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Research paper

The dynamic impact of biomass and natural resources on ecological footprint in BRICS economies: A quantile regression evidence

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A B S T R A C T

Many emerging economies, including the BRICS economies, are having difficulty meeting the Sustainable Development Goals' (SDGs) objectives. Consequently, this research discusses the creation of an SDG framework for the BRICS economies, which can be utilized as a model for other blocs. To achieve this purpose, this research probes into the effect of biomass energy usage on ecological footprint in the BRICS economies between 1992 and 2018, considering the roles of gross capital formation, natural resources, and globalization. The novel Methods of Moments-Quantile-Regression (MMQR) approach with fixed effects is used, the outcomes of which reveal that in all quantiles (10th to 90th), globalization and biomass energy use mitigate environmental degradation, whereas economic growth, natural resources, and gross capital formation contribute to environmental degradation. The present research applied a series of techniques such as panel FMOLS, and DOLS, FE-OLS, the outcomes of which disclosed that globalization and biomass energy utilization help mitigate environmental degradation, while economic growth, natural resources, and gross capital formation improve environmental degradation. On the basis of the study's findings, we suggest a shift in energy policies away from fossil fuels toward renewable energy alternatives by taking measures regarding the innovation of biomass to improve conversion efficiency.

1. Introduction

Multiple economies are currently focused on achieving the objectives of sustainable growth and development, which covers these three aspects of human life: economic, social, and environmental. However, environmental preservation is becoming increasingly important (Kirikkaleli and Adebayo, 2021). Rapid global economic expansion has boosted energy use and exacerbated environmental deterioration in the last few decades (Awosusi et al., 2021a; Yuping et al., 2021; Adebayo et al., 2021a). Climate change is considered a key constraint to the global population, affecting every living creature from the oceans to the atmosphere to the land, as well as tropical and arctic regions. Thus, immediate efforts and measures are required to combat climate change, mitigate the effects of global warming, and minimize air pollution (Ayobamiji and Kalmaz, 2020; Awosusi et al., 2021b; Adebayo et al., 2021b; Rjoub et al., 2021). One of the recommended remedies is to minimize the usage of fossil fuels, which are considered the main factors causing climate change. For instance, around 80% of total primary energy consumed in the world is accountable 75% of greenhouse gas emissions (GHGs); however, this problem can be alleviated by replacing them with cleaner energy sources (renewable energy) like biomass, solar, geothermal, and wind energy. Several scholars (e.g., Adebayo et al., 2021c; Akinsola et al., 2021; Güngör et al., 2021) have recommended that renewable energy can contribute to mitigating the threat of environmental deterioration by reducing the release of GHGs. Nevertheless, the utilization of renewable energy is now expanding at a record rate, because of the increase in energy

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List of abbreviations

BRICS	Brazil, Russia, India, China and South Africa
CO_2	CO_2 emissions
DOLS	Dynamic-OLS
ECF	Ecological footprint
EKC	Environmental Kuznets Curve
FE-OLS	Fixed effect OLS
FMOLS	Fully Modified OLS
GCF	Gross capital formation
GDP	Economic growth
GHGs	Greenhouse gases
GLO	Globalization
MMQR	Methods of Moments-Quantile-Regression
NRR	Natural resources rents
SDGs	Sustainable Development Goals

efficiency, advancements in scientific research and technological innovations, as well as supportive legislation (Gyamfi et al., 2021; Oladipupo et al., 2021; Rjoub and Adebayo, 2021).

Persistent economic expansion has been experienced in emerging or newly industrialized economies (including the BRICS economies—Brazil, Russia, India, China, and South Africa). The gross domestic product (GDP) (in constant 2010) of the BRICS economies increased from $2,187 billion in 1985 to US$16,266 billion in 2016, representing an averaging annual growth rate of 6.5 percent. The World Bank (2018) estimates that the overall GDP of the BRICS economies amounted to roughly 18.82 trillion US dollars in 2017, which is equivalent to around 23.31% of the global GDP. About 40% of the world's populace lives in the BRICS economies and consumes about 40% of the global energy. The rapid economic expansion of these economies means that they need energy imports to fulfil their energy needs, while their environmental problems are also becoming more prevalent. To address these issues, the BRICS economies should utilize alternative energy sources to satisfy the residential, commercial, and industrial energy demand. Biomass energy is commonly accessible, and its generation is quite rapid in this group of economies; for this reason, the BRICS economies should incorporate biomass energy into their sustainable development policy agendas (Shahbaz et al., 2016).

