Determinants of Material Footprint in BRICS Countries: An Empirical Analysis

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Determinants of material footprint in BRICS countries: an empirical analysis

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Abstract

This paper explores the relationship between renewable energy consumption, urbanization, human capital, trade, natural resources, and material footprint for BRICS countries from 1990 to 2016. We apply the cross-sectional dependency test to check the correlation among the cross-section. Then, we use the second-generation panel test like CADF and CIPS to check the stationary in the series. After that, we go for the panel cointegration test, i.e., Pedroni and Westerlund panel cointegration, to know the long-run relationship of the variable. The test results reject the null hypothesis of no cointegration among the variables and accept cointegration. The long-run results indicate that economic growth, natural resources, renewable energy, and urbanization have reduced the environmental quality for BRICS countries in case of material footprint employed to measure environmental degradation. However, foreign trade, human capital improves environmental quality. Based on the empirical results, the study recommended some important policy suggestions to achieve sustainable development in BRICS countries.

JEL classification: *Q20; C23; Q50*

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Abstract

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1. Introduction

Climate is changing at an unprecedented rate in the world. It poses a severe threat to humanity, natural life, and the global sustainable environment. The leading cause of climate change is the increase in greenhouse gases *(hereafter, GHGs)* into the atmosphere. Human activities, such as the production and consumption of non-renewable energy, forest clearing, etc., are responsible for the GHGs, which leads to global warming. The repercussion of global warming is gigantic both for humans as well as for the ecosystem. Rising sea levels, intense floods, drought, melting ice, massive loss of animal and plant species are the most visible global warming impact of the United Nations Framework Convention on Climate Change (2019). The energy sector is the largest emitter (around 68 %) of the global GHGs, and coal accounts for 30 % of the GHGs. Even though the world energy demand grew by 2.3 % in 2018, it rose in the global carbon dioxide (hereafter, CO_2) emission to 1.7 % International Energy Outlook (2018).

Until the emergence of the global financial crisis in 2008, the world witnessed enormous economic growth from 1990 to 2008. Industrializing economies in Asia converged towards high income developed economies as India's real gross domestic product per capita grew by 115 %, and China grew by 219 % Pothen and Welsch (2019). Industrialization always signifies the significant increase in energy use, extraction of non-renewable and renewable material Bruckner et al. (2012), which leads to emissions of GHGs.

Therefore, the world demand for materials during the same years rose rapidly. The extraction of minerals, biomass and fossil fuels increased to 69.7 billion tons in 2008 from 37.2 billion tons in 1990. Due to globalization and the free flow of international goods, material consumption has grown tremendously. Ansari et al. (2020) analyzed the environment-growth nexus by taking into account the material footprint and ecological footprint as a holistic measure of human pressure on the environment for Asian countries. Their finding supports the existence of the Environmental Kuznets curve (EKC), which means that environmental quality degrades during the initial phase of economic growth due to increased material consumption. After a certain level of economic development, environmental quality improves. Pothen and Welsch (2019) also examines the relationship between economic growth and material use for 144 countries between 1990 & 2008 but did not find evidence of decoupling material used for economic activity.

The rapid industrialization linked with significant increases in material consumption poses a severe threat to the environment, such as soil, water, air pollution, loss of biodiversity, and GHG emissions of GHGs. According to IEA (2010), the growth rate in GHGs increased hugely from the emerging economies in Asia.

For this reason, Wiedemann et al. (2015) developed a consumption-based indicator of natural resources, which is called Material Footprint. It measures the pressure on the natural resources and the material demand from the higher-income countries. They indicate it as another measure to examine cross-country sustainability apart from Ecological Footprint.

Most studies in the existing literature employ CO_2 emissions to measure environmental pollution. Co2 emissions as a sole measure of environmental degradation are not sufficient because it does not include other significant pollutants contributing to environmental degradation (Wackernagel and Rees, 1998; Al- Mulali et al. 2015; Ulucak and Apergis, 2018). CO_2 emissions are not a comprehensive measure of environmental hazards because hazards are limited to the atmosphere (Nathaniel et al. 2020b). Therefore, there has been a universal call for a more comprehensive indicator of environmental pollution. In this study, we use Material Footprint to measure environmental sustainability, which is a broader measure than CO_2 emissions solely as an indicator for environmental pollution (Ansari et al. 2020; Södersten et al. 2020).

The current study focuses on the major emerging economies globally, i.e., Brazil, Russia, India, and China & South Africa *(hereafter, BRICS)* countries for the following reasons: BRICS countries have become a significant player in global economic development. BRICS countries account for forty-two per cent (42%) of the world population, fifteen per cent (15%) of the world trade, and forty per cent (40%) of currency reserve. BRICS countries also contribute twenty-five per cent (25%) of the global GDP (Siddiqui 2016; Ahmed 2017). The average annual growth rate of BRICS countries is around 6.5 per cent World Development Indicator (2017). It is also projected that China and India will become the 1st and 2nd largest economies globally.

In contrast, Russia and Brazil will become the 5th and 6th largest economies behind Japan by 2050 (Siddiqui, 2016). Over the past decades, this considerable economic growth in this region has led to several resource consumption and environmental issues. In 2013, BRICS countries emitted more than forty per cent (40%) of global CO_2 emissions Liu (2017). There has always been a trade-off between economic growth and environmental quality. Therefore, to better understand the dynamics of the environment and economic development and reverse the current trend in the BRICS countries, robust policies are required.

Due to rapid industrialization and urbanization, it has led to considerable economic improvement over the past decades (Nathaniel and Khan, 2020). Still, these are the factors responsible for environmental degradation. Urbanization, solely, has caused the seventy per cent (70%) increase in CO_2 emissions, and it will continue to rise (around 76%) by 2030 International Energy Outlook (2019). Another important factor responsible for environmental degradation is international trade. Though globalization has brought the world closer, this has increased in the traded goods and material. Therefore, these traded goods and materials have a social, economic, and environmental impact on the world.

According to the World Development Indicator (2018), around seventy percentages (70%) of the world energy demand is attained by non-renewable energy. BRICS economies also depend heavily on non-renewable energy; in 2013, it accounted for more than thirty-five per cent (35%) of the global total. Global metal ore extraction tripled to 7.4 billion tons from 1970 to 2010, out of which fifty-four per cent (54%) is used by BRICS Tian et al. (2020). China and India are expected to use more natural resources in the future. Therefore, in the future, all this poses significant environmental challenges for the BRICS region. It makes the BRICS region an attractive case study because it is at a crossroads in new natural resource management and ecological Nathaniel et al. (2020).

Against this background, this study analyzed the effect of economic growth, renewable energy, human capital, urbanization, and trade on the Material Footprint. This study enriches the existing literature in the following way: i) the majority of previous studies in the context of BRICS have used CO_2 emissions and Ecological Footprint as an indicator of environmental sustainability; this is the first study to the best of our knowledge which has used Material Footprint as an indicator of the sustainability in the BRICS region. ii) We have also included human capital (based on school enrollment) in our model because education plays a vital role in improving environmental quality. iii) We have employed the advanced econometrics technique that gives robust estimates in the presence of endogeneity, cross-sectional dependence, and serial correlation.

Our results suggest that economic growth increases the material footprint in the BRICS region. Our findings are in line with (Wiebe et al., 2012; Pothen and Welsch, 2019; Ansari et al., 2020), which also finds that economic growth leads to a substantial increase in material extraction and which leads to deterioration of the environmental quality. We also find that natural resources, urbanization shows a positive and significant relation with material footprint. The previous studies (Zarzoso and Maruotti, 2011; Shahbaz et al. 2016; Adams and Nsiah, 2019; Bekun et al. 2019) find similar findings. We also seek to examine the possible effect of Human capital on material footprint and see that it helps conserve the environment. Next, we find an inverse relationship between foreign trade and material footprint. Our findings are in line with the seminal paper findings by Wiedemann et al. (2015), which shows that the fastest-growing countries India and China, have attained a relative decoupling for both material footprint and domestic material consumption while South Africa have achieved absolute decoupling. This study will help better understand the BRICS country scenario because of their growing energy demand, their contribution to GHGs, and their commitment to environmental sustainability and conservation.

