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Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS.

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ABSTRACT

There are studies on renewable energy, natural resources abundance, and their impact on the environment especially in BRICS countries. However, none of the studies has considered human capital in the nexus, knowing fully well that ecological distortions mainly emanates from human activities. Therefore, this study explores the linkage between natural resource, renewable energy, human capital, and ecological footprint (EF) in BRICS using a battery of advance econometric techniques. The findings from the study, across all models, affirm that economic growth and natural resource increase the EF, renewable energy decreases it, while human capital is not yet at a desirable level as to mitigate environmental deterioration. The country-specific results are in harmony in terms of the deteriorating impact of economic growth, and the abating role of renewable energy on the environment. Further findings suggest a feedback causality between human capital, urbanization, and EF. Policies that can enhance renewable energy consumption, human capital development, natural resource sustainability, and curb urban anomaly are discussed.

1. Introduction

Climate change poses a major challenge to humanity and global sustainable development. It is also a major threat to security, prosperity, and natural life. Climate change emanates mainly from an increase in greenhouse gases (GHGs). Human activities, through the consumption of non-renewable energy (NRE), add to GHGs which in turn promotes global warming. Many studies have favoured CO_2 emissions in studies that relate to environmental hazards mainly because it contributes the highest share to GHGs, and its data could be easily assessed. The concentration of CO_2 emissions in the atmosphere is now higher, with consequences that are far-reaching, such as droughts, floods, extreme storm, melting glaciers, and rising sea levels (UNFCCC, 2017). CO_2 emissions from fossil fuels contribute to global warming (Magazzino et al., 2020; Ahmed et al., 2019; Adedoyin et al., 2020). Unfortunately, there has been a ubiquitous call for a comprehensive indicator, as CO_2 emissions are a weak indicator, and environmental hazard is not limited to the atmosphere. CO_2 emissions are weak when it relates to stocks of resources such as forest, mining, soil, and oil (Ulucak and Apergis, 2018).

The EF is by far comprehensive when it comes to resource stock issues (Solarin and Bello, 2018). The EF measures ecological sustainability and anthropogenic pressure on the environment. As an indicator, it juxtaposes human-based consumption with the regenerative capacity of the biosphere (Rees, 1992). It captures the indirect and direct impact of consumption and production activities on the environment, as well as, the influence of human activities and environmental characteristics. The effects of the anthropogenic activities measured by EF relates to grazing land, built-up land, ocean, carbon footprint, forest products, and crops land. EF compares a nation's consumption to what it actually has (Nathaniel, 2020). Global warming is comprehensively captured by EF by following the effects of CO_2 emissions, land use, and deforestation on climate change. This study, analogous to recent studies (Destek and Sinha 2020; Nathaniel et al., 2020a,b; Ahmed et al., 2020a,b; Nathaniel

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2020; Hassan et al., 2019a,b; Alola et al., 2019a,b; Aydin et al., 2019; Baloch et al., 2019a; Danish and Wang 2019a; Destek and Sarkodie 2019; Dogan et al., 2020; Nathaniel et al., 2019) adopts the EF in place of CO_2 emissions due to its comprehensiveness.

The present study focuses only on the BRICS countries for the following reasons: (i) Contrary to many emerging economies, BRICS has experienced a rapid transition from ecological surplus to ecological deficit, mostly due to the remarkable growth of the region over the last decade. The BRICS countries contribute twenty-one per cent to the global GDP, and also account for forty-one per cent of the world's population with four trillion US$ of foreign exchange reserves (Ahmed, 2017). They control a larger chunk of the world's economy. The average annual growth rate of the region is 6.5% (World Bank, 2017). More so, between 2005 and 2016, the GDP of BRICS increased from US$2187 to US$16,266 billion. Economic growth has also seen the region consume more than forty per cent of global energy thereby being a major contributor to global CO_2 emissions (Danish and Wang, 2019b). In this light, sound policies are required to understand the environmental implications of this economic expansion in order to reverse the direction of the current trends in the BRICS region. (2) The BRICS countries rely heavily on fossil fuels, which poses major environmental challenges, to meet their energy demands despite the regions renewable energy (RE) potentials. Also, in the course of pursuing economic growth/expansion, the region has seen its biocapacity dwindling, and the development of human capital have been accorded little or no attention. Now, the BRICS economies are at a crossroads in terms of new environmental and natural resource management policies, making the region an attractive case study to examine the causal relationship between environmental protection, natural resource management, and human capital development. Besides, the outcomes from this study will help policymakers in designing sound policies of halting environmental degradation and improving human capital development.

