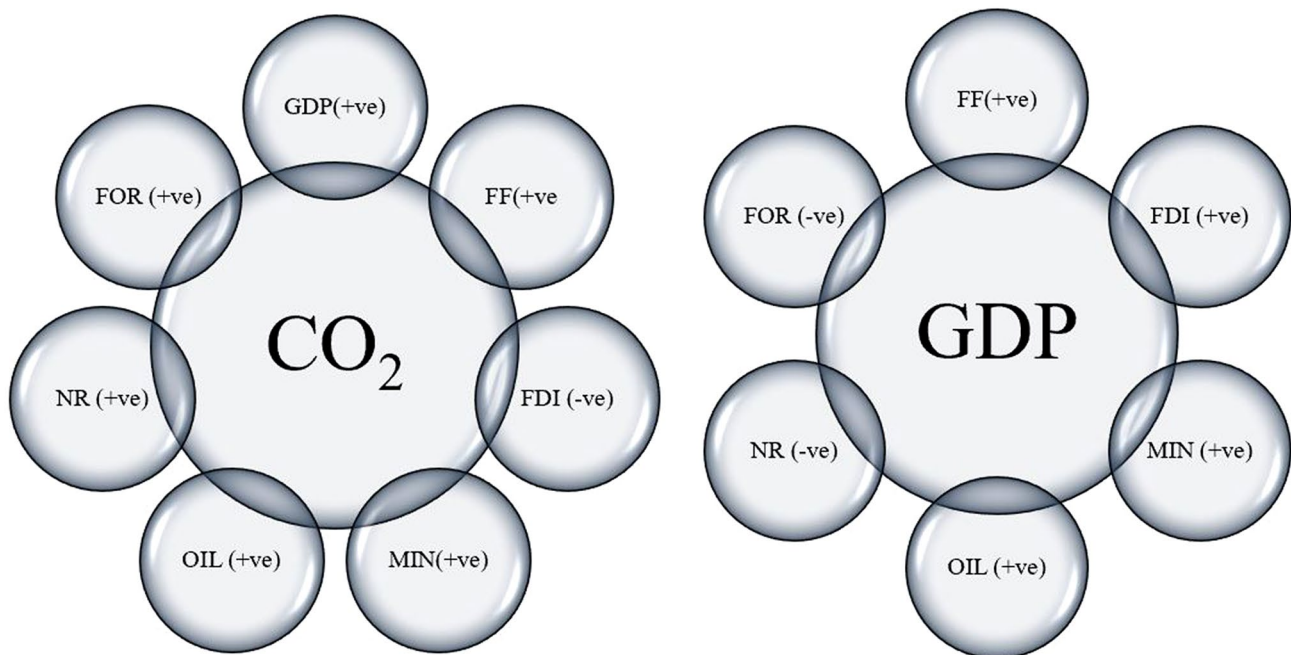
Extended author information available on the last page of the article

Abbreviations

AMG	Augmented mean group
ARDL	Autoregressive distributed lags
ASEAN	The Association of Southeast Asian Nations
BRICS	Brazil, Russia, India, China, and South Africa
CADF	Crossectional augmented ADF
CD	Crossectional dependent
CIPS	Crossectional Im, Pesaran, & Shin
DK	Driscoll & Kraay
DOLS	Dynamic OLS
D-H	Dumitrescu & Hurlin test
EU	European Union
FDI	Foreign direct investment
FF	Fossil fuel
FMOLS	Fully modified OLS
FOR	Forest rents
G7	Group of seven countries
GDP	Gross domestic product
GMM	Generalized method of moment
GVR	Group mean variance ratio
MENA	Middle East & North Africa
MIN	Minerals rents
MINT	Mexico, Indonesia, Nigeria, and Turkey
NR	Total natural resources rents
OECD	Organization of Economic Cooperation and Organization
OIL	Oil rents
PHH	Pollution haven hypothesis
PVR	Panel variance ratio
VAR	Vector autoregressive
VR	Variance ratio

Introduction

In the recent economic growth race, every country wants to achieve high economic growth aligned with prosperity for its population. The enormous growth process's reflection has a vital share in energy consumption in this race, transmitting CO_2 emissions into the natural climate. This process has widely affected the non-renewability of the natural environment. In particular, the emerging countries of BRICS have become more prosperous in the last three decades (Azevedo et al. 2018). The gross domestic product of these countries has risen many folds from 2187 billion US\$ in 1985 to 16,266 billion US\$ in 2017, with an estimated growth rate of 6.5% annually. This rise in economic activities is not without any cost, specifically in CO_2 emissions to the environment (Dong et al. 2017). Brazil, Russian, India, China, and South Africa are up-and-coming emerging economies that constitute BRICS. They do not only have a significant impact on global affairs due to their pace of economic growth, foreign reserves, and large population (Wang

et al. 2016; Cheng et al. 2019), but their role in global CO_2 emissions is also significant (Dong et al. 2017; Cheng et al. 2019; Khan et al. 2020d). Similarly, including Indonesia, the British petroleum has estimated that the CO_2 emissions of BRICS economies reached 14,110 mt (million tons) in 2013 (excluding Indonesia, it was estimated to be 13,768 million tons in 2016), and it contributes to 40% of global CO_2 emissions since 2009 (Cheng et al. 2019). This continuous rise in CO_2 emissions has shown tremendous threats to the environment's natural resources, specifically the BRICS economies.

Because of natural resources and their sustainable use, it is mandatory to study resource rents, which are the surplus values after costs and returns (Huang et al. 2020). Most countries utilize available natural resources to uplift the countries' economic progress; more formally, the natural resources have improved economic development (Lashitew and Werker 2020). There is another linkage between growth and natural resources, a resource curse that negatively links natural resources and economic growth. This literature relationship has been discussed, which states that resource-rich countries perform less than resource-poor countries (Tiba 2019). This has been justified by the human and institutional qualities of the countries. The contradictory claims have been aimed at natural resources and environmental degradation.

On the one hand, the continuous use of fossil-based "energy consumption" in exploring natural resources have subject to environmental degradation (Hussain et al. 2020); similarly, human activities in mining and deforestation are significant activities to exploit natural habitat, and resource depletion, water, and air pollution (Sarkodie 2018; Ahmed et al. 2020). On the other hand, abundant natural resources discourage fossil-based energy's massive imports (Balsalobre-Lorente et al. 2018). Based on the given arguments, we believe the empirical understanding of "natural resources and environmental sustainability" has not reached any conclusive consensus. For example, the study (Hussain et al. 2020; Ahmed et al. 2020), while some researchers have contradicted these outcomes (Zafar et al. 2019b; Danish 2020).