The most common renewable energy source is biomass energy. Modern bioenergy supplied over half of the renewable energy utilized in 2017, accounting for around 12.4% of global energy consumption (REN21, 2019). Biomass energy will be essential in fulfilling global energy demand in the foreseeable future (Bilgili et al., 2017). According to the International Energy Agency, bioenergy will expand at the highest pace (with a 30% estimated growth rate) among all renewable energy sources between 2018 and 2023. The increasing attention on biomass consumption may be explained by the benefits of biomass energy over other alternative energy sources. Firstly, biomass energy can be employed for a wide range of purposes, including transportation, electricity generation, heating, and cooking. Biomass energy is the only kind of renewable energy that can be transformed into liquid fuel. Secondly, biomass is an energy source that is renewable, abundant, and simple to manufacture. The reliance on fossil fuels and secure national energy security by using biomass energy (Ozturk and Bilgili, 2015). Thirdly, biomass energy generation helps in the creation of more job opportunities, thus boosting income and thereby decreasing the level of poverty amongst the labour force residing in rural areas. Lastly, biomass energy is a "carbon neutral" energy source (Sikka et al., 2013), while certain biomass with high moisture concentration could also be beneficial for achieving a comprehensive reduction in NOx emissions (Houshfar et al., 2012). Biomass energy is cleaner and safer for the environment than fossil fuels (Aydin, 2019). According to Shahbaz et al. (2016), about 36.8% of the total energy consumed in the BRICS economies is generated utilizing biomass energy; therefore, research into whether biomass energy sources could solve environmental deterioration since it can function as clean energy sources would be beneficial.

The excessive exploitation of biomass energy has the potential consequences of sacrificing natural areas to manage monocultures, polluting bodies of water mostly with agricultural pollutants, endangering supplies of food (causing an increase in food prices) and lifestyles of the farm due to land competition, and intensifying net carbon emissions to the atmosphere as a result of escalating deforestation or energy-intensive production technology. The potential is considerable, but these threats are also reasonable. However, there are numerous studies that have scrutinized the interconnection between biomass and environmental degradation, especially with regard to CO_2 emissions, and no consensus has been reached with respect to the subject matter. For instance, Zafar et al. (2021) established that biomass helps in decreasing environmental degradation, whereas Solarin et al. (2018) presented the opposite view that biomass energy increases environmental degradation. The study of Gao and Zhang (2021) also confirmed a positive association between biomass energy and CO_2 emissions, while the research of Shahbaz et al. (2019) uncovered a negative association between biomass energy and CO_2 emissions. Also, little to no attention has been given to the association between biomass energy and ecological footprint. Meanwhile, ecological footprint is a superior metric for evaluating environmental deterioration since it includes CO_2 emissions, forest products, fishing grounds, agriculture, and grazing land, whereas CO_2 emissions is arguably flawed. Therefore, this gap in the literature serves as one of the motivations of this study.

Ecological footprint (ECF) is a comprehensive metric of environmental pollution that reflects the proportion of biologically productive land and water consumed by an individual or population (Lu, 2020; Kirikkaleli et al., 2021; Kihombo et al., 2021b) and a broad determinant that encompasses anthropogenic stress on the ecosystem (Yang et al., 2021; Udemba, 2021). The ECF is extensively utilized for sustainability evaluations, and it was created for evaluating and managing resource usage throughout a country, as well as assessing the sustainability of people's consumption patterns, goods and services, companies, megacities, towns, regions, and nations.

Researchers are becoming extremely interested in another socioeconomic component described as globalization. Globalization is a diverse and complex process that exerts a long-term influence on economies across the globe (Adebayo and Kirikkaleli, 2021). Globalization alters economic growth and creates comparative advantages through trade with other countries' economies. It exerts compositional environmental impacts as well as factors of production domestically. It promotes reforms in trade policy aimed at eliminating cross-border barriers and boosting the use of green technology. These modifications could have an adverse impact on the allocation of resources, ecological management methods, and the environment. For example, Usman et al. (2020) and Sabir and Gorus (2019) established a positive interconnection between ecological footprint and globalization; conversely, the work of Saud et al. (2020), Ansari et al. (2021) and Yang and Usman (2021) uncovered that globalization has a negative impact on ecological footprint, while Ahmed et al. (2019) confirmed an insignificant interconnection between globalization and ecological footprint.

Several previous studies (Bui et al., 2020; Ulucak and Ozcan, 2020; Jiang et al., 2020; Hassan et al., 2019; Langnel et al., 2021; Nathaniel et al., 2021; Ahmed et al., 2020) have examined the possible implications of natural resources rent (NRR) on environmental deterioration. Zafar et al. (2019) uncovered a negative association between NRR and ECF. Bui et al. (2020) established that an increase in NRR results in a decrease in ECF in the ASEAN economies. Ulucak and Ozcan (2020) established an insignificant association between NRR and ECF. Although the investigation of Hassan et al. (2019) confirmed a positive association between ECF and NRR, Langnel et al. (2021) discovered that an increase in NRR causes an increase in ECF. The work of Jiang et al. (2020) detected a positive interaction between ECF and NRR. Also, Nathaniel and Adeleye (2021) established a positive interconnection between ECF and NRR. Therefore, it can be observed that significant debate surrounds the role of natural resources rent on ecological footprint.