The rest of the study is organized as follows. Section 2 is devoted to the Review of the literature. Section 3 discusses the data and econometric methodology. Section 4 provides the results. Section 5 concludes with a particular policy recommendation.

2. Review of literature

Extensive empirical studies have been carried out to investigate the underlying forces responsible for environmental degradation. Although CO_2 emissions are the leading cause of climate change, most research used this to measure environmental pollution. However, it has been blamed for using it as the primary proxy for environmental emissions as it ignores other significant contaminants that contribute to environmental degradation (Al-Mulali et al., 2015). Material consumption has also improved over the year and has been a considerable resource quality measure. Due to globalization and the free flow of international goods, material consumption has increased tremendously. For that reason, Wiedmann et al. (2015) developed a consumption-based indicator of natural resources called material footprint (MF). Hence we are considering MF as a proxy of environmental quality. This paper investigates the effect of renewable energy, human capital, urbanization, and trade on the MF.

2.1. Renewable energy, economic growth, and environmental quality

The number of studies that analyzed the relationship among renewable energy, economic growth, and environmental quality (Ozturk and Acaravci, 2010; Nassani et al. 2017; Destek and Sarkodie 2019; Baloch and Wang 2019; Khan et al. 2020; Ahmed et al. 2020). Some studies also investigate the environmental Kuznets curve (EKC) hypothesis like (Zhao et al., 2016; Ozatac et al., 2017; Pata, 2018; Dogan & Turkekul, 2018; Lin & Zhu, 2018; Salim et al., 2018; Ansari et al. 2019; Ansari et al. 2020a). A recent study by Ansari et al. (2020) examined the EKC in the Asian sub-region and found that in regions like central and East Asian countries, there is an existence of EKC hypothesis, and regions like west, south, and Southeast Asia does not validate the EKC hypothesis. Nathaniel et al. (2020c) explore the relationship between renewable energy consumption, urbanization, and environmental degradation. They have found that financial development, economic growth, and urbanization enhance environmental degradation in MENA regions. Few studies also discussed the determinants of environmental degradation with the macroeconomics variables like financial development, trade, economic growth are (Beckerman, 1992; Zhengge, 2008; Jalil & Feridun, 2011; Khan et al., 2018; Wang et al., 2018; Ali et al., 2019; Lv & Xu 2019; Mahmood et al., 2020; Abdouli & Hammami, 2020). The studies found that the determinants like urbanization, renewable energy, and economic growth reduce environmental degradation (Martínez & Maruotti, 2011; Zhang et al. 2015; Aye & Edoja, 2017; Sahoo and Sahoo, 2020a; Sahoo and Sahoo, 2020b). Ansari et al. (2020c) examined the relationship between the energy-growth-environment relationship with top 10 carbon dioxide emitters countries. They found that the EKC hypothesis is not valid for all countries except the USA.

Another strand of literature explores the relationship between renewable energy consumption and economic growth. Some studies found a positive relationship between renewable energy consumption and economic development (Leitao, 2014; Soava et al. 2018;

Ntanos et al. 2018). However, a study by Menegaki (2011) in 28 EU countries using panel regression analysis found that renewable energy does not significantly affect economic growth in the study period. Lean and Smyth (2013) used disaggregated energy consumption data like petrol, diesel. The results demonstrate that diesel and petrol are driving factors for economic growth. Apergis and Danuletiu (2014) empirically examined the relationship between non-renewable energy, renewable energy consumption, and economic development. They determine the positive relationship between renewable energy and economic growth and the causality of renewable energy to real GDP.

The researchers also investigate the role of energy efficiency for mitigating environmental quality in firm-level and country-level data case and suggest that with improved technologies and cross-border spending in performance improvement programs, materials, and energy efficiency should be enhanced (Haider and Ganaie, 2017; Haider and Bhat, 2018; Haider and Bhat, 2019; Haider et al. 2019; Haider and Mishra, 2019). The renewable energy sector transition is increasing nowadays to protect the environment. In this scenario, material technology plays an essential role in meeting the growing demand for energy in the economy (Starr, 2006). Giurco et al. (2019) Suggest that with the fast green energy growth and the transport system electrification needed in the 1.5 °C scenarios, the demands for resources, especially cobalt and lithium, are also growing significantly. The OECD (2015) reported that it needs aggressive policies to address these challenges scale to promote a significant increase in resource usage, mainly through technological progress and innovation. The push for better resource quality will generate new goods, markets, and job prospects. Karakaya et al. (2020) state that "there are many techniques that are deemed effective in increasing material quality, i.e., using fewer for material design, repair, reuse, and recycling ".

2.2. *Natural resources, human capital, urbanization, and environmental quality*

Researchers and policymakers have used different indicators to investigate environmental quality. Some of the studies have used CO_2 emissions as an indicator for measuring environmental quality (Shahbaz et al., 2020a, Nathaniel & Iheonu, 2019; Shahbaz et al., 2020b; Baloch et al., 2019; Mahmoodi, 2017; Pata, 2018). A study by Adams & Nsiah (2019) explores the linkage between renewable energy consumption, urbanization, and CO_2 emissions in Sub-Saharan countries. They have applied FMOLS and GMM techniques to analyze the results. They found that renewable energy consumption positively affects CO_2 emissions; however, urbanization reduces it. A similar study by Menyah & Wolde-Rufael (2010) argued that "green energy use has not achieved a stage where it will make a meaningful contribution to reducing pollution". However, Bilgili et al. (2016) examined the relationship between renewable energy consumption, economic growth, and CO_2 emissions in OECD countries. They found that renewable energy consumption has reduced CO_2 emissions in the study period. They argue the need for appropriate environmental policies should be implemented, and residents should meet industrial energy demand through renewable energy production. While some of the studies are neutral about the relationship between renewable energy consumption and CO_2 emissions, Pata (2018) empirically examined Turkey's case using ARDL and cointegration technique. They found that economic growth has a maximum effect on environmental degradation, followed by financial development and urbanization. Nevertheless, renewable energy consumption and hydropower energy consumption does not affect environmental degradation.

On the opposite, a much greater understanding of the connection between natural resources, economic growth, and environmental quality helps decision-makers and government officials minimize environmental emissions and stimulate growth in renewable energy sectors. A recent study by Ulucak & Khan (2020) examined the relationship between renewable energy consumption, economic development, and ecological footprint (EF) in the BRICS economies.

They argued that urbanization increases transport and industrialization demand and, in particular, increases the energy consumption of fossil fuel and the EF. Similarly, some of the papers which discussed the linkages between renewable energy, natural resources, urbanization, and environmental quality in BRICS economies are (Sebri & Ben-Salha, 2014; Zakarya et al., 2015; Wu et al., 2015; Adedoyin et al., 2020; Azevedo et al., 2018; Nathaniel et al., 2020b). There are many studies has investigated in different countries like Sub-saharan countries (Inglesi-Lotz & Dogan, 2018), for Turkey (Pata, 2018); for Latin American and Caribbean countries (Nathaniel et al., 2020a); for Europe (Al-Mulali et al., 2015; de Souza et al. 2018); for Pakistan (Alam et al., 2007; Shaheen et al., 2020; Ali et al., 2020; Hassan et al., 2019), for India (Wang et al., 2018; Alam et al. 2019).

From the above empirical literature, we can conclude that there are mixed results regarding the linkage between renewable energy consumption, urbanization, and environmental degradation in different countries. It may be due to their economic structure and environmental policies towards controlling environmental pollution. However, various studies have taken various environmental indicators like carbon dioxide emissions and ecological footprint as a proxy for measuring environmental quality. This paper adopts material footprint(MF) as recommended in a previous research paper (Giljum et al., 2015; Berrill et al., 2020; Ansari et al., 2020b; Karakaya et al., 2020). In light of the above factors, the goal is to explore the determinants of MF in five BRICS countries by using advanced panel techniques, including renewable energy, urbanization, and natural resources. This study period is constrained from 1990 to 2016 for BRICS countries as per the data limitation. The study contributes to the existing literature by looking at MF instead of carbon emissions because BRICS countries face challenges relating to high material extraction to meet the growing demand.