The current topic is significant in the BRICS economies, based on their continuous and non-stop economic activities and rising extraction of "natural resources" due to mounting demand in manufacturing and other production sectors. BRICS countries are rich in natural resources; for example, Russia constitutes 20% of the global natural resources, accounting for 95.7% of the national wealth of the Russian economy (Danish et al. 2019). Similarly, China, Brazil, and India have good bauxite and iron ore sectors. At the same time, Russia is rich in oil and gas reserves, whereas Brazil has major coal industries; therefore, the BRICS countries are labelled with resource powers (Wilson 2015). The clear outlook of the BRICS economies' resource situation is given in Table 1.

Table 1 Comparison of average values of chosen variables

Year/indicator	GDP per capita constant at 2010US$	CO$_2$ emissions (metric tons per capita)	Total natural resources rents (% of GDP)	Forest rents (% of GDP)	Mineral rents (% of GDP)	Oil rents (% of GDP)	Foreign direct investment, net inflows (% of GDP)	Fossil fuel energy consumption (% of total) (at 2014)
BRICS-average								
1995	4396.7602	4.9861	3.5966	0.6656	0.3567	1.4346	1.4865	74.3257
2000	4765.2553	4.9195	6.4664	0.5616	0.4126	3.8629	2.2032	75.4341
2005	5793.4051	5.4830	7.4098	0.3619	1.2177	3.8811	2.3468	76.7920
2010	7039.5743	6.1931	7.8021	0.3765	2.3868	2.6944	2.6366	78.2277
2016	7716.5379	6.3432	3.9532	0.4428	1.1071	1.2969	2.1853	79.8579
World-average								
1995	7402.6040	0.0040	1.3320	0.2236	0.0937	0.8144	1.1809	79.8174
2000	7886.6774	3.8345	2.1303	0.1403	0.0727	1.5271	4.6101	79.7838
2005	8667.76916	4.2099	3.1623	0.1293	0.1976	2.1961	3.2814	80.7244
2010	9370.3852	4.4848	3.7395	0.1745	0.6614	2.1063	2.8412	80.7781
2016	10,497.6488	0.0048	1.6992	0.1944	0.3898	0.8058	3.4733	80.9114

Source, own calculation based on world development indicator's (WDI) data

The study contributes to the literature by adding the empirical relationship of natural resource rents (oil rents, mineral rents, forest rents, total natural resource rents) on economic growth and the environment for the natural resource-rich BRICS economies. The study's second objective is to test the impression of fossil fuel and foreign direct investment (FDI) on the economic growth and environmental quality of BRICS economies using estimators that account for heteroscedasticity endogeneity and crossectional dependence, which have been overlooked in past research. The study's ultimate purpose is to offer significant policy proposals to achieve economic growth by not harming the region's environmental quality understudy.

After the introduction, the study continues with a literature review in the second section. The third section explains the methodological framework and the data. In the fourth section, econometric methods are discussed. Similarly, in the fifth part, the empirical results are discussed, and finally, the research concludes with conclusions and recommendations for the future of the BRICS economies.

Literature Review

Based on the current study's objectives, we have distributed the literature into three sub-strands. The first strand of the research sheds light on "natural resources and economic growth literature". The second sub-strand explains the relevant literature on natural resources and the environment. Finally, the research's third sub-strand explains the pollution haven hypothesis/ halo hypothesis in economic growth in the empirical models.

Economic Growth and Natural Resources

The heterogeneous impact has been seen on economic growth from the natural resources, including mineral rents, forest rents, oil rents, total natural resources rents, and coal rents (Prljić et al. 2018). Similarly, two different relationships have been observed between natural resources and economic growth. For example, Studies exploring natural resources and economic development have a beneficial relationship grouped into the hypothesis of natural resources (Nawaz et al. 2019). This hypothesis is tested using quantile regression on the data from 1970 to 2018 for Asian countries (Haseeb et al. 2021) concluded the effect of natural resources on economic growth is positive, therefore supporting natural resource blessing for Asian countries except for India, where it refuted the natural resources blessing hypothesis. Similarly, (Wei et al., 2020), the AMG framework for G7 countries consisting of "Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States" found that the relationship between finance and natural resource rents concluded a positive relationship, thus supporting the natural resource blessing phenomena. Similarly, the study for several Indonesian districts (Hilmawan and Clark 2019) refuted the resource curse phenomena by accepting that natural resources are a blessing for Indonesia districts' economic growth. On the other hand, studies have shown natural resources, and economic growth has negative linkages due to the natural resource curse phenomenon (Sachs and Warner 1995). Following this hypothesis, in developing countries from 1990 to 2012, (Kim and Lin 2018) witnessed that natural resources have a curse phenomenon with economic growth. Employing the data from 1996 to 2014 of oil abundant in the Middle East and North Africa (MENA)

countries using the GMM estimator (Matallah and Matallah 2016) has revealed the resource curse for the relationship between oil rents and economic growth. Along similar lines, (Tiba 2019) making the resources intensity index of various natural resource rents (oil rents, natural gas rents, forest rents, coal, and mineral rents) have found a negative relationship (resource curse) with economic growth in nonlinear form for 21 sub-Saharan countries over 1990–2015. They advised the analyzed countries to improve their institutional structure to improve natural resource rents in the long run. Similarly, many other studies, including (Khan et al. 2020a) for Belt and Road countries (Naseer et al. 2020) for the South Asia countries, (Guan et al. 2020), and (Wang et al. 2019) for China, supported the existence of natural resources curse hypothesis.