Despite the large volume of research on the factors influencing ecological footprint, no preceding investigation has been undertaken to examine the role of gross domestic capital on ecological footprint for the case of emerging economies like the BRICS. However, Nathaniel and Adeleye (2021) established a negative and insignificant association between gross capital formation (GCF) and ECF, while Zhang et al. (2021) established that gross capital formation positively affects ecological footprint. Abbas et al. (2020) and Adebayo and Kalmaz (2021) evaluated the impact of gross domestic capital on the environment using CO_2 emissions as a proxy. Abbas et al. (2020) established a negative association between GCF and CO_2, whereas Adebayo and Kalmaz (2021) uncovered an insignificant association between GCF and CO_2. This gap in the literature serves as one of the motivations of this study. Therefore, these recent studies have offered offers a different approach aimed at expanding the scope of environmental degradation utilizing ecological footprint as the proxy. Against this background, the current research scrutinizes the influence of biomass energy usage on ecological footprint in the BRICS economies between 1992 and 2018, considering the roles of gross capital formation, natural resources, and globalization

Taking into account the aforementioned discussions and concerns, this study adds to the current literature in three ways. (i) Based on our knowledge, this current research will be the first attempt to examine the interaction between biomass energy usage, economic growth, and ecological footprint for the BRICS economies by utilizing the novel "***Method of Moments Quantile Regression***" (MMQR) technique. (ii) This research adds to the growing body of literature that has utilized the MMQR approach. The use of this technique with fixed effects makes it easier to gain an experiential insight into the heterogeneity interconnection. Also, this approach allows for the heterogeneity interconnection at several levels of conditional quantiles distribution (usually 0.1–0.90 quantiles), which is not possible when using traditional mean regressions. (iii) This study also incorporates globalization, gross capital and natural resources formation into the economic-energy-environment nexus for the case of the BRICS economies. The evaluation of the economic-energy-environment nexus at various quantiles is motivated by various factors. Firstly, the conditional-mean evaluations are compared. These evaluations are prone to misrepresent the effects of outliers arising from ecological footprint determinants due to the relatively robust conditional quantiles. Secondly, the use of quantile regression is more attractive in the context of panel regression analysis owing to its extra intuitive use. Lastly, the distributional effects of exogenous variables on endogenous factors at different quantile ranges. However, conditional mean estimates are incapable of describing the complete distributional influence of economic growth, biomass energy consumption, natural resources, globalization and gross capital formation on ecological footprint. Therefore, categorizing the diverse impacts of groups of heterogeneous cross-sections becomes easier. The implications of this study will assist policymakers in this region, as well as those in other emerging economies, in developing appropriate policies to understand the effect of these determinants on environmental degradation.

The following outline is followed in the rest of the study: Section two gives insights into the relevant literature for this study, Section three describes the method used for the study, Section four provides the results, while Section five presents the concluding remarks.

2. Literature review

There are two main subsections in this segment, the first offers a brief summary of the study's theoretical framework, and later, the related empirical literature is reviewed.

2.1. Theoretical framework

The discourse regarding ecological footprints and its regressors will be primarily discussed in this section. Economic expansion has the potential to affect environmental quality in three phases. Firstly, it is critical to understand that when manufacturing continues to expand, more raw materials are required, which boosts economic activity while also degrading ecological quality. As a result, economic expansion raises the ecological footprint, and this phase is regarded as the scale effect. The second phase is the composition effect, which implies that the sectorial framework of a nation influences the trends of raw material for manufacturing and pollution levels. For illustration purposes, the service sector of any nation usually produces less pollution because raw materials are not needed. This phase marks a turning point in the effort to limit environmental deterioration. Composition channels help to minimize some of the negative effects of economic growth on the environment. Lastly, the technique effect suggests that governments may enhance environmental quality by using environmentally friendly technology that produces less pollution and slows down the rate of environmental deterioration.

Energy is recognized as an essential manufacturing component, and an increase in energy use is beneficial for improving economic productivity. However, increased energy consumption has an impact on environmental quality since the burning of energy resources, particularly fossil fuels, emits GHGs; as a consequence, it is possible to claim that increased energy consumption is harmful to the environment. Reducing the reliance on fossil fuels and rationalizing their usage will lead to greater energy efficiency, resulting in lower energy usage, lessened emissions, and substitution of fossil fuel (Ansari et al., 2021). To meet this goal, more renewable energy is being produced to help alleviate the shortage of the supply of these energy sources. One of the most common renewable energies is biomass because people can easily access it. It has been argued that biomass can help to reduce the dependency on fossil fuels and improve environmental quality when the generation is performed in a sustainable manner.