3. Data and econometrics methods

3.1. Data

The study has covered the sample period from 1990 to 2016 for BRICS (Brazil, Russia, India, China, and South Africa) to explore the relationship between renewable energy, urbanization, human capital, and material footprint. All variables were transformed into logarithmic form to reduce the data sets fluctuation (Villanthenkodath & Arakkal, 2020; Sahoo and Sahoo, 2020a; Sahoo and Sahoo, 2019). This study Following (Ansari et al., 2020b; Nathaniel et al., 2020b) the specification of the model is as follows:

$$MF_{it}=f\,(GDP_{it}, HC_{it}, NR_{it}, TR_{it}, REN_{it}, URB_{it}) \qquad (1)$$

Where material footprint (MF), gross domestic product per capita (GDP), human capital (HC), natural resources (NR), trade (TR), renewable energy (REN), and Urbanization (URB). More specifically, Global raw materials have simply been extracted to facilitate the sale to other countries of goods and services. As BRICS is an emerging country, people are mining and exploiting growing quantities of earth natural resources. Overconsumption in developing countries of natural resources and the environmental implications of emerging countries have been serious, For example, deforestation, water scarcity, and climate change. It is necessary to estimate the material extraction in emerging countries and its consequence on the environment. Some studies also highlighted domestic material consumption (Dittrich et al., 2012). Wang et al. (2012) state that the recent use of the resource investigated driving factors in China, the wealth factor most contributed to rising the direct input of materials. A material footprint is a special form of environmental footprint which assesses natural resources (biomass, fossil fuels, metal ores, and non-metal ores) measure in units of a tonne. In the above equation, i and t represent country and time, respectively. The above functional form can be written as a log-linear model:

$$lnMF_{it} = \beta_{1i}lnGDP_{it}+ \beta_{2i}lnHC_{it}+ \beta_{3i}lnNR_{it}+ \beta_{4i}lnTR_{it}+ \beta_{5i}lnREN_{it}+ \beta_{6i}lnURB_{it}+\varepsilon_{it} \qquad (2)$$

From the above equation (2) β_{1i}..... β_{6i} symbolizes the elasticity of material footprint, gross domestic product per capita, human capital, natural resources, trade, renewable energy, urbanization, and ε_{it} is the error term for BRICS economies. The measurement and sources of the variables are presents in table 1.

--Insert Table 1--

3.2. Econometrics methods

We have to look at the fact that either the data we obtain has the characteristics of cross-sectional dependency or independence. We selected the cross-sectional dependency test of Pesaran (2004) for this reason. The null hypothesis of the CD test is variables are cross-sectional independent, but the alternative hypothesis is they are cross-sectional dependent.

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \quad (3)$$

It is significant that when cross-sectional dependence occurs between cross-sections, then unit-root tests of the second generation are more suitable than unit root tests of first-generation (LLC and ADF). The analysis thus applies the unit root tests for each panel time-series data to the CADF and CIPS technique along with LLC. Both tests have a similar implementation process, except for the cross-sectional average of CADF test is CIPS. Based on the Dickey-Fuller Augmented approach (ADF), the model of panel unit root tests follows:

$$\Delta w_{it}=\alpha_i+\beta_i w_{i,t-1}+\rho_i T+\sum_{j=1}^{n}\delta_{ij}\Delta w_{i,t-1}+\varepsilon_{it} \quad (4)$$

The w_{it} represents variables, ρ is deterministic components, δ level of significance, and ε is error term in the model. Pesaran (2007) has developed the second generation unit of root testing of cross-sectional ADF (i.e., CADF) and cross-sectional IPS (i.e., CIPS). The cross-sectional IPS (CIPS) equation is the following:

$$CIPS=\frac{1}{N}\sum_{i=1}^{N}CADF_i \quad (5)$$

Where, $CADF_i$ is the cross-sectional augmented dickey fuller test, and N is the number of observations. After getting the CD and root tests results, we applied the second generation panel cointegration test and the Pedroni cointegration test. Pedroni (1999, 2004) developed seven different test statistics using the results obtained from panel cointegration regression to test the null hypothesis. Test statistics are calculated by following Eqs. (6) and (7)

$$y_{it} = \beta_{it} + \alpha_{it}t + \delta_i X_{it} + \epsilon_{it} \quad (6)$$

$$\Delta y_{it} = \delta_i \Delta X_{it} + \eta_{it} \quad (7)$$

The Westerlund (2007) cointegration, consider cross-sectional dependency. The significant advantage of Westerlund's cointegration test is that it produces accurate cross-sectional dependence results; it can be used in a small sample. The next step is to know the long-run relationship between renewable energy, natural resources, human capital, trade, urbanization, and material footprint. We apply a fully modified ordinary least square (FMOLS) to check the variables' long-run elasticity. Mathematically the FMOLS model as being written as follows:

$$\hat{\beta}_{i\,FMOLS} = N^{-1} \sum_{i=1}^{N} [\sum_{t=1}^{T} (Y_{it} - Y_i^*)^2]^{-1} \quad (8)$$

Where Y_{it} = $2(K+1) \times 1, \widehat{Y_{it}}$=$(X_{it} - X_i^*)$, X_i^* is the average ofX_t, ΔX_{it-k} = differential term of X. The results of the FMOLS model is presents in table 9. It is essential to know the causality of the stated variables in this study. The Granger (1969) non-causality test is extended by Dumitrescu and Hurlin (2012), and the new approach proposed for the checking of the causal direction between the explanatory variables.

$$y_{it} = \alpha_i + \sum_{i=1}^{k} \gamma_i^{(k)} y_{i,t-k} + \sum_{i=1}^{k} \beta_i^{(k)} x_{i,t-j} + \mu_{it} \quad (9)$$

$k \in N^+$ And$k \in N^*$, $\beta_i = (\beta_i^{(1)} \dots\dots\dots, \beta_i^{(k)}$ α_i $\gamma_i^{(k)}$ $\beta_i^{(k)}$ and α_i, $y_i^{(k)}$ and $\beta_i^{(k)}$ indicate constant term, lag parameter and coefficient slope, respectively.

4. Result discussions

4.1 Descriptive statistics and trend analysis

Table 2 highlight the summary statistics for the panel, in which the highest average mean for the material footprint (21.49) followed by economic growth (8.32), human capital (4.31), urbanization (3.96), trade openness (3.64), natural resource rent (148) and renewable energy consumption (0.992), respectively. The median value is almost close to the mean for all the variables. In terms of variances, material footprint (1.20%) has the high variance followed by economic growth (0.95%), natural resource rent (0.71%), renewable energy consumption (0.67%), urbanization (0.40%) and human capital (0.31%), respectively.

--Insert Table 2---------------------------------------

In Table 3, the emerging country-wise mean value of each variable is reported during 1990-2016. It is evident from the result that the highest material footprint use was reported in China (23.29). India stands at the second position (22.03), and South Africa reported the least material footprint use. However, the emerging economy average material footprint use stands at (21.49). In terms of per capita GDP, Brazil (9.163) and Russia (9.039) in the top two, followed by South Africa (8.77) and China (7.76). India stands at last in per capita income among these emerging economies. It indicates that countries differ in terms of economic growth. The highest human capital is in Brazil (4.51), and the lowest human capital is in India (3.97). Russia stands at the top in natural resource rent (2.49), whereas the emerging economics average stands (1.48). The trade openness of each emerging economy is almost equal to the average, i.e.; the economies follow similar trade openness practices. In terms of renewable energy consumption, these emerging countries have a different pattern. China is the top renewable energy-consuming country, whereas South Africa is the least renewable energy-consuming country among these emerging countries. The top two urbanization positions go to Brazil and South Africa, whereas the least urbanized country among the emerging country is India.

--Insert Table 3---------------------------------------

Fig. 1 shows the pattern of the employed variables during 1990-2016 for the BRICS countries along with global economic variations. Material footprint follows a similar pattern for all the nations. It is also evident that per capita GDP is higher for Russia and Brazil. A rising trend for human capital is visible for all the emerging countries. Similarly, renewable energy consumption shows an upward trend for all countries. In the case of renewable energy consumption in Russia, a significant fall can be observed from the beginning of the 1990s. It may be due to the destruction of the USSR.

In contrast, natural resource rent shows a declining trend during the period for all the panel units. Openness and urbanization of these countries are also increasing during the study period. From the plot, it unveils that the urbanization process is more rapid in China. Moreover, similar increasing behaviour of urbanization for all the countries in the analysis.