Environmental Degradation and Natural Resources

The relationship between natural resources and the environment is essential in empirical literature due to energy-intensive technologies adopted to explore the mineral resources for production and consumption. Therefore, many empirical studies show a negative and significant relationship with environmental quality (Hassan et al. 2019; Bekun et al. 2019; Khan et al. 2020d). Testing the natural resources, human capital, and FDI with ecological footprints in the United States (Zafar et al. 2019b) have found that human capital and natural resources help curtail ecological footprints. Similarly, (Balsalobre-Lorente et al. 2018) for EU-5 countries have found that natural resources significantly reduce CO_2 emissions. Likewise, (Joshua and Bekun 2020) have found that natural resources negatively contribute to South Africa's pollutant emissions. For Chinese data, Ahmed et al., (2020) narrated those natural resources increased ecological footprints over 1970–2016 in the "Autoregressive Distributed Lag (ARDL)" framework. A similar study (Danish et al. 2019) using an "Augmented Mean Group estimator (AMG)" estimator found the insignificant impact of natural resources on CO_2 emissions. Their results supported a significant positive relationship between the two variables for South Africa significant negative relationship for Russia. Further, using the Fully Modified-OLS (FM-OLS) and Dynamic-OLS (DOLS) for BRICS from 1992to 2016 (Danish 2020) have found that natural resource rents, urbanization, and renewable energy are acting as catalysts to reduce the ecological footprints.

FDI, Growth, and Environment

The impact of FDI on economic growth and the environment has been previously discussed. FDI's role is considered an efficient indicator to utilize natural resources in increasing the economic pace of growth (Huang et al. 2020). Many studies show that FDI inflows significantly contribute to the countries' economic growth (Li and Liu 2005; Gudaro et al. 2012; Bermejo Carbonell and Werner 2018). Similarly, FDI does not induce economic growth in the case of BRICS countries (Pao and Tsai 2011). Testing the data of "Organization for Economic Co-operation and Development" (OECD) countries using the GMM estimator over 1996–2013, Raza et al. (2019) revealed FDI has a positive effect on economic growth. In the case of the environment, FDI has two distinct relationships; the first is the pollution haven hypothesis (PHH), which states that an increase in FDI inflows to host countries further deteriorates the environment due to less stringent environmental policies (Sapkota and Bastola 2017). A recent study (Guzel and Okumus 2020) conducted for ASEAN-5 has supported PHH.

In comparison, another school believes that more FDI inflows tend to raise economic and environmental prosperity due to inflows of green technologies, unlike the host country's existing polluting technologies called the pollution halo hypothesis (Phalo) (Mert and Caglar 2020). A similar hypothesis is supported by Zafar et al. (2019b), testing the FDI, human capital, and natural resources and finding that these decrease the United States' ecological footprints. Along similar lines (Mert and Caglar 2020), using the data over 1974–2018, found supporting results for the "Phalo" hypothesis. The study conducted by Balsalobre-Lorente et al., (2019) for the "MINT countries" found inverted-U phenomena between FDI and environment, which in the initial phase supported both pollution haven after a certain level of investment through FDI have supported the pollution halo hypothesis.

In summary, from the discussion mentioned above, we found the insufficiency of previous literature on the relationship between economy, environment, and natural resources (mineral, oil, forest, and total rent of natural resources). Just a few studies use total natural resource rentals with various outcomes. No studies have used heterogeneous resource rents (mineral, oil, forest and total natural resource rents). However, only two studies (Huang et al. 2020; Tiba 2019) in literature, as per our knowledge, have evaluated the impact on economic growth while ignoring the environment. Differences in the characteristics of countries and natural resource production and management methods may explain different outcomes. The role of natural resources in the resource curse or resource blessing hypothesis has been investigated by some studies. Therefore, the current work explores the long-term relationship between natural resources, FDI, consumption of fossil fuels, economic development, and the environment and introduces minerals, forests, oil, and total resource rents. This can help explain some new potential aspects of sustainable use of resources, economic growth and environmental prosperity. More specifically, the

purpose of using different resource rents in an analytical context is to provide accurate and sufficient direction for efficient use of resources and, in the long run, successful and prosperous environmental policies.

Economic Modelling and Data

Economic Modelling

Economic rents obtained from various natural resources (oil rents, mineral rents, total natural resources rents, and forest rents) are considered positive and significant elements of the economic growth process (Huang et al. 2020). Similarly, fossil-based energy use, natural resources, and foreign direct investment are significant economic growth components (Ishida 2011; Asafu-Adjaye et al. 2016; Bermejo Carbonell and Werner 2018; Anser et al. 2020). On the other hand, if all these factors significantly impact economic growth, we cannot deny the relevant impression on BRICS economies' environment. Since various past studies have disclosed that the role of natural resources, FDI, and fossil fuels are crucial to economic growth, their impact on environmental sources is also vital (Demena and Afesorgbor 2020; Gurney et al. 2009; Umar et al. 2020; Balsalobre-Lorente et al. 2018). In line with these arguments, we have established two different equations, each separately for economic growth and "environmental degradation", similar to Huang et al., (2020) and Zafar et al., (2019a) as below;

$$CO_{2i} = \int (GDP, FF, FDI, MIN, NR, OIL, FOR) \tag{1}$$

$$GDP = \int (FF, FDI, MIN, NR, OIL, FOR) \tag{2}$$

From Eqs. 1 & 2, the linear growth and CO_2 emission functions can be converted into linear econometric forms as below:

$$CO_{2it} = \varphi_{it} + \pi_{1it}GDP_{it} + \pi_{2it}FF_{it} + \pi_{3it}FDI_{it} + \pi_{4it}MIN_{it} + \pi_{5it}NR_{it} + \pi_{6it}OIL_{it} + \pi_{7it}FOR_{it} + \beth_{it} \tag{3}$$

$$GDP_{it} = \varphi_{it} + \pi_{1it}FF_{it} + \pi_{2it}FDI_{it} + \pi_{3it}MIN_{it} + \pi_{4it}NR_{it} + \pi_{5it}OIL_{it} + \pi_{6it}FOR_{it} + \beth_{it} \tag{4}$$

The subscripts *i* and *t* indicate the time (1995–2018), and cross-sections (BRICS), φ and $\beth$ are the regression slope and residual of the regression equations. Where, $\pi_1 \dots \pi_7$ are the coefficients of the chosen variables which have to be estimated.

Data

The data on five BRICS are sourced from (World Bank 2019) from 1995 to 2018. The selection of the BRICS panel for these specific variables comes from various reasons. The first is the natural resource-rich panel (Wilson 2015); the countries in BRICS are comparatively high emitters of CO_2 (Cheng et al. 2019), annexed with experiencing an increased pace of economic growth (Wang et al. 2016; Cheng et al. 2019). CO_2 is the "Carbon dioxide emissions metric tons per capita" for the formal empirical analysis. Figure 1 exhibits the plot of CO_2 for all five BRICS countries over the specified period. From the graphs, we note that when values turn to darker colors, it shows the intensity of increasing CO_2 emissions in the BRICS economies. This is consistent with the graphs for all the variables chosen for the study. Compared to the five BRICS countries, Russia is the highest emitter of CO_2, and India is the lowest emitter of CO_2 to climate. This trend implies the diversity in CO_2 emissions among the five BRICS countries.