The loss of biocapacity has been caused by the usage of the richness of nature that has significantly outpaced the production of the earth (Marti and Puertas, 2020). The globe is increasingly confronted with various environmental issues, such as: forest exploitation is increasingly surpassing growth in tropical regions (Pendrill et al., 2019); the excessive extraction of natural resources such as fossil fuels, biomass, minerals and metals that could not be regenerated; rising GHG emissions, which causes ecological imbalances, and increased anthropogenic environmental impacts. Each of these problems underline the necessity of investigating the role of natural resources on ecological footprint in the BRICS. The role of natural resources on ecological footprint is negative (Zafar et al., 2019; Bui et al., 2020). Grazing areas, developed lands, fishing grounds, forests, and croplands are examples of natural resources that minimize human-induced carbon emissions. On the contrary, some natural resources, such as coal and petroleum, adversely impact the ecosystem (Jiang et al., 2020; Hassan et al., 2019). The significance of natural resources is closely related to the prosperity of any economy. At the developmental phase of any nation, the usage of energy is high (extraction of natural resources) and environmental effects are not considered, but as growth continues, the focus moves to cleaner energy. At this point, people begin to seek a clean and healthy environment, the conservation of natural resources, and energy-efficient products. As a result, the environmental quality begins to improve.

Globalization is a term that transcends trade liberalization and the flow of capital, which comprises economic, social, and political dimensions. At the global level, the globalization process has resulted in several environmental issues like depletion of the ozone layer, increased resource usage, deforestation, and desertification (Saud et al., 2020; He et al., 2021). Moreover, globalization can increase global CO_2 emissions and other GHGs by encouraging economic activity and energy usage. Conversely, it can contribute to enhance the quality of the environment by promoting ecologically friendly energy technology (Ansari et al., 2021).

2.2. Summary of related studies

This section presents a comprehensive review of related literature on the role of ecological footprint. This literature covers ecological footprints, economic growth, biomass energy consumption, natural resources, globalization and gross capital formation, including the recently published studies of Akinsola et al. (2021), Umar et al. (2021), Udemba (2020, 2021), Kongbuamai et al. (2020), Saqib and Benhmad (2021), Qayyum et al. (2021), Lu (2020), Kihombo et al. (2021a,b), Kirikkaleli and Adebayo (2021), Yang et al. (2021), Ullah et al. (2021), Ahmed et al. (2020, 2021), Ajmi and Inglesi-Lotz (2020), Wang et al. (2020), Hadj (2021), Zafar et al. (2019), Bui et al. (2020), Ulucak and Ozcan (2020), Jiang et al. (2020), Hassan et al. (2019), Langnel et al. (2021), and Nathaniel and Adeleye (2021)

2.2.1. Environmental degradation and economic growth nexus

Akinsola et al. (2021) discovered a positive association between GDP and ecological footprint over the period from 1983 to 2017 in Brazil. Udemba (2020) also found a similar outcome in the case of Nigeria utilizing the ARDL approach for the period between 1981 and 2018. Conversely, the study of Kirikkaleli and Adebayo (2021) utilized the Dual-adjustment method to examine the ecological footprint-GDP interconnection over the period between 1985 and 2017 and discovered a negative association. Therefore, as GDP increases in Turkey, the level of environmental degradation decreases. Moreover, another study by Udemba (2021) in the UAE (United Arab Emirates), which covered the period between 1980 and 2018, validated the EKC in the case of that country. Also, the study of Ahmed et al. (2021) validated the presence of the EKC in Japan for the timeframe between 1971 and 2016 using the ARDL approach. Furthermore, this outcome was supported by the research of Ajmi and Inglesi-Lotz (2020) in Tunisia over the period from 1965 to 2013.

For the case of grouped countries (panel dataset), the study of Kongbuamai et al. (2020) on the ASEAN Nations over the period from 1995 to 2016 employed the Driscoll–Kraay approach and confirmed the validity of the EKC, finding that as income continues to expand, the ecological footprint will also grow until it reaches a threshold, and then begins to gradually fall. Also, the study of Saqib and Benhmad (2021) affirmed a similar outcome in 22 European Nations over the period from 1995 to 2015, where the FMOLS approach was applied as the study's estimator. Qayyum et al. (2021) also corroborated this finding in the South Asian Nations using the ARDL approach over the period from 1984 to 2019. Moreover, the study of Lu (2020) in 13 Asian Nations established a positive interconnection between ecological footprint and GDP for the period between 1973 and 2014. Kihombo et al. (2021a) studied the interaction between GDP and ecological footprint in WAME (West Asia and Middle East) economies over the period from 1990 to 2017. The authors suggested that as these economies experience continuous economic expansion, the level of ecological footprint also increases. For the BICS (Brazil, India, China, and South Africa) economies, Yang et al. (2021) confirmed that the interaction between ecological footprint and GDP over the period from 1990 to 2019 was positive. Ullah et al. (2021) studied the ecological footprint-GDP connection in 15 economies between 1996 and 2018, employing the PSTR technique and establishing a positive interaction in all regimes.