---Insert Figure 1---

4.2 Correlations

Table 4 delineates the correlations among material footprint, economic growth, human capital, natural resource rent, trade openness, renewable energy consumption, and urbanization during 1990-2016. The result indicates that material footprint negatively correlates with economic growth, human capital, natural resource rent, trade openness, and urbanization, but it has a positive relation was exhibited with renewable energy consumption. Economic growth indicates a positive relationship with natural resource rent, trade openness, renewable energy consumption, and urbanization. It means that economic growth can push the variable positively. Trade openness and urbanization are positively influenced by natural resource rent, whereas renewable energy consumption negatively impacts natural resource rent. A positive relationship between trade openness and urbanization has been observed against a negative association between renewable energy consumption and trade openness. Again, a positive relation between urbanization and renewable consumption has been revealed. In sum, all the variables except renewable energy consumption negatively correlated with our dependent variable, i.e., material footprint.

--Insert Table 4--

4.3 Panel unit root tests results

The results in Table 5 demonstrate the empirical analysis of the integration order of the used variables. In the study, choosing the appropriate panel data econometric models sequentially, the first step is to determine the integration order of variables. The first step is critical because it gives directions about the series under consideration. To attain this goal in the study, authors employed the Levin, Lin, and Chu (LLC) unit root proposed by Levin et al. (2002). This unit root test works within the assumptions related to the general process of the unit root test. Hence, it has the null hypothesis of a non-stationary or unit root against the stationarity assumption associated with the alternative hypothesis. In the unit root testing process, the lag length section is important to overcome the inconsistent result; therefore, we have employed the Schwarz Information Criterion (SIC) in the LLC. The evolved results from LLC indicates that the null hypothesis has to accept for material footprint, economic growth, human capital, natural resource rent, trade openness, renewable energy consumption, and urbanization at the levels of the variables. In contrast, after taking the first difference of the variables, the results of LLC firmly reject the null hypothesis in the case of material footprint, economic growth, human capital, natural resource rent, trade openness, renewable energy consumption, and urbanization. All the variables except urbanization statistically significant at a 1 % level, but urbanization shows the statistical significance at 5% in the rejection of the null hypothesis. Therefore, it highlights that the variables are stationary at the first difference or variables are I (1) series.

--Insert Table 5--

4.4 Test for cross-sectional dependence and second-generation unit root tests

Table 6 reports the result of cross-sectional dependence proposed by Pesaran (2004). The alternative hypothesis of cross-sectional dependence has unanimously accepted by providing evidence against the null hypothesis regarding CD test statistics and its statistical significance. On the backdrop of cross-sectional dependence, we have to use those methods to consider the cross-sectional dependence to overcome the biased estimated results.

--Insert Table 6--

The motive behind employing the second generation panel unit root test is the presence of cross-sectional dependence in the data. Table 7 delineates the results of the CIPS and CADF panel unit root test. The outcome reveals that all the variables are non-stationary at their levels by accepting the null hypothesis. However, the variables follow the mean-reverting process in their first difference. The finding implies that the series under consideration is integrated at I (1). The findings evolved from the second generation unit root test is also support the first generation unit root, which does not consider the cross-sectional dependence.

--Insert Table 7--

4.5 Pedroni panel cointegration test

Table 8 reports the results of the Pedroni panel cointegration test proposed by Pedroni (1999, 2004). The Pedroni cointegration relay on the seven test statistics with two dimensions, i.e., within-dimension and between–dimension. In within-dimension, it uses Panel v-Statistic, Panel rho-Statistic, and Panel PP-Statistic for the cointegration analysis. Similarly, in-between dimensions it relies on Group rho-Statistic, Group PP-Statistic, and Group ADF-Statistic for the cointegration. The result reveals that four out of seven statistics, i.e., Panel PP-statistic and Panel ADF-statistic (within-dimension); Group PP-statistic and Group ADF-statistic(between-dimension), affirm the long-run association (cointegration) among the considered variables in the study. Hence, the Pedroni cointegration test based result concluded that the variables like the material footprint, economic growth, human capital, natural resource rent, trade openness, renewable energy consumption, and urbanization are in long-run cointegration equilibrium relation dynamics of the variables over the study period.

--Insert Table 8--

Table 9 reports the Westerlund panel cointegration test results. The test belongs to the second generation category and uses four error-correction-based panel cointegration tests. Moreover, it depends on the structural dynamics. The test takes no cointegration as its null hypothesis. The results reveal that out of four tests, two (i.e. Gt and Pt) have rejected the null hypothesis at a 5% and 1% level of significance, respectively. The result is possible to infer that the series are expected to move together in the long-run or cointegration existence. The mixed significance of the second generation cointegration outcomes are consistent with the cointegration finding observed by Usman et al. (2020) for the panel of Africa, Asia and America, where they observed some test statistics are not significant, but the study concluded in favour of long-run cointegration of the series. Further, this finding supports a Chinese region-based panel study by Liu (2013), where a mixed significance has revealed for the central region from the second generation cointegration. Therefore, it is possible to argue that if any of the second generation cointegration statistics is significant, then the series is the cointegrating series.

--Insert Table 9--

4.6 Long-run elasticity of panel data estimates

Results of long-run elasticity in the BRICS economies have displayed in Table 10. Fully modified ordinary least square (FMOLS) has been employed to estimate the long-run elasticity. The result revealed that the 1% increase in economic growth leads to a positive and significant increase in material footprint by 0.609%. This result is not surprising because economic growth is the outcome of production, which requires various kinds of raw material as an input; hence it degrades the environment by consuming the resources. This finding corroborates the need to feed the increasing population, economic growth is necessary, but it put pressure on natural resources. Hence, sustainability in natural resource use is vital in emerging economies. There are some kinds of literature found similar findings like (Khan et al., 2018; Zhengge, 2008; Jalil and Feridun, 2011; Abdouli and Hammami, 2020; Ali et al., 2019)

In contrast, an increase in human capital accumulation helps to reduce the material footprint significantly. More precisely, a 1% increase in the accumulation of human capital reduces the material footprint at a rate of -0.392%. It may be because people equip with education are cautious about their consumption. Moreover, in schooling, they may attain environmental education amid rising climate change across the globe. Therefore, human capital accumulation helps to improve environmental quality by preserving the material footprint. This finding is in line with the long-run coefficient by Nathaniel et al. (2020a) for Latin American and Caribbean countries in a CO_2 emissions-based study.

In the case of natural resource rent, the result reveals that a 1% increase in natural resource rent leads to a 0.310% increase in material footprint. The finding desirable since it indicates that natural resources exploration pushes economic growth by earning the revenue from exploration, which needs the depletion of the material footprint. This finding is in line with the long-run coefficient by Bekun et al. (2019) for 16-EU countries in a CO_2 emissions-based study.

Regarding the foreign trade is concerned, there exists a statistically significant inverse relationship with the material footprint. This finding is laudable, and the potential interpretation may be that national environmental policy stringency is related to the trade liberalization policies in the era of global warming and climate change. Hence, the trade liberalization policies can be classified into three categories, i.e., the scale effect, the composition effect, and the technique effect in line with Grossman and Krueger (1991). In trade liberalization policies, countries with a comparative advantage in dirty industries may be pushing technique effects over the other two effects, or countries with clean industries may be promoting technique together with the other two effects.

In terms of renewable energy consumption, there is a significant and positive relation with material footprint. Possible implication associated with this result could be that the renewable energy technologies that use renewable energy flows like solar and wind energy may be depleting the mineral resources in these countries. Another possible explanation may be that the resource is also depleting in renewable energy generation, thereby adversely affecting the environmental quality by increasing the material footprint. Our results support the findings of Adams and Nsiah (2019).

The result of urbanization also shows a positive and significant relation with material footprint. Since urbanization is a crucial driver that speeds up depletion, urbanization contributes to natural resource consumption. Suppose people move to urban areas for their settlement. In that case, there is a chance of deforestation, more energy consumption from both industrial and household levels, excess use of water, and so on. The previous studies like Martínez-Zarzoso and Maruotti (2011) for developing economies; Shahbaz et al. (2016) in the case of Malaysia and for Pakistan Ali et al. (2019) also similar to our findings. Figure 2 depicts the actual, fitted, and residual graph of the FMOLS model.