GDP of a country is considered the nation's wealth; here, we had taken it at real per capita GDP at 2010 prices, widely recognized economic growth as a significant positive determinant of environmental degradation in various past studies (Khan et al. 2020c; Sarkodie and Strezov 2018; Destek et al. 2018). Figure 1 reveals that India is the poorest (2.829), and Brazil is the wealthiest (4.0789) country based on the share in GDP per capita in logarithmic form. The intensity of the GDP increase can be depicted from the figure that lighter values are smaller, and the darker the colour, the GDP rises exponentially.

FDI indicates nonresident investors' volume inflows in domestic countries. The relevance of FDI to CO_2 emissions and GDP has a special relationship. First, FDI inflows accelerate the economic growth while upsurges CO_2 emissions postulating the Pollution haven hypothesis (PHH), which implies that the FDI inflows are not environmental friendly and deteriorate the environment (Yildirim 2014; Sapkota and Bastola 2017); while if these investments are centralized on the clean energy industries, tends to rise economic growth, and improves the environment by declining the severity of CO_2 emissions into atmosphere which is termed to be pollution halo hypothesis (Phalo) (Balsalobre-Lorente et al. 2019; Mert and Caglar 2020). By knowing the nature and distinct impact of FDI, we adopted it as a controlled variable in the study. Figure 1 indicate that FDI inflows are highest in China and lowest in South Africa (− 0.6393)
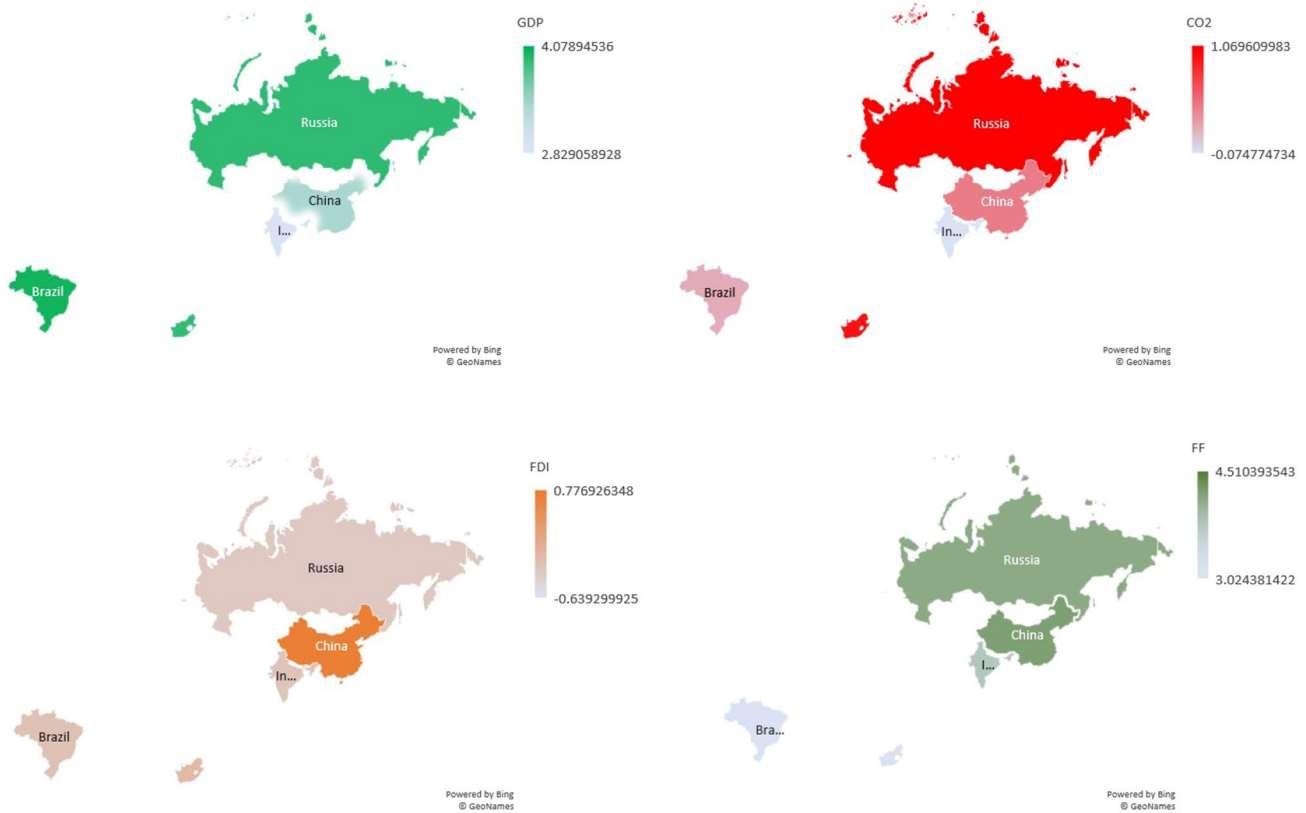
Fig. 1 Pictorial view of the chosen variables

based on the transition of colour from darker to lighter in a panel of BRICS countries, which indicates the heterogeneity of inflows of FDI into BRICS.

Fossil fuel energy consummation (FF) is used in the study as the share of fossil fuel in total energy consumption (%). Figure 1 shows the time series plot of FF for BRICS energy. Overall, the value of 4.0935 in China implies the highest consumption of fossil-based energy in logarithmic form, while Brazil (3.0244) has the lowest consumption. This shows the disparities of fossil-based fuel consumption alongside BRICS economics, which may have heterogeneous environmental and economic growth impacts.

The pictorial view of natural resource rents is exhibited in Fig. 2; the study employed four heterogeneous resource rents in the model to explore the relevant impact on economic growth and CO_2 emissions simultaneously. To this end, we used oil rent, forest rents, mineral rents, and natural resource rent, all as a percentage of GDP. In addition, the sum aggregate of these resources as total natural resources rent (% of GDP) is also taken as the main variable of the study. Based on these indicators, the highest rent is paid for oil in Russia (1.16137), where lowest in South Africa (-2.29222); similarly, mineral rents in South Africa (0.606951) remain highest, as compared to -1.6964 in China. The economic rents paid for forests remain highest in South Africa (0.087558)

and lowest in China (-1.08303). Finally, the economic rents for total natural resources were 1.33659 in Russia compared to 0.082684 in Brazil. The differences in the rents paid for various natural resources were heterogeneous across the BRICS economies, thus having a vital significance in studying their economic and environmental impacts to showcase sustainable economic development's reliable policies.