2.2.2. Environmental degradation and biomass energy usage nexus

Researchers have used various economic approaches to evaluate the contentious usage of biomass energy for improving the quality of the environment. Unfortunately, no consensus has been reached with regard to whether biomass energy worsens or improves the environment. For instance, Wang (2019) studied the interaction between CO_2 and biomass energy usage (BIO) in the BRICS over the period from 1992 to 2013 using the GMM approaches. Using the Dynamic ARDL technique, Ulucak (2020) also discovered a negative interaction between CO_2 and BIO over the period from 1982 to 2017 in China. Furthermore, the work of Balsalobre-Lorente et al. (2019) on the MENA economies over the period from 1990 to 2015 uncovered an adverse interaction between CO_2 and BIO using the GMM approach. Sulaiman et al. (2020) collected data ranging from 1990 to 2017 and considered the CO_2-BIO interaction for 27 European economies utilizing the DOLS approach, where the findings revealed a negative association. Likewise, the study of Sulaiman and Abdul-Rahim (2020) confirmed a negative interaction between CO_2 and BIO over the period from 1980 to 2015 in 8 African economies. Conversely, the study of Solarin et al. (2018) on 80 economies (both developed and developing) detected a positive connection between CO_2 and BIO over the period from 1980 to 2010 using the GMM and DCEEM approaches. Also, based on data covering a similar period, the study of Gao and Zhang (2021) found a similar outcome in the case of 13 Asian developing economies.

Unlike CO_2 emission, few studies have investigated the interaction between BIO and ECF. However, the study of Wang et al. (2020) attempted to uncover the association between BIO and ECF in the G-7 economies covering the period from 1980 to 2016. The empirical analysis established a positive connection between BIO and ECF. Conversely, the study of Hadj (2021) discovered that biomass energy usage reduced ecological footprint in Saudi Arabia between 1984 and 2017 using the ARDL and NARDL.

2.2.3. Environmental degradation and natural resource abundance

Zafar et al. (2019) uncovered a negative association between natural resources abundance (NR) and ECF in the USA for the period from 1970 to 2018, employing the ARDL approach. Also, the study of Bui et al. (2020) collected data spanning from 1995 to 2016 and established that an increase in NR results in a decrease in ECF in ASEAN economies. Conversely, using the AMG approach, Ulucak and Ozcan (2020) studied the NR-ECF interaction using a dataset spanning the period between 1980 and 2016, and the empirical analysis established an insignificant association between NR and ECF. Although the research of Hassan et al. (2019) was able to confirm a positive association between ECF and NR in Pakistan, Langnel et al. (2021) discovered that an increase in NR produced an increase in ECF in the ECOWAS region between 1984 and 2016. This finding was also reported by Ahmed et al. (2020) in their study on China over the period from 1970 to 2016 using the ARDL approach. The study of Jiang et al. (2020) detected a direct interaction between ECF and NR over the period from 1984 to 2016 utilizing the CS-ARDL approach. Also, Nathaniel and Adeleye (2021) utilized a number of techniques to establish a positive association between ECF and NR over the period from 1992 to 2016 in the BRICS economies.

2.2.4. Environmental degradation and globalization

Using the PMG approach, Saud et al. (2020) examined the ECF and globalization (GLO) interconnection in the OBOR nations from 1990 to 2014; the empirical analysis established that as the level of globalization increases, the condition of the environment improves. Also, Yang and Usman (2021) found a negative interconnection between ECF and GLO in 10 selected economies. Ansari et al. (2021) utilized the DOLS, FMOLS and PMG approaches to detect the GLO-ECF interconnection in the leading renewable energy nations from 1991 to 2016. They discovered that globalization reduces ecological footprint. Moreover, the research of Alola et al. (2021a) for 10 nations found a contradicting outcome by establishing that globalization increases ecological footprint, whereas the study of Ahmed et al. (2019) established an insignificant association between GLO and ECF in Malaysia over the period from 1971 to 2014. For emerging economies, the study of Salari et al. (2021) confirmed a negative association between GLO and ECF across all quantiles for the period between 2002 and 2016. Usman et al. (2020) evaluated the role of globalization in improving environmental quality, and discovered that globalization decreases the quality of the environment by increasing the ecological footprint in the USA. A similar outcome was uncovered by Sabir and Gorus (2019) for South Asian nations by applying the ARDL approach to a dataset spanning between 1975 and 2017.

However, few studies have investigated the association between gross capital formation and ecological footprint for a panel of nations. One such study was undertaken by Nathaniel and Adeleye (2021), who established a negative and insignificant association between gross capital formation and ECF over the period from 1992 to 2016 in 44 African Nations. Zhang et al. (2021) studied the effect of gross capital formation on ecological footprint and established that gross capital formation positively affects ecological footprint in Malaysia. However, with regard to carbon emissions, Abbas et al. (2020) established a negative interconnection between GCF and CO_2 in 24 selected emerging economies between 1995 and 2014.