The key objective of this study is to investigate the effects of natural resources on environmental quality in BRICS. This will expose the environmental impact of natural resource exploration and consumption in BRICS and inform the necessary policies to either promote natural resource consumption or mitigate the environmental distortions associated with resource exploration. This study also seeks to examine the possible effect of human capital and RE on environmental preservation in BRICS. The potential effects of economic growth, RE and natural resources on environmental degradation in BRICS have been analyzed in several earlier studies (e.g. Hassan and Tarar 2020; Adedoyin et al., 2020; Danish and Ulucak 2020; Khan et al., 2020; Ahmed et al., 2020; Sinha et al., 2019; Danish et al., 2019; Cheng et al., 2019; Baloch and Wang 2019; Mallick et al., 2019; Dong et al., 2017; Nassani et al., 2017). Invariably, these studies directly or indirectly assess the effects of economic growth, natural resources, and urbanization on the environment proxy by CO_2 emissions. The current study takes a significantly different approach. This study is an attempt to broaden such scope. Therefore, we intend to use a more comprehensive measure of environmental quality thus ensuring a more nuanced picture can be seen. It is believed that the effect of natural resources, urbanization, human capital, and economic growth on environmental degradation using such a comprehensive measure of environmental quality will provide more insightful directions to relevant policymakers in the region.

To achieve this goal, this study measures environmental quality using EF. Methodologically also, this study is much stronger than those used in previous studies of the environment and natural resource nexus as, unlike in the earlier empirical literature, it adopts a set of second-generation panel data techniques that accommodate some potentially crucial panel data estimation issues such as cross country heterogeneity and cross-sectional dependence (CD). These nuanced issues were ignored in previous studies in this area.

This study is super useful for BRICS countries due to their energy consumption pattern, resource endowments, contribution to global CO_2 emissions, difficulties in gaining environmental quality, commitments for environmental preservation and sustainability and the persistent ecological distortions in BRICS as all the countries currently harbours an ecological deficit territory (see Table 1 for details). Ecological sustainability requires the biocapacity (BIO) to be greater than the EF. From Table 1, South Africa, China, India, Russia, and Brazil all occupy an ecological deficit territory.

The contributions of this study are immense: (i) it is the first attempt to explore the linkage between natural resources, RE, urbanization, and EF in BRICS economies. (ii) Findings from earlier studies with regards to the environmental effect of urbanization, economic growth, natural resource, and RE were at best limited. Human activities contribute more to environmental degradation and climate change. However, despite the increasing studies on measures to ameliorate the menace of environmental degradation and climate change, the problems have shown no signs of abating. Hence, the need to investigate beyond conventional thinking and consider other aspects, such as education and awareness, to control environmental degradation. Therefore, this study included human capital in the natural resource-EF nexus for BRICS economies. This is a huge improvement on previous studies, which mostly ignore the vital role of human capital in ensuring environmental quality. (iii) Apart from using a comprehensive measure of human capital, we applied advanced econometric techniques that show country-wise results and address panel data issues to avoid being trapped in the guise of overgeneralization of policies that marred most previous studies. This will help with the alignment of policies to suit each countries peculiarity. Hence, a more policy-oriented result.

The remainder of the study is organized as follows; Section 2 is devoted to a review of the extant literature. Section 3 discusses the estimation methods. Section 4 presents the results of the estimation. Section 5 concludes with some policy implications.

2. Literature review

A plethora of studies is channelled to the effects of NR on emissions mitigation. From the review, we have discovered that CO_2 emissions were used to proxy environmental degradation. For instance, Balsalobre-Lorente et al. (2018) explored the effect of NR on CO_2 emissions in five EU countries from 1985 to 2016. Trade exacted a devastating impact on the environment, while NR and renewable electricity assist in mitigating emissions. The findings prompted the authors to suggest an improvement in regulations which will boost the consumption of renewables and minimize fossils fuel consumption. Sarkodie (2018) noted that activities such as deforestation, mining and other human acts contribute to the destruction of water, natural habitat, soil, etc. The author argued that when the ecosystem is destroyed, pollution will be inevitable.

There are also some set of studies that focused on the impact of income on the EF within the EKC framework. Some confirmed EKC existence (Uddin et al., 2017; Wang and Dong 2019; Destek and Okumus 2019; Destek et al., 2018; Destek and Sarkodie 2019; Ulucak et al., 2019; Uddin et al., 2019; Danish and Wang 2019a; Katircioglu et al., 2018; Balsalobre-Lorente et al., 2019) while others did not (Ozcan et al., 2018; Aydin et al., 2019).

Table 1
EF values and Biocapacity (BIO) of BRICS countries from 1990 to 2016.

Countries	1990		2000		2010		2016	
	EF	BIO	EF	BIO	EF	BIO	EF	BIO
Brazil	2.89	1.40	3.08	1.66	3.00	1.76	2.81	1.73
Russia	6.90	3.34	4.69	2.52	5.35	3.15	5.16	3.17
India	0.78	0.38	0.86	0.46	1.07	0.63	1.17	0.72
China	1.53	0.74	1.92	1.03	3.36	1.98	3.62	2.22
S/Africa	3.36	1.62	3.05	1.64	3.60	2.12	3.15	1.93

Source: Global Footprint Network (2019).