Before the empirical study's formal analysis, the current study variables are converted into logarithmic to reduce measurement errors due to outliers. Similarly, the present study indicators may have several similar issues, simultaneously affecting the policy and planning mechanisms. Therefore, we may face the problems of crossectional dependence in the residuals. Standard OLS can provide inefficient estimates; hence, we developed long-run relationships between the variables using different estimators.

Methodological Framework

To apply the most suitable estimators for the data before estimating the long-run relationship coefficients, some mandatory econometric procedures have to be conducted, such as crossectional dependence (CD), unit root analysis, and
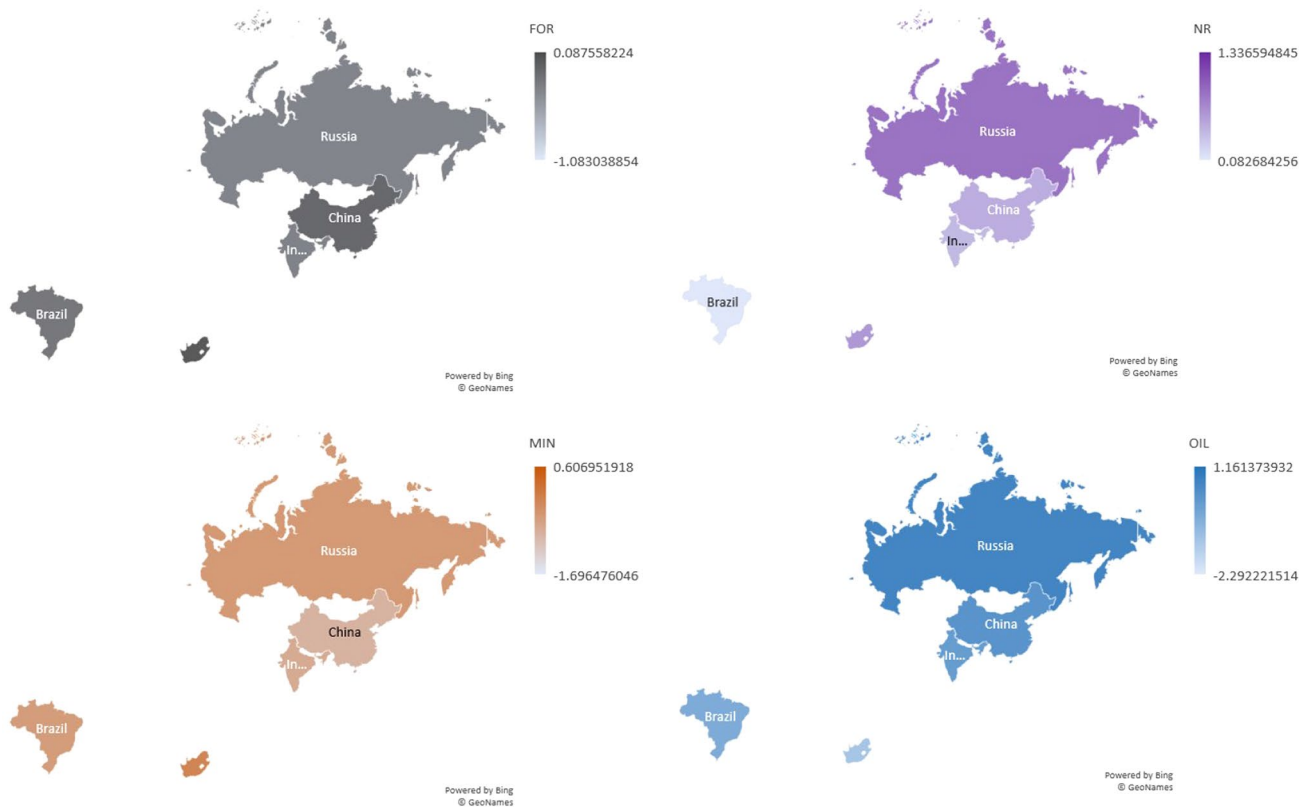
Fig. 2 Pictorial view of the chosen variables

cointegrating relationships, to apply the most suitable estimators for the data (Danish 2020).

Crossectional Dependence (CD)

The recent developments in econometrics have raised the problem of crossectional dependence stemming from the spillover effects; for example, a shock, un-observed components, and spatial dependence to one country may spill over to another, which may affect the long-run policy implications (Pesaran 2004; Westerlund and Basher 2008; Danish 2020). Hence not accounting for CD may lead to biased and inconsistent results (Breitung 2005; Dong et al. 2018). Following these arguments, the current study first tests CD in the data (Pesaran 2004). The test's null hypothesis elaborates that cross-sections are independent, while the alternative explains there is dependence in cross-sections.

Unit Root Analysis

The next step in panel data econometrics is to identify the integration order in the variables, so the current study, by keeping in mind the CD, applies (Pesaran 2007) "crossectional Im-Pesaran-Shin (CIPS) and Crossectional augmented Dickey-Fuller (CADF)" in the study on the chosen sample

of panel data. Since the "first-generation unit root tests" are not capable of addressing the issues of CD. The null of no unit roots is rejected if the variables are integrated of order one for both the tests.

Cointegration Analysis

In the next step to determine the existence of the cointegration relationship, this study first applies residual-based cointegration introduced by Pedroni (2001) and Kao (1999), and then (Westerlund 2005) cointegration based on the Durbin-Hausman principle. The Westerlund (2005) approach is robust in panel heterogeneity and crossectional dependence in the residuals; similarly, it does not require correcting temporal dependence (Westerlund 2005). To test the null hypothesis of no-cointegration, the following panel form of cointegration is considered;

$$\widehat{\theta}_{it} = \delta_i \widehat{\theta}_{it-1} + \widehat{\mu}_{it} \qquad (5)$$

Westerlund (2005) proposes two variance ratio (VR) test statistics obtained by testing for a unit root in the predicted residuals using the DF regression given in Eq. (5). Those are panel variance ratio statistics (PVR) and group mean–variance ratio (GVR). Panel variance ratio (PVR)

statistics and group mean–variance ratio (GVR). These two VR tests are based on Phillips et al. (1990) and Breitung (2002), in which the test statistics are constructed as a variance ratio. One difficulty is intended to test the alternative statement that the panel is co-integrated. The others measure the positive alternative for a fraction of cointegrated individuals. The test extracts the restrictive distributions of the experiments and demonstrates that nuisance parameters are free. The findings of a small Monte Carlo study indicate that even in small samples, the experiments have small size distortions and retain strong power against strongly autoregressive alternatives at the same time.