After the review of related literature, the dearth of literature with regards to biomass energy usage and ecological footprint is not only the motivation of this current study but also the integrating and evaluating the role of gross capital formation into the model. It also employed a recently advanced technique called "method of moments" panel quantile regression approach, which is an innovation of Machado and Silva (2019). The summary of the reviewed literature for this study is presented in Table 1.

3. Data and methods

3.1. Data

This present study attempts to investigate the role of economic growth, biomass energy usage, natural resource abundance, globalization and gross capital formation using the dataset spanning from 1992 to 2018 for BRICS economies. However, the period of consideration is subject to not readily present, especially globalization and biomass energy usage. Ecological footprint (environmental deterioration) is the endogenous variable of this current study and the exogenous variables of this study are: economic growth, biomass energy usage, natural resource, globalization and gross capital formation. These parameters are been transmuted to their natural logarithms. The measurement and origin of the dataset utilized are stated in Table 2. Also, the flow of analysis is presented in Fig. 1.

3.2. Model specification

The model for this research is premised on Akinsola et al. (2021), Langnel et al. (2021), and Hadj (2021), which is constructed as follows:

$$ECF_{it} = f\,(GDP_{it}, BIO_{it}, NRR_{it}, GLO_{it}, GCF_{it}) \quad (1)$$

$$ECF_{,it} = \vartheta_0 + \vartheta_1 GDP_{it} + \vartheta_2 BIO_{it} + \vartheta_3 NRR_{it} + \vartheta_4 GLO_{it} + \vartheta_5 GCF_{it} + \varepsilon_{it} \quad (2)$$

where: i indicates the cross-sections (BRICS economies); period of study (1992 to 2018) is depicted as t; ϑ denotes the coefficient of the parameters; ε depicts the error term. We envisage that the signs for the drivers of ecological footprint will be as follows: it anticipated that a positive connection between GDP and ecological footprint $\left(\vartheta_1 = \frac{\partial ECF}{\partial GDP} > 0\right)$. Biomass energy usage has been presented in the prior literature to increase and decrease environmental degradation. However, we anticipate a negative association between BIO and ECF i.e., $\left(\vartheta_2 = \frac{\partial ECF}{\partial BIO} < 0\right)$. For natural resources abundance, we envisage a positive association between NRR and ECF i.e., $\left(\vartheta_3 = \frac{\partial ECF}{\partial NRR} > 0\right)$. We expect that there is a negative association between globalization and ecological footprint i.e., $\left(\vartheta_4 = \frac{\partial ECF}{\partial GLO} < 0\right)$. Lastly, for gross capital formation, we envisage a positive association between GCF and ECF i.e., $\left(\vartheta_5 = \frac{\partial ECF}{\partial GCF} > 0\right)$. The trend of ecological footprint, GDP, biomass energy usage. Figs. 2–7 reveal the historical data of BRICS for all variables used in this study.

3.3. Estimation procedures

3.3.1. Cross-sectional dependence (CSD) test

Panel data analysis is more prone to cross-sectional dependency now that the world is becoming more interconnected and trade barriers are being reduced. Unreliable and biased evaluations may arise if the problem of cross-sectional interdependence cannot be resolved while professing independence between cross-sections (Adebayo et al., 2020). Cross-sectional dependency is assessed in this study by utilizing the Pesaran (2007) test, which is computed as follows:

$$CSD_{TM} = \left[\frac{TN(N-1)}{2}\right]^{1/2} \overline{\rho}_N \quad (3)$$

where: $\overline{\rho}_N$ represents the parameters of pair-wise correlation; the cross-sectional units with respect to numbers are denoted as N and the period is denoted as T. Also, assuming a homogeneous slope coefficient without testing for a heterogeneous slope coefficient would provide deceptive estimator outcomes (He et al., 2021). Therefore, this study employed the Pesaran and Yamagata (2008) to investigate the cross-sectional slope heterogeneity.

Table 1
Overview of the reviewed literature.