---Insert Table 10---

---Insert Figure 2---

4.7 Heterogeneous panel causality test

After validating the long-run relationship among variables, we examined the variables' causality using the heterogeneous panel non-causality test by Dumitrescu and Hurlin (2012).

Table 11 demonstrates the empirical results of the short-run panel causality test among the material footprint, economic growth, natural resource rent, renewable energy consumption, urbanization, and human capital. The pairwise heterogeneous panel causality test requires the stationarity of the variables under consideration. The study has transformed the variables at their first difference to obtain the objective of stationarity of the variables. The findings reveal that a unidirectional causality from economic growth to the martial footprint. Similarly, a one-way causality has been established from material footprint to human capital, natural resource rent, and renewable energy consumption to material footprint. However, a bidirectional causality has been established between trade openness and material footprint. A similar conclusion has reached between urbanization and material footprint. These findings from the panel causality tests show the importance of explanatory variables on the multivariate function of the material footprint, and its directions are valuable for the policy formulation.

--Insert Table 11--

5. Conclusion and policy implication

This paper aims to investigate the relationship between renewable energy consumption, urbanization, human capital, trade, natural resources, and material footprint for a balanced panel five BRICS countries over the year from 1990 to 2016. In this paper, we apply the cross-sectional dependency test to check the correlation among the cross-section. Then, as the first-generation panel unit root test is not appropriate, we use second-generation panel test like CADF and CIPS to check the stationarity in the series. After that, we go for the panel cointegration test, i.e., Pedroni and Westerlund panel cointegration, to know the long-run relationship among the variables. The results of both the test reject the null hypothesis of no cointegration among the variables, and hence we can conclude that all variables are cointegrated. We apply FMOLS to check the long-run relationship among the variables, and after that, for causality, we test the panel non-Granger causality test.

The long-run results revealed there is a positive relationship between economic growth and material footprint in BRICS countries. This finding is not unexpected, since the production is a pre-condition for economic growth, which needs different raw materials as an input, which degrades the environment through consumption of energy. In contrast, an increase in human capital helps to reduce the material footprint significantly. It may be because people equip with education may be cautious about their consumption. They will also gain environmental education during schooling in the sense of growing global climate change. Regarding the foreign trade is concerned, there exists a statistically significant inverse relationship with the material footprint. It is praiseworthy, and the likely explanation may be the national environmental policy strictness in the age of global warming and climate change applied to trade liberalization policies. In terms of renewable energy consumption, there is a significant and positive relation with material footprint. Possible implication associated with this result could be that the renewable energy technologies that use renewable energy flows like solar and wind energy may be depleting the mineral resources in these countries. The result of urbanization also shows a positive and significant relation with material footprint. Since urbanization is a crucial driver that speeds up depletion, urbanization contributes to an increase in natural resource consumption. The results of causality revealed that there is bi-directional causality between trade and urbanization with material footprint.

In the era of climate change and global warming, economic development should be sustainable (Mahalik et al. 2020; MK, 2020; Villanthenkodath and Mahalik, 2020). Hence, the emerging economies have to reduce the overexploitation of the resources that leads to environmental consequences as a part of economic activities. Therefore, in the emerging economies must policies must be aim to revert the resource consumption pattern to address climate change. The growth with overexploitation of natural resources is not sustainable for the long run; hence the economic agents should be cautious about the resource depletion and subsequent environmental degradation while performing the production process. The measurement of economic growth should consider both GDP and stock of wealth consisting the natural resources. Making economic growth more sustainable; there is a need for policies like introducing a price mechanism that consists of environmental degradation due to the individual or private activities. Further, deployment of new technology to mitigate environmental degradation due to economic grounds enhances sustainable development investments. The above-stated policies may be used as a catalyst for mitigating the climate change emerging from the consumption of resources., but the extent of the implementation depends on the existing institutional and social settings.

Moreover, enhancing energy efficiency in all the areas of economic activities, thereby reducing the use of resources like fossil fuels. Therefore, introducing new technology to improve efficiency in renewable energy use, doing so the countries can reduce pollution and power loss. If the countries do not have enough access to clean financing technology, they can receive foreign aid to mitigate environmental pollution from energy consumption. It is important to note that new technology has to be introduced from the production and exploration to the final energy consumption. However, energy efficiency is attainable only through energy conversion measures. The study also suggests a clear cut delineation of the regions and countries with a need for clean energy technology. Therefore, at the global level priority in the technology distribution has to be done accordingly.

The study also advocate that the rent accrued from the natural resources has to be spent on spreading the information related to environmental protection and ecological sustainability. Moreover, the same fund has to be used for sustainable development projects in these countries. Do so; resource rent has to be collected to follow the principle of equity and sustainability. The distribution of such funds should be used to promote the eco-friendly projects or environmental conservation programs in these countries; then there is a possibility of future environmental sustainability. The policy related to urban sustainability is highly recommended in the context of environmental degradation. Resource efficiency is an important ingredient in urban sustainability; therefore, it has to be promoted in different temporal and spatial scales. Further, the study recommends an approach to urbanization that depends on environmental management, economic and social development at the national and international level to mitigate the pollution. Hence, policies have to be formulated with all the stakeholders of the urbanization such as people, local and national governments.

To protect the material footprint, the role of human capital is pivotal; hence following a well-designed policy for education with a focus on environmental conservation would help the youngsters to understand the impotence quality environment. The inclusion of both theory and application of environmental conservation in the curriculum helps the youngsters think broadly and practically about environmental degradation. Since trade openness shows a negative link with the material footprint, we suggest participation in international trade protect the environment by reducing the material footprint. Hence, the further implementation of new technology in the export sector is inevitable. Also, import quality has to be assured in line with environmental standards so that the countries will get the gains from trade along with environmental sustainability.

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References

Abdouli, M., & Hammami, S. (2020). Economic growth, environment, fdi inflows, and financial development in Middle East countries: Fresh evidence from simultaneous equation models. *Journal of the Knowledge Economy*, *11*(2), 479-511.

Adams, S., & Nsiah, C. (2019). Reducing carbon dioxide emissions; Does renewable energy matter?. *Science of The Total Environment*, *693*, 133288.

Adedoyin, F. F., Gumede, M. I., Bekun, F. V., Etokakpan, M. U., & Balsalobre-lorente, D. (2020). Modelling coal rent, economic growth and CO2 emissions: Does regulatory quality matter in BRICS economies?. *Science of the Total Environment*, *710*, 136284.

Ahmed, K. (2017). Revisiting the role of financial development for energy-growth-trade nexus in BRICS economies. *Energy*, *128*, 487-495.

Alam, R., & Adil, M. H. (2019). Validating the environmental Kuznets curve in India: ARDL bounds testing framework. *OPEC Energy Review*, *43*(3), 277-300.

Alam, S., Fatima, A., & Butt, M. S. (2007). Sustainable development in Pakistan in the context of energy consumption demand and environmental degradation. *Journal of Asian Economics*, *18*(5), 825-837.

Ali, R., Bakhsh, K., & Yasin, M. A. (2019). Impact of urbanization on CO2 emissions in emerging economy: evidence from Pakistan. *Sustainable Cities and Society*, *48*, 101553.

Al-Mulali, U., Saboori, B., & Ozturk, I. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy*, *76*, 123-131.

Ansari, M. A., Ahmad, M. R., Siddique, S., & Mansoor, K. (2020a). An environment Kuznets curve for ecological footprint: Evidence from GCC countries. *Carbon Management*, *11*(4), 355-368.

Ansari, M. A., Haider, S., & Khan, N. A. (2020b). Does trade openness affects global carbon dioxide emissions. *Management of Environmental Quality: An International Journal*.

Ansari, M. A., Haider, S., & Khan, N. A. (2020c). Environmental Kuznets curve revisited: An analysis using ecological and material footprint. *Ecological Indicators*, *115*, 106416.

Ansari, M. A., Khan, N. A., & Ganaie, A. A. (2019). Does foreign direct investment impede environmental quality in Asian countries? A panel data analysis. *OPEC Energy Review*, *43*(2), 109-135.