2.1. Natural resources, urbanization, and ecological footprint

The nexus between NR, urbanization and EF have also been well debated in the literature. NR can adversely impact on the environment by increasing the EF (Hassan et al., 2019b). On the other hand, NR can perform the exact opposite if properly managed (Zafar et al., 2019). Danish et al. (2020) used the FMOLS and DOLS techniques to examine the impact of NR and urbanization on the EF in BRICS from 1992 to 2016 within the EKC framework while totally ignoring the useful role of human capital in the nexus. From their findings, the EKC exist. RE, NR, and urbanization reduce the EF. Ahmed at al. (2020a) provided a divergent view from those of Danish et al. (2020). They discovered that human capital reduces the EF while urbanization adds to the EF in G7 countries.

Ahmed at al. (2020b) used the ARDL technique to investigate the NR-EF nexus in China from 1970 to 2016. Analogous to Ahmed at al. (2020a) for G7, urbanization, economic growth and NR increase the EF, while human capital performed the exact opposite. The authors called on the Chinese government to enact policies that will reduce the consumption of non-renewables and curb the upward surge in urbanization. Nathaniel et al. (2020a) used the Augmented Mean Group (AMG) estimator to confirm that urbanization and economic growth increase the EF in MENA countries. With the same methodology as Nathaniel et al. (2020a), Nathaniel et al. (2020b) reported that urbanization and non-renewable energy increase the EF for CIVETS countries. They recommended that CIVETS countries tap into their rich resource endowments and promote clean energy consumption.

Zafar et al. (2019) used the ARDL approach to examine the effect of human capital, NR, energy consumption, economic growth, and foreign direct investment on the EF using the US data from 1970 to 2015. Their findings suggest that energy consumption and economic growth have negative relationships with the EF. NR, FDI, and human capital are helpful in curtailing EF. Further findings revealed a feedback causality between energy consumption and the EF and between economic growth and the EF, while a one-way causality runs from NR to the EF and from human capital to NR. Ulucak and Bilgili (2018) investigated the impact of human capital on the EF within the framework of the EKC hypothesis by dividing countries into low, middle, and high-income countries. Their results showed that human capital decreases the EF for all countries. Hassan et al. (2019a) applied the autoregressive distributed lag (ARDL) technique to examine the link among human capital, economic growth, NR, and the EF over the period 1971–2014 for Pakistan and found that economic growth and NR increase the EF.

2.2. Renewable energy, economic growth, and ecological footprint

After lots of findings on the negative influence of non-renewables on the environment, the research trend has shifted to the impact of RE on the EF. Fakher (2019) explored the impact of economic growth on the EF in OPEC countries from 1996 to 2016. From the findings, economic growth, population and energy consumption increase the EF. Solarin and Al-Mulali (2018) conducted a similar study for 20 countries using the AMG estimator. They concluded that pollution emanates from economic growth and energy consumption. Destek and Sinha (2020) investigated the effect of RE on EF in 24 OECD countries from 1980 to 2014. Expectedly, RE protects the environment, while non-renewable energy deteriorates it. Recent studies such as (Baloch et al., 2019a,b; Chen et al., 2019a,b; Ma et al., 2019; Ghazali and Ali 2019) had earlier called for the consumption of renewables to mitigate pollution. Ahmed et al. (2019) investigated the impact of globalization, energy consumption, population, and economic growth on EF with the ARDL technique in Malaysia from 1971 to 2014. Globalization had no meaningful influence on the EF, while energy consumption and economic growth significantly increase the EF.

We found no panel study that investigated the determinants of EF by discussing the role of natural resources, human capital, and urbanization in BRICS EF. The literature review exposed the fact that human capital is seldom considered as one of the determinants of the EF. Also, most of the studies showed that RE is germane for environmental sustainability. The influence of NR abundance on the EF still remains inconclusive. The results vary based on the region and econometric techniques adopted. Finally, we observed that energy consumption and economic growth are the key drivers of the EF, so the lack of empirical evidence on the relationship between these variables encourages us to fill this gap for BRICS countries.

3. Theoretical framework, model, and method

3.1. Theoretical framework and model

The EF was initially proposed by Rees (1992) and developed by Wachernagel and Rees (1996). The EF is an indicator of human demand on natural resources and services and comprises six footprint sub-components: grazing land, cropland, fishing grounds, forest products, built-up land, and the carbon footprint. By combining these six footprint subcomponents, the EF responds to how much nature countries have and how much they use productive areas in nature (Bilgili and Ulucak, 2018). The EF measures environmental degradation as human-based consumption of resources, where the total earth use is an appropriate indicator of humans' impact on natural resources. Ever since its introduction, a lot of studies have adopted the EF as an environmental indicator, along with such determinants as energy consumption, urbanization, NR, international trade, human capital, innovation, energy consumption, financial development, and economic growth.