Authors	Country(s)	Period of study	Methods	Outcome
Ecological footprint and GDP				
Akinsola et al. (2021)	Brazil	1983–2017	ARDL, FMOLS and DOLS	Positive association
Udemba (2020)	Nigeria	1981–2018	ARDL	Positive association
Kongbuamai et al. (2020)	ASEAN Nations	1995–2016	Driscoll–Kraay approach	EKC is valid
Saqib and Benhmad (2021)	22 European Nations	1995–2015	FMOLS	EKC is valid
Qayyum et al. (2021)	South Asian Nations	1984–2019	ARDL	EKC is valid
Lu (2020)	13 Asian Nations	1973–2014	PMG	Positive association GDP ↔ ECF
Kihombo et al. (2021a,b)	WAME (West Asia and Middle East) Nations	1990–2017	CUP-FM and CUP-BC	Positive association GDP ↔ ECF
Kirikkaleli and Adebayo (2021)	Turkey	1985–2017	Dual adjustment approach	Negative association
Yang et al. (2021)	BICS Nations	1990–2016	DSUR approach and FMOLS	Positive association
Udemba (2021)	UAE	1980–2018	ARDL	EKC is valid
Ullah et al. (2021)	15 economies	1996–2018	PSTR	Positive association in all regimes
Ahmed et al. (2021)	Japan	1971–2016	NARDL	EKC is valid
Ajmi and Inglesi-Lotz (2020)	Tunisian	1965–2013	ARDL	EKC is valid
Biomass energy and environmental degradation				
Wang et al. (2020)	G-7 economies	1980–2016	DSUR	BIO → ECF (+)
Hadj (2021)	Saudi Arabia	1984–2017	NARDL and ARDL	BIO → ECF (-)
Wang (2019)	BRICS	1992–2013	GMM	BIO → CO_2 (-)
Ulucak (2020)	China	1982–2017	DARDL	BIO → CO_2 (-)
Balsalobre-Lorente et al. (2019)	MENA	1990–2015	GMM	BIO → CO_2 (−)
Sulaiman and Abdul-Rahim (2020)	27 European Nations	1990–2017	DOLS	BIO → CO_2 (−)
Sulaiman and Abdul-Rahim (2020)	8 African nations	1980–2015	PMG and DFE	BIO → CO_2 (−)
Solarin et al. (2018)	80 Nations	1980–2010	GMM and DCEEM	BIO → CO_2 (+)
Gao and Zhang (2021)	13 Asian developing economies	1980–2010	FMOLS	BIO → CO_2 (+)
Ecological footprint and Natural resource rent				
Zafar et al. (2019)	United States	1970–2015	ARDL	Negative association
Bui et al. (2020)	ASEAN	1995–2016	Driscoll–Kraay approach	Negative association
Ulucak and Ozcan (2020)	OECD	1980–2016	AMG	No significant association
Jiang et al. (2020)	22 economies	1984–2016	CS-ARDL	Positive association
Hassan et al. (2019)	Pakistan	1970–2014	ARDL	Positive association
Langnel et al. (2021)	ECOWAS	1984–2016	PMG	Positive association
Nathaniel and Adeleye (2021)	BRICS	1992–2016	DOLS, CCEMG, FMOLS, AMG, and PMG	Positive association
Ahmed et al. (2020)	China	1970–2016	ARDL	Positive association
Ecological footprint and globalization				
Saud et al. (2020)	OBOR	1990–2014	PMG	Negative association
Yang and Usman (2021)	10 selected Nations	1995–2018	AMG and CCEMG	Negative association
Ansari et al. (2021)	Top renewable energy economies	1991–2016	PMG, DOLS and FMOLS	Negative association
Alola et al. (2021a,b)	10 Nations	1995–2016	ARDL	Positive association
Salari et al. (2021)	Emerging economies	2002–2016	PQR	Negative association across all quantile
Usman et al. (2020)	USA	1985Q1–2014Q4	ARDL	Positive association
Sabir and Gorus (2019)	South Asian Nations	1975–2017	ARDL	Positive association
Ahmed et al. (2019)	Malaysia	1971–2014	ARDL	No significant association

ARDL: Autoregressive Distributive lag model, PMG: Pool mean group, AMG: Augmented mean group, PQR: panel quantile regression, GMM: Generalized method of moment, CS-ARDL: cross-sectional Autoregressive Distributive lag model, DARDL: Dynamic Autoregressive Distributive lag model, NARDL: non-linear Autoregressive Distributive lag model, BICS: Brazil, India, China and South Africa.

Table 2
Data description.

Variable	Symbol	Measurement	Source
Ecological footprint	ECF	Gha per capita	GCA
Economic growth	GDP	GDP per capita (constant 2010$)	WDI
Biomass energy consumption	BIO	Tons per capita (second-generation biomass)	MFD
Natural resources	NR	Natural resources rent (% of GDP)	WDI
Globalization	GLO	Globalization index in the context of economic, social, and political dimensions	KOF
Gross capital formation	GCF	% of GDP	WDI

Note: WDI—world development indicators; MFD—Material Flows Database; GFN—Global Footprint Network; KOF—KOF Swiss economic institute.

3.3.2. Panel unit root tests

Cross-sectional stationary tests, also known as CADF and CIPS tests, are an innovation of Pesaran (2007) and are used to uncover the stationary characteristics of the concerned variable. To compute the CADF, Eq. (4) provides it as follows:

$$\Delta Y_{i,t} = \gamma_i + \gamma_i Y_{i,t-1} + \gamma_i \overline{X}_{t-1} + \sum_{l=0}^{p} \gamma_{il} \Delta \overline{Y_{t-l}} + \sum_{l=1}^{p} \gamma_{il} \Delta Y_{i,t-l} + \varepsilon_{it} \quad (4)$$

where: $\overline{Y}_{t-1}$ explains the average lagged; $\Delta\overline{Y_{t-l}}$ depicts the first difference of the averages.