Apergis, N., & Danuletiu, D. C. (2014). Renewable energy and economic growth: Evidence from the sign of panel long-run causality. *International Journal of Energy Economics and Policy*, *4*(4), 578.

Aye, G. C., & Edoja, P. E. (2017). Effect of economic growth on CO_2 emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Economics & Finance*, *5*(1), 1379239.

Azevedo, V. G., Sartori, S., & Campos, L. M. (2018). CO_2 emissions: A quantitative analysis among the BRICS nations. *Renewable and Sustainable Energy Reviews*, *81*, 107-115.

Baloch, M. A., Mahmood, N., & Zhang, J. W. (2019). Effect of natural resources, renewable energy and economic development on CO_2 emissions in BRICS countries. *Science of the Total Environment*, *678*, 632-638.

Beckerman, W. (1992). Economic growth and the environment: Whose growth? Whose environment?. *World development*, *20*(4), 481-496.

Berrill, P., Miller, T. R., Kondo, Y., & Hertwich, E. G. (2020). Capital in the American carbon, energy, and material footprint. *Journal of Industrial Ecology*, *24*(3), 589-600.

Bilgili, F., Koçak, E., & Bulut, Ü. (2016). The dynamic impact of renewable energy consumption on CO_2 emissions: a revisited Environmental Kuznets Curve approach. *Renewable and Sustainable Energy Reviews*, *54*, 838-845.

Bruckner, M., Giljum, S., Lutz, C., & Wiebe, K. S. (2012). Materials embodied in international trade–Global material extraction and consumption between 1995 and 2005. *Global Environmental Change*, *22*(3), 568-576.

Csavina, J., Field, J., Taylor, M. P., Gao, S., Landázuri, A., Betterton, E. A., & Sáez, A. E. (2012). A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations. *Science of the Total Environment*, *433*, 58-73.

Danish, & Wang, Z. (2019a). Does biomass energy consumption help to controlenvironmental pollution? Evidence from BRICS countries. *Science of the TotalEnvironment*, *670*, 1075–1083. https://doi.org/10.1016/j.scitotenv.2019.03.268

Danish, Baloch, M. A., Mahmood, N., & Zhang, J. W. (2019). Effect of naturalresources, renewable energy and economic development on CO_2 emissions inBRICS countries. *Science of the Total Environment*, *678*, 632–638.https://doi.org/10.1016/j.scitotenv.2019.05.028

de Souza ES, de Souza Freire F, Pires J (2018) Determinants of CO_2 emissions in the MERCOSUR: the role of economic growth, and renewable and non-renewable energy. Environ Sci Pollut Res 25(21):20769–20781.

Dogan, E., & Turkekul, B. (2016). CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. *Environmental Science and Pollution Research*, *23*(2), 1203-1213.

Dumitrescu, E.-I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), 1450–1460.

Giljum, S., Bruckner, M., & Martinez, A. (2015). Material footprint assessment in a global input-output framework. *Journal of Industrial Ecology*, *19*(5), 792-804.

Giurco, D., Dominish, E., Florin, N., Watari, T., & McLellan, B. (2019). Requirements for minerals and metals for 100% renewable scenarios. In *Achieving the Paris Climate Agreement Goals* (pp. 437-457). Springer, Cham.

Haider, S., & Bhat, J. A. (2018). Inter-state analysis of energy efficiency- a stochastic frontier approach to the Indian paper industry. International Journal of Energy Sector Management, 12(4), 547-565.

Haider, S., & Bhat, J. A. (2019). Does total factor productivity affect the energy efficiency: Evidence from the Indian paper industry. International Journal of Energy Sector Management, ahead-of-print(ahead-of-print).

Haider, S., & Ganaie, A. A. (2017). Does energy efficiency enhance total factor productivity in case of India? OPEC Energy Review, 41(2), 153-163.

Haider, S., & Mishra, P. P. (2019). Benchmarking energy use of iron and steel industry: A data envelopment analysis. Benchmarking: An International Journal, 26(4), 1314-1335.

Haider, S., Danish, M. S., & Sharma, R. (2019). Assessing energy efficiency of Indian paper industry and influencing factors: A slack-based firm-level analysis. Energy Economics, 81, 454-464.

Hassan, S. T., Xia, E., Khan, N. H., & Shah, S. M. A. (2019). Economic growth, natural resources, and ecological footprints: evidence from Pakistan. *Environmental Science and Pollution Research*, *26*(3), 2929-2938.

Inglesi-Lotz, R., & Dogan, E. (2018). The role of renewable versus non-renewable energy to the level of CO2 emissions a panel analysis of sub-Saharan Africa's Big 10 electricity generators. *Renewable Energy*, *123*, 36-43.

International Energy Outlook (2018). Global energy and co2 status report 2019. Retrieved from https://www.iea.org/reports/global-energy-co2-status-report-2019#global-trends

Jalil, A., & Feridun, M. (2011). The impact of growth, energy and financial development on the environment in China: a cointegration analysis. *Energy Economics*, *33*(2), 284-291.

Karakaya, E., Sarı, E., & Alataş, S. (2020). What drives material use in the EU? Evidence from club convergence and decomposition analysis on domestic material consumption and material footprint. *Resources Policy*, 101904.

Khan, S. A. R., Zhang, Y., Anees, M., Golpîra, H., Lahmar, A., & Qianli, D. (2018). Green supply chain management, economic growth and environment: A GMM based evidence. *Journal of Cleaner Production*, *185*, 588-599.

Lean, H. H., & Smyth, R. (2014). Disaggregated energy demand by fuel type and economic growth in Malaysia. *Applied energy*, *132*, 168-177.

Leitão, N. C. (2014). Economic growth, carbon dioxide emissions, renewable energy and globalization. *International Journal of Energy Economics and Policy*, *3*, 391-399.

Levin, A., Lin, C.-F., & James Chu, C.-S. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, *108*(1), 1–24.

Lin, B., & Zhu, J. (2018). Changes in urban air quality during urbanization in China. *Journal of cleaner production*, *188*, 312-321.

Liu, X., Zhang, S., & Bae, J. (2017). The nexus of renewable energy-agriculture-environment in BRICS. *Applied energy*, *204*, 489-496.

Liu, Y. (2013). Energy Production and Regional Economic Growth in China: A More Comprehensive Analysis Using a Panel Model. *Energies*, *6*(3), 1–12.

Lv, Z., & Xu, T. (2019). Trade openness, urbanization and CO2 emissions: Dynamic panel data analysis of middle-income countries. *The Journal of International Trade & Economic Development*, *28*(3), 317-330.

Mahalik, M. K., Villanthenkodath, M. A., Mallick, H., & Gupta, M. (2020). Assessing the effectiveness of total foreign aid and foreign energy aid inflows on environmental quality in India. *Energy Policy*, 112015.

Mahmood, H., Alkhateeb, T. T. Y., & Furqan, M. (2020). Industrialization, urbanization and CO2 emissions in Saudi Arabia: Asymmetry analysis. *Energy Reports*, *6*, 1553-1560.

Mahmoodi, M. (2017). The relationship between economic growth, renewable energy, and CO2 emissions: Evidence from panel data approach. *International Journal of Energy Economics and Policy*, *7*(6), 96-102.

Martínez-Zarzoso, I., & Maruotti, A. (2011). The impact of urbanization on CO2 emissions: evidence from developing countries. *Ecological Economics*, *70*(7), 1344-1353.

Menegaki, A. N. (2011). Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. *Energy economics*, *33*(2), 257-263.

Menyah, K., & Wolde-Rufael, Y. (2010). CO2 emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Policy*, *38*(6), 2911-2915.

MK, A. N. (2020). Role of energy use in the prediction of CO 2 emissions and economic growth in India: Evidence from artificial neural networks (ANN). *Environmental Science and Pollution Research*, *27*(19), 23631–23642.

Nathaniel, S. P., & Iheonu, C. O. (2019). Carbon dioxide abatement in Africa: The role of renewable and non-renewable energy consumption. *Science of the Total Environment*, *679*, 337-345.

Nathaniel, S. P., Nwulu, N., & Bekun, F. (2020a). Natural resource, globalization, urbanization, human capital, and environmental degradation in Latin American and Caribbean countries. *Environmental Science and Pollution Research*, 1-15.