In the recent century, the consumption of nature's wealth has surpassed the earth's production leading to biocapacity lose (Haberl et al., 2007). This has left the world with lots of environmental challenges including the consumption of forest in the tropical zones which is occurring faster than its growth (UNEP, 2007); over-extraction/exploration of NR such as metals, minerals, biomass, and fossil fuels which may not regenerates (Krausmann et al., 2009); increasing GHGs that drives ecological distortions, and more anthropogenic impact on the environment (Hertwich and Peters, 2009). All of these challenges inform the importance of studying the BRICS EF with regard to its NR consumption. NR impacts EF (Zafar et al., 2019). NR like croplands, forest, fishing grounds, developed lands, and grazing lands reduce human-caused CO_2 emissions (GFN, 2018). On the flip side, some NR like coal and petroleum deteriorate the environment (Zafar et al., 2019; Ahmadov and van der Borg, 2019). NR has a close link with any economies income. At the start of development, countries consume more energy (that is, more NR) without considering its environmental consequences, but as development persists, attention shifts to renewables (clean energies). At this stage, people start demanding for a cleaner environment, NR preservation, and energy-efficient products. Hence, the quality of the environment starts improving. This is the intuition behind the EKC hypothesis in the relationship between energy consumption and EF.

Human capital is the main input in the production process (Ahmed et al., 2020a). It includes the health, knowledge, education, work experience, training, and skills of the people in a particular economy. Human capital has three broad strands: human capital stock (experience and education), firm-specific human capital (that is, the education, skills, and knowledge acquired at the firm level), and task-specific human capital (the training, skills, experience, and knowledge that pertain to a specific task) (Kwon, 2009). Economic growth drives industrialization, which increases NR extraction. An increase in NR consumption, through deforestation, mining, and agriculture can negatively impact the environment (Danish et al., 2019). NR extraction and exploration promote income increase, decrease the biocapacity, and drives the EF. Economic growth exacerbates NR extraction, and EF increases (Panayotou, 1993). Resources will be allowed to regenerate only if sustainable management practices form part of the production and consumption activities.

The literature is awash with studies that examined the relationship between economic growth and environmental quality. To investigate the impact of urbanization, NR, human capital, RE, and economic growth on EF, this study uses the following equation:

$$lnEF_{it} = \phi_0 + \phi_1 lnGR_{it} + \phi_2 lnNR_{it} + \phi_3 lnRE_{it} + +\phi_4 lnHC_{it} + \phi_5 lnUB_{it} + \varepsilon_{it} \quad (1)$$

where EF is ecological footprint (global hectares per capita), *GR* is GDP per capita (constant 2010 US$), *UB* is urbanization (percentage of total population), *RE* is renewable energy (% of total energy consumption), *NR* is natural resource rent (% of GDP), and *HC* is human capital (human capital index in relation to schooling years and returns on different education levels). Data on *GR*, *NR*, *RE* and *UB* were obtained from (World Bank, 2019), *EF* from (GFN, 2018), and *HC* from Penn World Table. The data collected for this study is secondary by nature. To uncover the association between NR, human capital and the EF in BRICS countries, we use an annual dataset for the time span from 1992 to 2016, a decision constrained by data availability.

3.2. Method

This study proceeds with the CD test so as to overcome panel data issues and be sure that our estimators are not inefficient and biased. Three CD tests are used for this purpose with the equation given as:

$$CD = \left[\frac{TN(N-1)}{2}\right]^{1/2} \bar{\bar{\rho}} \quad (2)$$

$\bar{\bar{\rho}} = \left[\frac{2}{N(N-1)}\right] \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{\rho_{ij}}$, and $\widehat{\rho_{ij}}$ is the pair-wise cross-sectional correlation coefficients. The panel size and sample are represented by N and T respectively. If CD exist, attention will be shifted to second-generation techniques. This will warrant the use of a second-generation unit root test (CADF) to make up for the inefficiency of the former. Following Pesaran (2007), the (CADF) unit root equation is given as:

$$\Delta y_{it} = \Delta\phi_{it} + \beta_i x_{it-1} + \rho_i T + \sum_{j=1}^{n} \theta_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \quad (3)$$

where T, $\Delta\ x_{it}$, ϕ_{it}, and ε_{it} represent time span, difference operator, study variables, the intercept, and disturbance term respectively. We used the Westerlund (2007) test to investigate the existence of cointegration (see Eq. (4)).

$$\Delta y_{it} = \delta_i' d_t + \varphi_i y_{it-1} + \lambda_i' x_{it-1} + \sum_{j=1}^{pi} \varphi_{ij}\ \Delta y_{it-j} + \sum_{j=0}^{pi} \gamma_{ij}\ \Delta x_{it-j} + e_{it} \quad (4)$$

φ, $d_t = (1,\ t)'$, and $\delta_t = (\delta_{i1},\ \delta_{i2})'$ are the error correction parameter, deterministic components, and the vector of parameters respectively. From this test, φ_i is used to develop four tests: group mean statistics $G_\tau = \frac{1}{N}\sum_{i=1}^{N} \frac{\widehat{\alpha_i}}{SE(\widehat{\alpha_i})}$ and $G_\alpha = \frac{1}{N}\sum_{i=1}^{N} \frac{T\widehat{\alpha_i}}{\widehat{\alpha_i}(1)}$ and the panel mean tests $P_\tau = \frac{\widehat{\alpha_i}}{SE(\widehat{\alpha_i})}$ and $P_\alpha = T\widehat{\alpha}$. The later assumes cointegration for the entire panel.