Long-Run Estimators

Knowing the cointegration relationship in the models infers establishing the long-run relationship between how and to what extent an explanatory variable affects the dependent variable in the long run. In forming a long-run relationship, Pedroni (2000) adjusted fully modified-OLS (FM-OLS) to estimate the coefficient for the long-run relationship in panel data models. They used the following test statistics to gauge the FM-OLS;

$$\widehat{\beta}_{\text{FMOLS}} = \left[\frac{1}{N} \sum_{i=1}^{N} \langle \sum_{t=1}^{T} \left(m_{it} - \overline{m}_i \right)^2 \rangle \right]^{-1} \times \left[\langle \sum_{t=1}^{T} \left(m_{it} - \overline{m}_i \right) \widehat{b}_{it} - T \widehat{\Delta}_{eu} \rangle \right] \tag{6}$$

where m, $and b$ are dependent and independent variables, $\widehat{\Delta}_{eu}$ is used to denote the estimated value covariance term with the Kernel estimator, which accounts for the serial correlation. Similarly, the N and T in the equation indicate the time and cross-sections taken in the study.

The power of FM-OLS is good, as it can eliminate heteroscedasticity by allowing the Bartlett and Kernel procedures from the data (Kiefer and Vogelsang 2000; Danish 2020). Similarly, the $\widehat{\Delta}_{eu}$ term in FM-OLS corrects for possible effects of endogeneity, and autocorrelation therefore to estimate robust estimates (Funk and Strauss 2000). Although they are unable to address the problem of crosssectional dependence, but their superior powers in estimating the cointegrated panels, this estimator got huge attention in econometric studies (Ozturk and Al-Mulali 2015; Danish 2020). In addition to FM-OLS, as a second estimator, the study intends to apply the (Driscoll and Kraay 1998) (DK) regression, as it gives good results in balanced and unbalanced data (Danish 2020). Similarly, it averages the explanatory variables' products with residuals in the HAC weighted approach to generate robust standard errors, which remain free from CD's problem (Danish et al. 2019; Khan et al. 2020b).

Panel Granger Non-causality Test

The ability of long-run estimators is that they can identify the impact of the independent variable on the dependent and shows the sign of a relationship; however, they have no power to determine the short-run causal direction between the variables, which has significant importance in policy formulation (Zafar et al. 2019a). To this end, we apply the (Dumitrescu and Hurlin 2012) test to analyze the causal linkages between the variables. This test works in a vector autoregressive (VAR) framework, which allows for the data's unobserved heterogeneity. Similarly, it has good small sample properties and can control the possible effects of CD (Destek and Sarkodie 2019). Dumitrescu and Hurlin (2012) produce the most consistent and robust causal results (Danish 2020).

Results and Discussions

The foremost thing to consider in modern econometrics is crossectional dependence in an empirical estimation of panel data. To diagnose the possibilities of the crossectional dependence in the residuals, in line with the studies (Dong et al. 2017; Zafar et al. 2020), the variables here are tested with (Pesaran 2004), and the outcomes are portrayed in Table 2. From the given results, the null hypothesis of "crossectional independence" is rejected at a 1% level by accepting the alternative inferring crossectional dependence between the variables chosen in the study.

Due to the failure of first-generation unit root tests, current literature in environmental economics focuses on the second-generation unit root tests, accounting for crossectional dependence. Keeping this property in mind, we tested

Table 2 CD-test

Variable(s)	Statistics	P-values	Corr
CO_2	7.95	0.00	0.513
GDP	14.77	0.00	0.933
FF	13.55	0.00	0.875
FDI	1.04	0.30	0.067
MIN	13.28	0.00	0.858
NR	10.73	0.00	0.693
OIL	8.7	0.00	0.562
FOR	5.61	0.00	0.362

Table 3 CIPS and CADF results

Variables	$CIPS^{Level}$	$CIPS^{First\ diff}$	$CADF^{Level}$	$CADF^{First\ diff}$	Order of integration
CO_2	− 2.32	− 3.573	− 2.269	− 2.488*	First-order
GDP	− 2.021	− 3.369	− 2.08	− 2.985***	First-order
FDI	− 2.501	− 5.042	− 1.375	− 2.784**	First-order
FF	− 2.67	− 3.632	− 2.004	− 2.434*	First-order
NR	− 1.592	− 4.186	− 1.729	− 3.654***	First-order
MIN	− 2.783	− 5.025	− 2.233	− 3.629***	First-order
OIL	− 1.768	− 4.863	− 1.31	− 2.865**	First-order
FOR	− 2.295	− 4.283	− 1.833	− 3.091***	First-order

Critical values for CIPS at 1%, and 5% are − 2.33, and − 2.57; where *, **, and *** indicates the significance level at 10%, 5%, and 1%

Table 4 CO_2-model

	Statistics	Probability
Pedroni cointegration		
Modified Phillip perron test	2.5295	0.00
Phillip Perron test	− 6.3122	0.00
Augmented Dicey fuller test	− 3.7684	0.00
Kao cointegration		
"Modified Dickey fuller test"	− 5.4642	0.00
"Dickey Fuller test"	− 6.2537	0.00
"Augmented Dicey fuller test"	− 3.6529	0.00
"Unadjusted modified Dickey-Fuller test"	− 10.7934	0.00
"Unadjusted Dickey-Fuller test"	− 7.4579	0.00
Westerlund cointegration		
Variance ratio (Some)	− 1.5914	0.05
Variance ratio (All)	− 1.3379	0.04

Table 5 GDP-model

	Statistics	Probability
Pedroni cointegration		
Modified Phillip perron test	3.1131	0.00
Phillip Perron test	1.029	0.15
Augmented Dicey fuller test	1.666	0.04
Kao cointegration		
"Modified Dickey fuller test"	− 2.2728	0.00
"Dickey Fuller test"	− 3.0166	0.00
"Augmented Dicey fuller test"	− 2.6028	0.00
"Unadjusted modified Dickey-Fuller test"	− 3.6662	0.00
"Unadjusted Dickey-Fuller test"	− 3.4918	0.00
Westerlund cointegration		
Variance ratio (some)	3.4112	0.00
Variance ratio (all)	3.8132	0.00

stationarity variables with (Pesaran 2007) CIPS and CADF in the study, and the results are summarized in Table 3. From the results, we found that variables are non-stationary at levels. In contrast, after converting them to the first difference, the variables turned stationary, implying that they have an integration order of one. These characteristics of variables have provided guidelines to examine the cointegration relationship between the variables.