Nathaniel, S. P., Yalçiner, K., & Bekun, F. V. (2020b). Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS. *Resources Policy*, 101924.

Nathaniel, S., & Khan, S. A. R. (2020). The nexus between urbanization, renewable energy, trade, and ecological footprint in ASEAN countries. *Journal of Cleaner Production*, *272*, 122709.

Nathaniel, S., Anyanwu, O., & Shah, M. (2020c). Renewable energy, urbanization, and ecological footprint in the Middle East and North Africa region. *Environmental Science and Pollution Research*, 1-13.

Ntanos, S., Skordoulis, M., Kyriakopoulos, G., Arabatzis, G., Chalikias, M., Galatsidas, S., ... & Katsarou, A. (2018). Renewable energy and economic growth: Evidence from European countries. *Sustainability*, *10*(8), 2626.

OECD. (2015). Material Resources, Productivity and the Environment, OECD Green Growth Studies. Retrieved from https://www.oecd.org/environment/waste/material-resources-productivity-and-the-environment-9789264190504-en.htm

Ozatac, N., Gokmenoglu, K. K., & Taspinar, N. (2017). Testing the EKC hypothesis by considering trade openness, urbanization, and financial development: the case of Turkey. *Environmental Science and Pollution Research*, *24*(20), 16690-16701.

Pata, U. K. (2018). Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: testing EKC hypothesis with structural breaks. *Journal of Cleaner Production*, *187*, 770-779.

Pedroni, P. (1999). Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 653–670.

Pedroni, P. (2004). PANEL COINTEGRATION: ASYMPTOTIC AND FINITE SAMPLE PROPERTIES OF POOLED TIME SERIES TESTS WITH AN APPLICATION TO THE PPP HYPOTHESIS. *Econometric Theory*, *20*(3), 597–625.

Pesaran, M. H. (2004). General Diagnostic Tests for Cross Section Dependence in Panels. In *IZA Discussion Papers* (No. 1240; IZA Discussion Papers). Institute of Labor Economics (IZA).

Pothen, F., & Welsch, H. (2019). Economic development and material use. Evidence from international panel data. *World Development*, *115*, 107-119.

Sahoo, M., & Sahoo, J. (2020a). Effects of renewable and non-renewable energy consumption on CO2 emissions in India: Empirical evidence from disaggregated data analysis. *Journal of Public Affairs*, e2307.

Sahoo, M., & Sahoo, D. (2020b). Corruption, technological innovation and environmental quality in South Asian countries: An empirical insight. *Theoretical and Applied Economics*, *22*(3 (624), Autumn), 235-242.

Sahoo, M., & Sahoo, J. (2019). The relationship between unemployment and some macroeconomic variables: Empirical evidence from India. *Theoretical & Applied Economics*, *26*(1).

Salim, R., Rafiq, S., Shafiei, S., & Yao, Y. (2019). Does urbanization increase pollutant emission and energy intensity? evidence from some Asian developing economies. *Applied Economics*, *51*(36), 4008-4024.

Sebri, M., & Ben-Salha, O. (2014). On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: Fresh evidence from BRICS countries. *Renewable and Sustainable Energy Reviews*, *39*, 14-23.

Shahbaz, M., Haouas, I., Sohag, K., & Ozturk, I. (2020a). The financial development-environmental degradation nexus in the United Arab Emirates: the importance of growth, globalization and structural breaks. *Environmental Science and Pollution Research*, 1-15.

Shahbaz, M., Loganathan, N., Muzaffar, A. T., Ahmed, K., & Jabran, M. A. (2016). How urbanization affects CO2 emissions in Malaysia? The application of STIRPAT model. *Renewable and Sustainable Energy Reviews*, *57*, 83-93.

Shahbaz, M., Sharma, R., Sinha, A., & Jiao, Z. (2020b). Analyzing nonlinear impact of economic growth drivers on CO2 emissions: Designing an SDG framework for India. *Energy Policy*, *148*, 111965.

Shaheen, A., Sheng, J., Arshad, S., Salam, S., & Hafeez, M. (2020). The Dynamic Linkage between Income, Energy Consumption, Urbanization and Carbon Emissions in Pakistan. *Polish Journal of Environmental Studies*, *29*(1).

Siddiqui, K. (2016). Will the Growth of the BRICs Cause a Shift in the Global Balance of Economic Power in the 21st Century?. *International Journal of Political Economy*, *45*(4), 315-338.

Soava, G., Mehedintu, A., Sterpu, M., & Raduteanu, M. (2018). Impact of renewable energy consumption on economic growth: evidence from European Union countries. *Technological and Economic Development of Economy*, *24*(3), 914-932.

Södersten, C. J., Wood, R., & Wiedmann, T. (2020). The capital load of global material footprints. *Resources, Conservation and Recycling*, *158*, 104811.

Starr, F. (2006). The extraction, conversion and use of energy resources: future challenge to materials technology. *Energy Materials*, *1*(1), 7-10.

Tian, X., Sarkis, J., Geng, Y., Bleischwitz, R., Qian, Y., Xu, L., & Wu, R. (2020). Examining the role of BRICS countries at the global economic and environmental resources nexus. *Journal of Environmental Management*, *262*, 110330

Ulucak, R., & Bilgili, F. (2018). A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. *Journal of cleaner production*, *188*, 144-157.

Ulucak, R., & Khan, S. U. D. (2020). Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization. *Sustainable Cities and Society*, *54*, 101996.

United Nations Framework Convention on Climate Change (2019). United Nations Climate Change Annual Report 2019. Retrieved from https://unfccc.int/sites/default/files/resource/unfccc_annual_report_2019.pdf

Usman, M., Kousar, R., Yaseen, M. R., & Makhdum, M. S. A. (2020). An empirical nexus between economic growth, energy utilization, trade policy, and ecological footprint: A

continent-wise comparison in upper-middle-income countries. *Environmental Science and Pollution Research*, *27*(31), 38995–39018.
Venkatraja, B. (2020). Does renewable energy affect economic growth? Evidence from panel data estimation of BRIC countries. *INTERNATIONAL JOURNAL OF SUSTAINABLE DEVELOPMENT AND WORLD ECOLOGY*, *27*(2), 107-113.
Villanthenkodath, M. A., & Arakkal, M. F. (2020). Exploring the existence of environmental Kuznets curve in the midst of financial development, openness, and foreign direct investment in New Zealand: insights from ARDL bound test. *Environmental Science and Pollution Research*, *27*(29), 36511-36527.
Villanthenkodath, M. A., & Mahalik, M. K. (2020). Technological innovation and environmental quality nexus in India: Does inward remittance matter? *Journal of Public Affairs*, *n/a*(n/a), e2291.
Villanthenkodath, M. A., & Mushtaq, U. (2021). Modelling the Nexus Between Foreign Aid and Economic Growth: A Case of Afghanistan and Egypt. *Studies of Applied Economics*, *39*(1), Article 1.
Wackernagel, M., & Rees, W. (1998). *Our ecological footprint: reducing human impact on the earth* (Vol. 9). New society publishers.
Wang, Q., Su, M., & Li, R. (2018). Toward to economic growth without emission growth: The role of urbanization and industrialization in China and India. *Journal of cleaner production*, *205*, 499-511.
Wang, S., Zeng, J., Huang, Y., Shi, C., & Zhan, P. (2018). The effects of urbanization on CO2 emissions in the Pearl River Delta: a comprehensive assessment and panel data analysis. *Applied Energy*, *228*, 1693-1706.
Wang, Z. (2019). Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. *Science of the total environment*, *670*, 1075-1083.
Westerlund, J. (2007). Testing for Error Correction in Panel Data*. *Oxford Bulletin of Economics and Statistics*, *69*(6), 709–748.
Wiebe, K. S., Bruckner, M., Giljum, S., Lutz, C., & Polzin, C. (2012). Carbon and materials embodied in the international trade of emerging economies: a multiregional input-output assessment of trends between 1995 and 2005. *Journal of Industrial Ecology*, *16*(4), 636-646.
World Development Indicator (2018). https://databank.worldbank.org/source/world-development-indicators
Wu, L., Liu, S., Liu, D., Fang, Z., & Xu, H. (2015). Modelling and forecasting CO2 emissions in the BRICS (Brazil, Russia, India, China, and South Africa) countries using a novel multi-variable grey model. *Energy*, *79*, 489-495.
Zakarya, G. Y., Mostefa, B. E. L. M. O. K. A. D. D. E. M., Abbes, S. M., & Seghir, G. M. (2015). Factors affecting CO2 emissions in the BRICS countries: a panel data analysis. *Procedia Economics and Finance*, *26*, 114-125.
Zhang, Y. J., Yi, W. C., & Li, B. W. (2015). The impact of urbanization on carbon emission: empirical evidence in Beijing. *Energy Procedia*, *75*, 2963-2968.
Zhao, Y., Wang, S., & Zhou, C. (2016). Understanding the relation between urbanization and the eco-environment in China's Yangtze River Delta using an improved EKC model and coupling analysis. *Science of the Total Environment*, *571*, 862-875.
Zhengge, T. (2008). The Coordination of Industrial Growth with Environment and Resource [J]. *Economic Research Journal*, *2*(3), 125-130.