$SE(\widehat{\alpha_i})$ is the standard error of $\widehat{\alpha}_i$. $\widehat{\alpha}_i(1)$ is the semiparametric kernel estimator of $\alpha_i(1)$. The Augmented Mean Group estimator of Bond and Eberhardt (2013), Common Correlated Effects Mean Group (CCEMG), and the Pool Mean Group (PMG) were applied to examine the effects of the underlined variables on EF, while the FMOLS and DOLS were used for robustness check.

The AMG addresses the two major panel data issues; heterogeneity and CD (Dogan et al., 2020). Also, it is a useful tool capable of showing country-specific estimates of coefficients. The CCEMG shares the same advantages as the AMG, and it is also robust amidst nonstationary data (Guzel and Okumus 2020). The point of divergence between both estimators lies in the way they deal with CD. The CCEMG used cross-sectional average to proxy unobserved common factors to address CD, while the AMG uses the year dummies instead. However, both techniques (AMG and CCEMG) do not correct for biases associated with the endogeneity of explanatory variables and the problems induced by unobserved country-specific effects. The PMG involves both pooling and averaging. There are other advantages to the deployment of the PMG estimator. It is an intermediate estimator which allows the error variances, short-run coefficients, and intercepts to be different across groups, but the long-run coefficients are constrained to be homogeneous. The PMG estimator allows for the estimation of long-run coefficients without making the less plausible assumption of identical dynamics in each country, but fails to address CD (Tan, 2009).

The FMOLS estimator has the advantage of correcting endogeneity bias and serial correlation (Ozcan, 2013). It is a suitable technique for the panel which includes heterogeneous cointegration (Hamit-Haggar, 2012). The FMOLS technique modifies least squares to account for serial correlation effects and test for the endogeneity in the regressors that result from the existence of co-integrating relationships (Kalim and Shahbaz, 2009). The DOLS estimator had the same asymptotic distribution as that of the panel FMOLS estimation, and also corrects for some of the bias caused by the endogeneity problem (Månsson et al., 2018). Given the higher chance of endogeneity persistence in our model, we use the FMOLS and DOLS models to deal with endogeneity issues effectively. The DOLS and FMOLS do not account for CD and heterogeneity. However, they were performed as shown to confirm the consistency of the outcome.

For causality check, the Dumitrescu and Hurlin (D-H) (2012) Granger non-causality test was applied. The D-H equation is given as:

$$y_{i,t} = \omega_i + \sum_{i=1}^{p} \lambda_i^{(p)} y_{i,t-n} + \sum_{i=1}^{p} \vartheta_i^{(p)} x_{i,t-n} + \mu_{i,t} \quad (5)$$

The regression coefficient and autoregressive parameters are respectively $\vartheta_i^{(p)}$and $\lambda_i^{(p)}$.

4. Results presentation and discussion

Table 2 presents the largest and smallest mean values of EF as 21.92 and 18.88 for China and South Africa respectively. A look at the mean GR values confirmed India as the least developed country (6.918) and China is the richest with (9.887) (see Table 3).

Also, India has consumed more RE (45.72) than the other BRICS countries, while Russia consumed the lowest (3.443). Finally, HC development has improved more in China and Russia than in India.

Table 3 Confirms the existence of CD. Therefore, further analysis in this study takes CD into consideration. Table 4 shows the unit root results. All the variables are I (1). This provides the justification to check for cointegration.

Table 5 provides evidence of long-run relations among the selected variables. The Gt and Pt are both significant at 5% and 1% levels respectively. Therefore, we cannot deny the existence of a cointegrating relationship among the variables.

In the presence of cointegration, we applied the AMG, CCEMG, and PMG estimators to gain information on the interaction(s) among the variables (see Table 6).

The results in Table 6 confirmed how economic growth has contributed to environmental degradation in BRICS countries. The result was consistent across the three models. This result explains the fact that most of the BRICS countries are still developing. At the early stage of development, countries tend to pay little attention to the quality of their environment. The focus is always to achieve more growth while the environment deteriorates. These findings complement those of Nathaniel et al. (2020a), Khan et al. (2020), Danish et al. (2020), Ahmed et al. (2019) for MENA, Pakistan, BRICS, and Malaysia respectively, but

Table 2
Descriptive statistics.