Cointegration Results

In the next estimation step, we have performed various cointegration tests to examine the equilibrium relationship between the variables by accommodating the crosssectional dependence for each model. First, we adopted the Pedroni and Kao cointegration approaches; after knowing the results, we again applied the Westerlund cointegration; both models are given in Tables 4 & 5. In Table 4, Pedroni, Kao, and Westerlund's results supported a cointegration relationship between the variables for the CO_2 model. Similarly, the results in Table 5 for the GDP model also explore that

the given probability values are smaller than 0.01, which rejects the null hypothesis of non-cointegration at 1% or less, supporting the presence of a cointegration relationship. The distinct nature of the cointegration relationship guides us to determine the long-run relationship between the variables using appropriate long-run estimators in the following steps.

Long-Run Estimates

The study analyzes the "long-run relationship" between the variables using the two most attractive approaches, the FM-OLS and Driscoll & Kraay (DK) estimator. Both the approaches are best for their distinct advantages. The FM-OLS is best in heteroscedasticity, autocorrelation, and endogeneity, while later is reasonable to account for crosssectional dependence, adjust the data with missing observations, and handle balanced and unbalanced panel data sets. We have applied these estimators to the current data in line with these advantages, and estimated coefficients are given in Tables 6 & 7.

Table 6 CO_2-model

Variables	FM-OLS	Prob	DK	Prob
GDP	0.1825	0.02	0.1683	0.00
FF	0.6779	0.00	0.6918	0.00
FDI	− 0.0195	0.12	− 0.1156	0.13
MIN	0.0332	0.09	0.0163	0.15
OIL	0.0452	0.00	0.0366	0.00
NR	− 0.1094	0.00	− 0.0783	0.00
FOR	0.0857	0.01	0.0652	0.00

Table 7   GDP-model

Variables	FM-OLS	Prob	DK	Prob
FF	0.8318	0.00	0.8317	0.00
FDI	0.0016	0.95	0.0016	0.91
MIN	0.0928	0.01	0.0927	0.00
OIL	0.0257	0.29	0.0256	0.07
NR	− 0.1778	0.01	− 0.1777	0.01
FOR	− 0.2411	0.00	− 0.2411	0.00

Table 6 for CO_2-model results implies that gross domestic product is the positive determinant of the environment; for example, a one per cent increase in the GDP of the BRICS economies raises the CO_2 emissions by 0.1825% in the long run. This relationship between the variables is not surprising; many studies have previously verified the ties for the BRICS economies (Shahbaz et al. 2013; Bakhsh et al. 2017; Cheng et al. 2019). Similarly, the consumption of fossil-based energy is also liable to emit more, which implies that a one per cent rise in fossil-based energy consumption raises 0.6779% emissions in BRICS economies; this relationship is also robust and has been verified by many known scholars for the BRICS economies (Pao and Tsai 2010; Ahmad et al. 2019; Muhammad 2019; Arora and Kaur 2020). While the policies in energy conservation tend to improve the environment in the long run (Nejat et al. 2015). Similarly, the role of FDI in CO_2 emissions is negative yet insignificant, which implies that the role of FDI in environmental degradation is turned to be beneficial from the contributor. Similarly, the role of mineral rents, oil rents, and forest rents are continuously contributing to environmental degradation based on CO_2 emissions. These results proposed that a 1% rise in oil rents increases CO_2 emissions by 0.0366%, and forest rents escalate the CO_2 emissions by 0.0652%, respectively. While natural resource rents' role in CO_2 emissions is negative, a one per cent increase in "total natural resource rents" tends to reduce the CO_2 emissions by 0.0783% respectively, in the long run. The varied nature of resource rents with the environment is because the energy-intensive capital is employed to extract oil and forest resources, increasing CO_2 emissions

instead of declining. Similarly, the use of energy-intensive capital in total natural resource rents is comparatively lower, which reduces the burden on CO_2 emissions compared to other forms of natural resources.

While turning to the growth model results given in Table 7, the value of fossil fuel is positive and strongly significant with both estimators, which indicates that a one per cent increase in fossil fuel consummation improves economic growth in BRICS economies by 0.8317% annually. This correlation between economic growth and fossil fuels is not surprising. At the same time, in most of the previous studies, the researchers have found similar relationships (Ishida 2011), who disclosed that fossil-based fuels are low-entropy natural resources that are very effective for economic prosperity, and any decline in the consumption of fossil energy may hamper the economic growth process. The findings were also supported by Asafu-Adjaye et al. (2016), who said that conserving fossil resources might hinder economic growth. The role of FDI with FM-OLS and DK has non-significant results, indicating that the FDI inflows to these countries on average do not support economic growth. Similarly, mineral rent and oil rents are significant positive determinants of economic growth; this indicates that a one per cent increase in mineral rent and oil rent tends to increase economic growth by 0.0927% and 0.0257%, respectively, with each other estimator. In the BRICS economies, the mineral and oil rents contribute significantly and positively to the economic growth process compared to the other forms of natural resources, which indicates the natural resources blessing hypothesis for minerals and oil resources. Our results endorse the past findings of Prljić et al. (2018), Huang et al. (2020). The forest rents and total natural resources rents are supporting negatively the economic growth of the BRICS economies, which disclosed that a one per cent increase in forest rent and total natural resources rents tend to decrease the economic growth of BRICS economies by − 0.177, and − 0.2411% respectively. The negative relationship between these indicators with economic growth supports the natural resources curse hypothesis (Sachs and Warner 1995). The natural resources curse theory analyzes that most resource-rich countries tend to grow slower than resource-poor countries, primarily due to institutional failures, political instabilities, and most probably corruption (Naseer et al. 2020), and in the countries where institutions are good. Our results are endorsed by Kim and Lin (2018) for the case of developing countries.