Figures

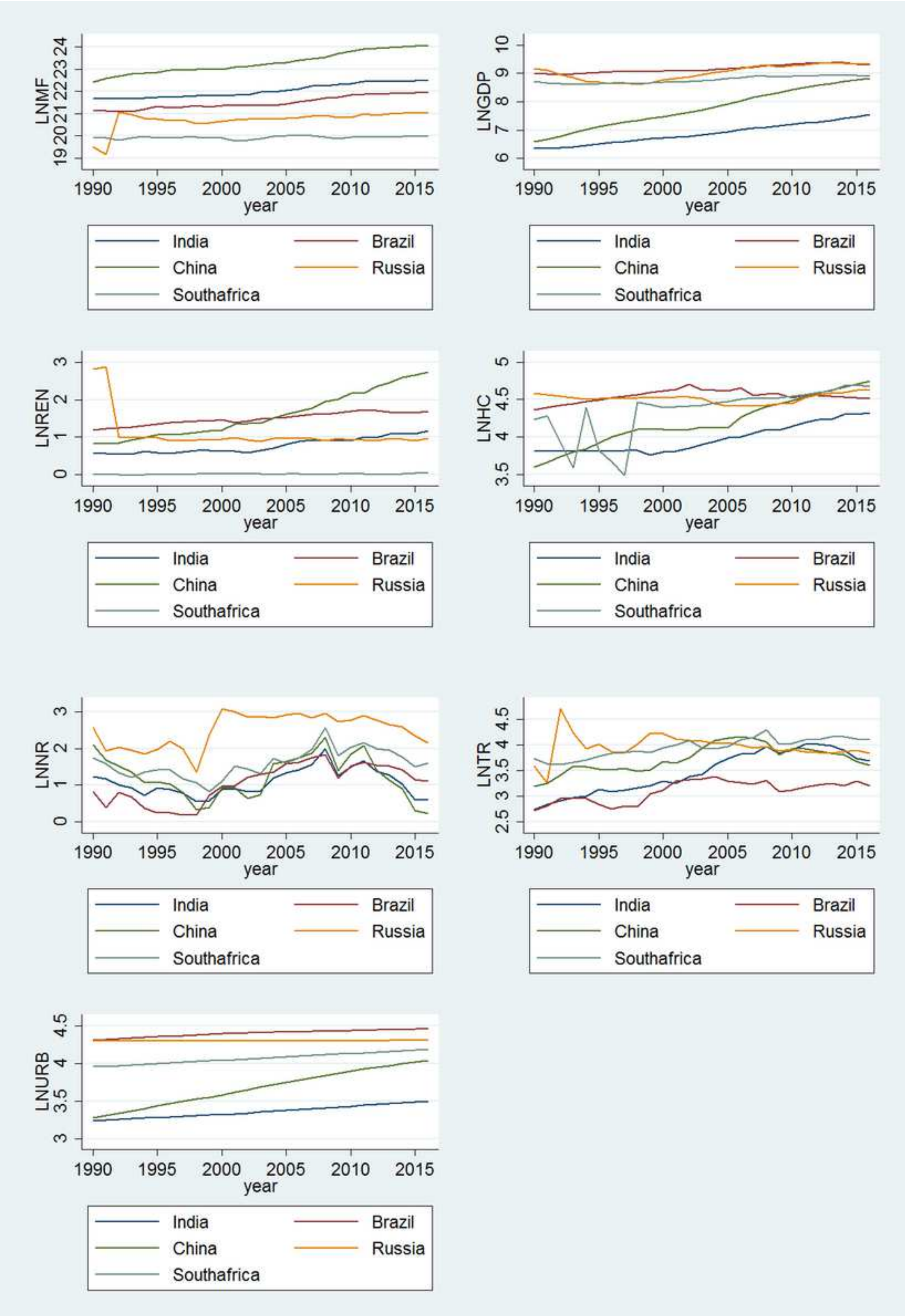

Figure 1

The pattern of variables during 1990-2016.

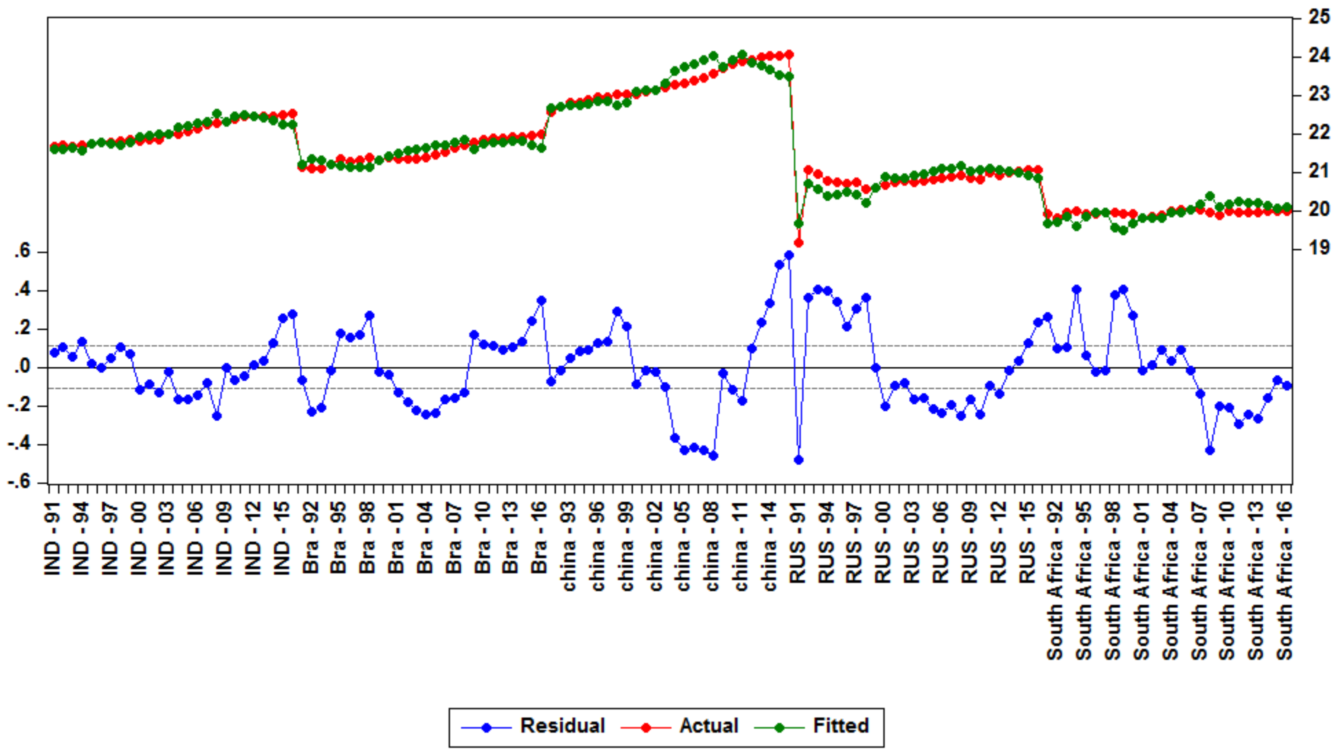

Figure 2

Actual, fitted, and residual graph of the FMOLS model.