Countries	Statistics	EF	GR	HC	NR	RE	UR
BRAZIL	Mean	20.10	9.176	0.799	1.085	3.777	4.404
	Std.D	0.096	0.137	0.148	0.524	0.178	0.038
	Max.	20.26	9.392	1.058	1.820	3.894	4.454
	Min.	19.91	8.960	0.572	0.191	2.952	4.323
	Obs.	25	25	25	25	25	25
RUSSIA	Mean	20.44	9.029	1.150	2.515	3.443	4.297
	Std.D	0.096	0.273	0.059	0.459	0.751	0.003
	Max.	20.74	9.367	1.220	3.076	4.038	4.306
	Min.	20.28	8.613	1.025	1.354	0.000	4.295
	Obs.	25	25	25	25	25	25
INDIA	Mean	20.76	6.918	0.602	1.089	45.72	3.369
	Std.D	0.244	0.348	0.094	0.363	11.67	0.076
	Max.	21.16	7.535	0.742	1.994	57.23	3.502
	Min.	20.41	6.388	0.426	0.564	0.000	3.257
	Obs.	25	25	25	25	25	25
CHINA	Mean	21.92	9.887	0.805	1.135	21.11	3.706
	Std.D	0.343	0.602	0.076	0.576	9.149	0.220
	Max.	22.38	8.836	0.930	2.293	32.93	4.038
	Min.	21.40	6.906	0.654	0.229	0.000	3.339
	Obs.	25	25	25	25	25	25
S/AFRICA	Mean	18.88	8.783	0.820	1.581	16.57	4.076
	Std.D	0.146	0.123	0.115	0.394	3.592	0.064
	Max.	19.08	8.933	1.016	2.560	19.12	4.179
	Min.	18.64	8.615	0.663	0.806	0.000	3.971
	Obs.	25	25	25	25	25	25
PANEL	Mean	20.42	8.359	0.820	0.835	2.960	3.971
	Std.D	1.007	0.916	0.204	0.720	0.955	0.400
	Max.	22.38	9.392	1.220	3.076	4.047	4.454
	Min.	18.64	6.388	0.426	0.191	1.171	3.257
	Obs.	25	25	25	25	25	25

Source: Author's computation.

Table 3
Cross-sectional dependence test.

Variables	Breusch-Pagan LM	Pesaran scaled LM	Pesaran CD
Ecological Footprint (log)	120.9476***	24.80864***	8.624062***
RE (log)	89.61399***	17.80223***	6.952330***
UB (log)	220.4439***	47.05669***	14.80967***
NR (log)	103.0209***	20.80011***	9.853895***
HC (log)	232.8613***	49.83330***	15.25191***
GR (log)	221.8660***	47.37468***	14.89063***

Note: *** imply statistical significance at the 1% level.
Source: Author's computation.

Table 4
Panel Unit Root Tests

Variables	Level		First Difference	
	CIPS	CADF	CIPS	CADF
EFP (log)	−3.061	10.11	−4.152***	23.13***
HC (log)	−1.468	12.01	−2.306***	32.32***
GR (log)	−1.724	13.22	−3.783***	42.12***
UB (log)	−0.355	15.24	−1.801***	42.56***
NR (log)	−2.905	21.66	−5.509***	34.21***
RE (log)	−2.401	24.03	−3.662***	43.29***

Source: Authors' Computations

contradicts the findings of Ulucak et al. (2020), Ahmed et al. (2020a) and Liu et al. (2020) for BRICS and G7 respectively. The discrepancies in the findings could be as a result of the region considered or/and the estimation technique adopted.

Similarly, NR increases the EF across the three estimations. BRICS countries are endowed with lots of resources, and mostly explore these resources to gain foreign exchange. The aftermath of such resource exploration could result in deforestation and other activities that could be harmful to the environment. These results are analogous to the studies of (Hassan et al., 2019a; Ahmed at al. 2020b) but contradicts those of (Zafar et al., 2019; Danish et al., 2019). This finding is revealing. It portrays how the extraction, as well as, the consumption of NR have not been sustainable in BRICS countries. China leads coal production in the world. South Africa is also known for coal mining. Joshua and Bekun (2020), Udi et al. (2020), and Joshua et al. (2020) had earlier confirmed the contributions of coal consumption to pollution in South Africa. Adedoyin et al. (2020) further reported the negative impact of coal on the environment in BRICS economies. Ahmed et al. (2020b) discovered that NR increases EF in China.

Table 5
Cointegration results.

Statistic	Value	Robust P-value
Gt	−3.176*	0.016
Ga	−4.144	0.986
Pt	−5.213***	0.005
Pa	−2.494	0.762

Note:***and * show significance at 1% and 5% levels.
Source: Author's computation.

Table 6
CCEMG, AMG, and PMG results.

Variables	CCEMG	AMG	PMG
GR (log)	0.7566 (4.15)	0.5509 (3.60)	0.6362 (5.35)
NR (log)	0.0115 (2.39)	0.0176 (2.21)	0.0400 (2.88)
RE (log)	−0.4014 (−4.81)	−0.2582 (−2.40)	−0.0118 (−4.42)
HC (log)	−0.0212 (−0.02)	−0.2249 (−0.04)	−0.5628 (−1.85)
UB (log)	−2.6067 (−0.55)	7.4025 (1.27)	−1.0489 (−1.15)

Note: The t-values are in parenthesis. The selected model for the PMG based on AIC was ARDL (1,1,1,1,1,1).
Source: Author's computation.

The effect of urbanization on the EF is still unclear. The results appear to vary, but the majority of the results (FMOLS, AMG, and DOLS) confirm the harmful impact of urbanization on the environment in BRICS. South Africa is the most urbanized country in Africa (Salahuddin et al., 2019). India, Brazil, Russia and China also have issues of urbanization. This is consistent with the findings of Ahmed et al. (2020) and Nathaniel et al. (2019). Urbanization encourages more energy consumption. It intensifies social and economic activities which increase energy demand (Lin and Du, 2015; Zhou et al., 2012). In BRICS, the high urbanization rate could be attributed to industrial advancement which comes with low energy efficiency and lots of energy consumption. Another way urbanization promotes ecological distortion is through waste generation and infrastructure demand (Ahmed et al., 2020b).