Causality Results

Finally, the long-run estimators have no potential to explain the direction of causality flowing; therefore, we have tested the chosen variables for crossectional augmented causality using D-H Granger non-causality test, and the results are

summarized in Table 8. The causality results reject the non-causality between GDP and CO_2 emissions below the 1% level by supporting the feedback effect, which is endorsed by the previous study (Chaabouni and Saidi 2017). Similarly, the results supported the bidirectional causality between fossil-based energy and CO_2 emissions for BRICS economies (Magazzino 2014). Like the given results in long-run estimates, the causality results between FDI and CO_2, FDI, and GDP are not significant, making the results for long-run estimators robust. Further, the calculated coefficients of causality imply two-way causal linkages between mineral resources and CO_2 emissions. In contrast, unilateral causality was exposed from NR to emissions of CO_2 and from CO_2 emissions to FOR. The empirical results also supported the feedback effect between fossil fuels and economic growth for BRICS (Asafu-Adjaye et al. 2016). The one-way causal linkage was observed from GDP to MIN, OIL, NR, and FOR. The next bidirectional causal relationship is revealed between fossil fuel and MIN, where the unidirectional causal relationship is detected from FF to OIL, NR, and FOR in the short run. Similarly, only a causal relationship from FDI to FOR is observed for the short run in BRICS economies. The one-way causal relationship has been observed from MIN to FOR, OIL to FOR, and finally from NR to FOR in RBICS. For easy understanding, the pictorial view of the summary of causal linkages is provided in Fig. 3.

Conclusion and Recommendations

The study attempted to heterogenous the role of four kinds of natural resources in the environment and economic growth by accounting for fossil fuel and foreign direct investment from 1995 to 2018 in BRICS countries. To this end, the study incorporated crosssectional dependence and panel heterogeneity to reach efficient outcomes. We employed multiple sets of unit roots and long-run estimators to control for CD, heteroscedasticity, autocorrelation, and endogeneity in the data. The results obtained from the CIPS and CADF unit
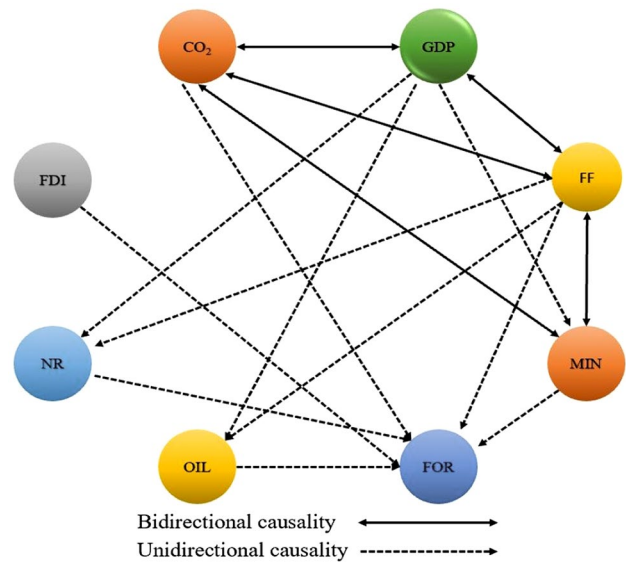

Fig. 3 Causal diagram

root tests reveal that the variables considered are integrated of the first order, hence negating the null of no unit roots at the level. While the cointegration test results supported the long-run relationship between the variables is constructed, models. The empirical results obtained from the long-run estimators concluded the heterogeneous effects of natural resources on the environmental and economic growth process. For example, oil and forest resources tend to increase environmental degradation, where total natural resource rents diminish. Similarly, the mineral and oil rents improve economic growth by supporting resources as a blessing phenomenon.

In contrast, the total rents and forest resources tend to decline in the BRICS economies' economic growth, which supports the natural resource curse phenomenon in the BRICS economies for the given period. Moreover, FDI in both the environment and growth model has no response, where fossil fuel consumption increases economic growth

Table 8 Causal results

Variables	CO_2	GDP	FF	FDI	MIN	OIL	NR	FOR
CO_2	–	6.06***	5.30**	2.19	4.24*	3.19	3.44	6.88***
GDP	11.04***	–	9.61***	3.90	7.39***	4.23*	7.84***	9.82***
FF	5.13**	5.57***	–	2.53	5.08**	4.61**	4.68**	7.05***
FDI	2.00	1.21	2.90	–	1.18	3.73	1.99	5.77***
MIN	9.22***	1.90	5.02**	2.32	–	2.12	1.95	7.94***
OIL	2.83	1.35	1.37	3.51	1.78	–	1.53	10.08***
NR	4.26*	2.09	3.18	3.86	1.16	2.81	–	7.18***
FOR	2.75	3.83	3.08	2.09	1.80	1.02	1.10	–

The given values are the Wald (W) statistic, were *, **, and *** indicate the significance level at 10%, 5%, and 1%

and environmental degradation. The findings are further confirmed using the crossectional augmented causal test, which supported the feedback hypothesis between economic growth and CO_2 emissions, similarly to FF, GDP, and CO_2 emissions. Similarly, the feedback hypothesis also supported the FF, CO_2 emissions, and MIN and CO_2 emissions, which indicates that the extraction of minerals utilizes more fossil fuels that lead to environmental waste generation. Simultaneously, the unidirectional causal relationship was revealed to FOR for the RBICS economies from all the chosen variables. Similarly, natural resources and oil rents are simultaneously caused by GDP and fossil fuels.

For the domain of policy proposals for the BRICS economies, we suggest the policymakers in these countries rethink natural resource consumption; there is still room for technical advancement and human capital investment, which can be reliable in the economic and environmental prosperity of the BRICS. Implementing such programs can prosper their people by not harming natural resources. Since fossil-based energy supports economic growth and contributes to the CO_2 emissions of the BRICS, reliable policies in renewable energy are also mandatory to accelerate economic activities by reducing the discharge of environmental waste. The causal relationships revealed that all the variables are simultaneously causing the forest rents; therefore, in the RBICS countries, it is recommended to invest in plantations, thereby reducing the burden of environmental degradation but not decreasing the economic activities. This study has constraints in data availability or natural resource rents; future research could eliminate this barrier. Similar studies would also be extended based on the income group and resource potentials to explore more reliable policy awareness outcomes.

Declarations

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