Unlike NR and economic growth, RE reduces the EF. This outcome is consistent with the studies of Danish et al. (2019) and Danish et al. (2020) for BRICS, Charfeddine and Kahia (2019) for MENA, and Destek and Sinha (2020) for OECD. This points to the fact that when renewables are consumed, environmental quality is enhanced. BRICS countries have invested a lot on renewables, which is beginning to yield results. This has placed them on the pathway toward achieving the SDGs by 2030. Human capital reduces the EF, though insignificantly. The justification for this hinges on the fact that human capital has been an important factor in the development of the BRICS countries via growth in educational attainment. Educated human capital promotes demand for a clean environment and is key for energy-saving, efficient use of NR, environmental preservation, and innovation. This complements the studies of Ahmed et al. (2020b) for China, Ahmed et al. (2020a) for the G7, and Zafar et al. (2019) for the US.

A second look at Table 6 showed NR and economic growth have a higher coefficient than human capital. Furthermore, the additive effects of NR and economic growth will supersede the negative effect of human capital. Therefore, one might conclude that the efficiency of human capital towards environmental sustainability is lower in BRICS. Suffice to say that human capital is still not at a desirable level where it can significantly reduce the EF. However, BRICS countries still need to improve on their human capital development strategy so as to gain more meaningful results as it relates to their growth trajectory and environmental sustainability.

Table 7 confirms the findings in Table 6. This reaffirms the robustness of our findings. Therefore, similar explanations apply. The need for a causality test arises amidst cointegrating relationship among variables since effects differ from causation. The country-specific results are in harmony in terms of the deteriorating impact of economic growth, and the abating role of RE on the environment, similar to Danish et al. (2020) for BRICS. NR appears to be environmentally-friendly only in Brazil, but hazardous in Russia, India, South Africa, and China. Human capital reduces the EF in all the countries except China. This contradicts the findings of Ahmed et al. (2020b). The reason for the divergence in findings could be due to the estimation technique. More so, theirs was a time-series study (see Table 8).

The impact of urbanization on the environment is mixed. It is harmful in Brazil, Russia, and South Africa, but not in China and India. BRICS economies need to be diversified. Economic growth need not come only from NR exploration.

In Table 9, NR causes EF, UB, and RE, GR causes HC and UB, RE drives UB, while a bidirectional causality exists between EF and HC, UB and EF, RE and GR, and UB and HC. These findings reaffirmed that NR abundance can actually drive environmental degradation, and promote urbanization. It further shows that NR consumption/exploration has not been sustainable in BRICS, as natural resources are not allowed to regenerate. This amounts to lose in biocapacity and increase the EF further. Also, economic growth could enhance Human capital development. The bidirectional causality between EF and human capital shows how they are intrinsically linked. Human capital development could be a panacea for environmental deterioration. The relationship between GR and RE is intuitive. It lays credence to the fact that the adoption of renewables (that is, clean energy sources) can actually promote economic growth. One factor responsible for the persistent growth in BRICS is the adoption of RE. Studies like Khobai and Le Roux (2017) and Khobai and Le Roux (2018) discovered the same direction of causality for South Africa.

5. Conclusion

This study investigated the linkage between NR, RE, HC, UB, and EF in BRICS from 1992 to 2016. Findings revealed that NR and economic growth increase the EF, RE decreases it, while HC is not developed enough, and therefore its influence remains insignificant. It was discovered that NR drives EF, UB and RE, GR Granger causes HC and UB, while RE causes UB. Further findings suggest a feedback causality between HC, UB, and EF. These findings necessitated some policy direction/implications.

First, sustainability practices should be followed in the exploration of NR in BRICS since the findings revealed that NR increases EF. The need for "green exploration" demands the improvements and enforcement in legislation that relates to mineral pollution, soil, and water in BRICS. This will not only reduce pollution but also ensure environmental sustainability. The consumption of low polluting natural resources like wind, solar, hydropower, etc. will allow for resource regeneration, protect the biodiversity, and reduce the EF with less NR depletion. More so, forests should be protected through penalties for violators.

The results revealed that human capital is not at a desirable level to efficiently mitigate pollution and ensure environmental sustainability in BRICS. Human capital development can mitigate pollution and environmental deterioration in various ways. BRICS countries must now shift attention to improving their human capital resources so as to avoid further environmental pressure and distortions. When people are educated, they will aim for cleaner energy sources and able to protect their environments better. Apart from human capital development,

Table 7
Robustness check with FMOLS and DOLS.

Variables	FMOLS	DOLS
GR (log)	0.1608 (2.86)	0.3603 (1.82)
NR (log)	0.0476 (2.57)	0.0379 (2.14)
RE (log)	−0.0065 (−4.33)	−0.0193 (−2.30)
HC (log)	−0.0817 (0.73)	−0.2044 (−1.77)
UB (log)	0.9273 (5.25)	5.4378 (3.87)

Source: Author's computation.

Table 8
Country-specific FMOLS results.

Countries	lnGR	lnNR	lnHC	lnRE	lnUB
Brazil	0.75 (15.52)	−0.05 (−9.48)	−0.46 (−6.17)	−0.03 (−2.70)	1.98 (10.47)
Russia	0.37 (17.95)	0.05 (5.64)	−1.70 (−14.72)	−0.05 (−1.09)	2.56 (1.56)
India	0.86 (19.48)	0.01 (5.68)	−0.04 (−1.05)	−0.69 (−30.80)	−2.13 (−11.68)
China	0.34 (18.84)	0.02 (−12.32)	1.02 (9.06)	−0.59 (−38.33)	−0.82 (−11.05)
South Africa	0.00 (0.07)	0.10 (20.69)	−0.87 (−13.79)	−0.67 (−27.05)	2.88 (22.07)

Source: Author's computation. **Note:** The t-values are in parenthesis.

Table 9
D-H causality test.

Null Hypothesis	W-stat.	Zbar-stat.	Probability	Decision
*ln*GR → *ln*EF	8.550	5.522	3.E−08	No causality
*ln*EF →*ln*GR	8.443	5.428	6.E−08	
*ln*NR → *ln*EF	4.330	1.823	0.068	Unidirectional causality
*ln*EF →*ln*BR	3.708	1.278	0.201	
*ln*RE → *ln*EF	3.935	1.446	0.147	No causality
*ln*EF →*ln*RE	4.126	1.612	0.106	
*ln*HC → *ln*EF	5.550	2.892	0.003	Bidirectional causality
*ln*EF → *ln*HC	4.839	2.269	0.023	
*ln*UB → *ln*EF	6.527	3.748	0.000	Bidirectional causality
*ln*EF → *ln*UB	5.720	3.041	0.002	
*ln*NR → *ln*GR	4.095	1.617	0.105	No causality
*ln*GR → *ln*NR	2.013	−0.207	0.835	
*ln*RE → *ln*GR	5.295	2.624	0.008	Bidirectional causality
*ln*GR →*ln*RE	6.505	3.671	0.000	
*ln*HC → *ln*GR	9.204	6.624	1.E−09	Unidirectional causality
*ln*GR →*ln*HC	4.628	2.084	0.026	
*ln*UB → *ln*GR	9.808	6.624	3.E−11	Unidirectional causality
*ln*GR →*ln*UB	4.628	2.084	0.037	
*ln*RE → *ln*NR	2.835	0.495	0.620	Unidirectional causality
*ln*NR → *ln*RE	5.584	2.874	0.004	
*ln*HC → *ln*NR	3.144	0.783	0.433	Unidirectional causality
*ln*NR → *ln*HC	6.063	3.342	0.008	
*ln*UB → *ln*NR	3.605	1.188	0.234	No causality
*ln*NR →*ln*UB	3.344	0.959	0.337	
*ln*HC → *ln*RE	7.435	4.475	8.E−06	No causality
*ln*RE → *ln*HC	3.912	1.427	0.153	
*ln*UB → *ln*RE	7.869	4.851	1.E−06	Unidirectional causality
*ln*RE → *ln*UB	5.643	2.925	0.003	
*ln*UB → *ln*HC	4.763	2.203	0.027	Bidirectional causality
*ln*HC →*ln*UB	22.31	17.58	0.000	

Note: →represents "does not homogeneously cause," and all variables remained as earlier explained.
Source: Author's computation.

there is a need to intensify the consumption of renewables, as our findings suggest that RE is capable of ensuring environmental sustainability. Coal and oil, the major energy sources in most BRICS countries, are finite and pollutants. A gradual transition to clean consumption and production would not only reduce the EF but put these countries on the pathway to achieving SDGs 7 (Affordable and Clean Energy) and SDGs 6 (Clean Water and Sanitation).

A feedback causality between EF and UB indicates that urbanization could be detrimental to the environment. Urbanization adds to the population of cities which already possess limited resources. Consequently, the demand for public utilities, electric appliances, commercial buildings, water, housing, energy, transportation, etc. increases which exacerbate pollution and drive climate change. This suggests that developmental issues like basic amenities, household income, and infrastructural provision are culpable for the increased urban population. It is when the aforementioned factors are missing in rural areas that people will see the need to move to urban centres. As such, urban sustainability should interest policymakers in BRICS countries. Policymakers can motivate the urban population to imbibe a sustainable lifestyle that is in consonance with recycling, energy-saving, and the usage of renewable energy instruments. The provision of the needed amenities in the rural areas is one of the ways to curb urbanization and all it anomaly while ensuring the feasibility of SDGs 11 (Sustainable Cities and Communities). Another way to deal with the menace created by urbanization is to introduce smart cities. Smart cities promote the quality and performance of urban services such as energy, transportation, etc. to achieve innovation, sustainability, and efficiency.

This study was constrained by data availability. Also, some determinants of EF were not considered. Future research could improve on these areas, and the study could as well be extended to other regions/economies.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resourpol.2020.101924.

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