For CIPS, the Eq. (5) provides it computation as follows:

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

where: CIPS: cross-sectional augmented IPS; CADF: cross-sectional augmented ADF. These unit root methods are known as second-generation unit root testing. As opposed to the first generation of unit root testing, these approaches produce accurate estimates when attempting to deal with CSD.

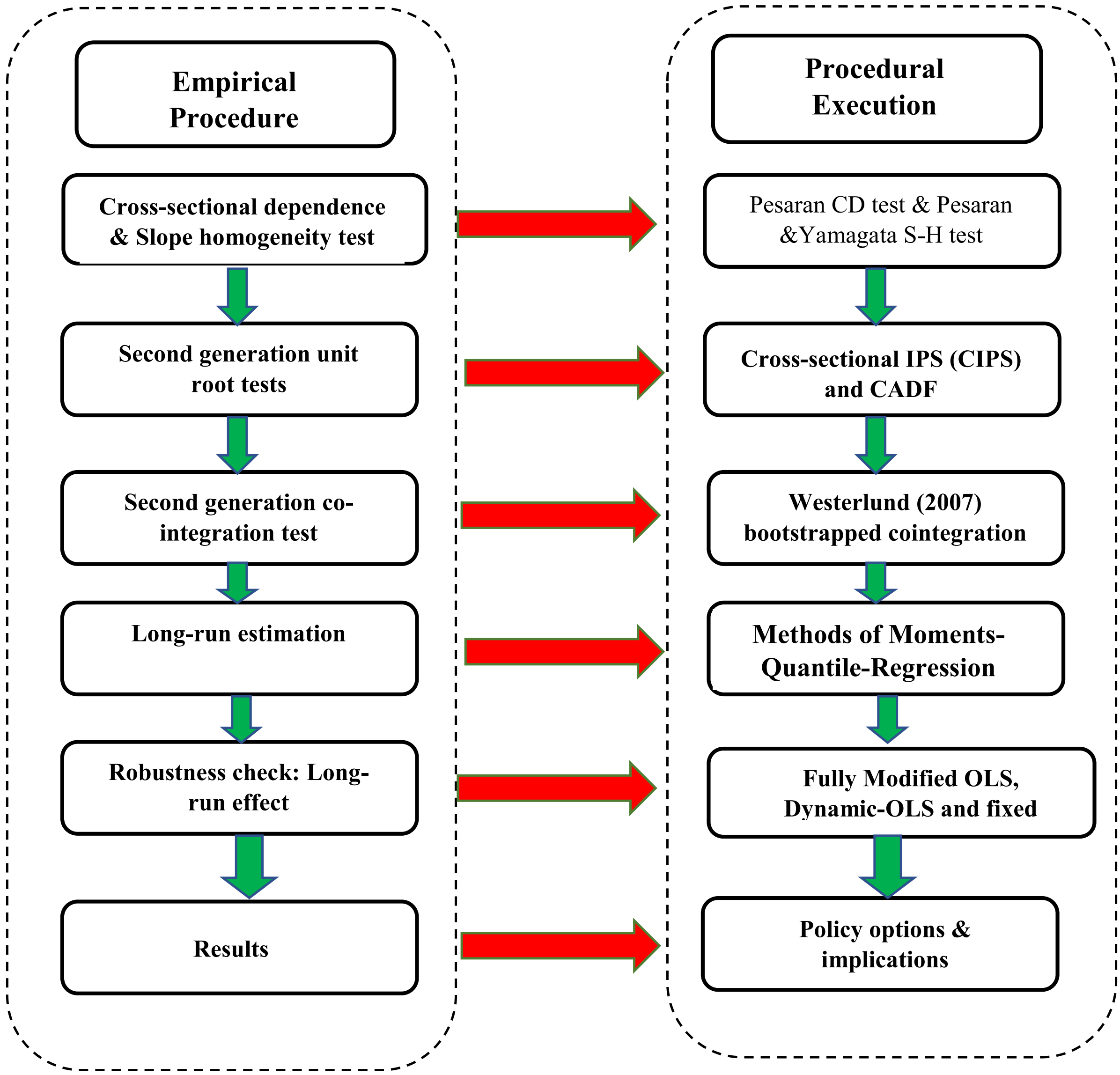

Fig. 1. Flow of analysis.

3.3.3. Panel cointegration test

When the outcome of the stationary test revealed that the concerned variables are integrated at level, the ordinary least square (OLS) method will be utilized in estimating the long run association. Conversely, when it is evident that these variables are integrated at the first difference, the OLS cannot be employed to verify the co-integration among these variables. For this reason, several co-integration approaches such as McCoskey and Kao (1998), and Pedroni (2004) can be undertaken; however, this approach lack the capacity to detect the co-integration in the presence of CSD; therefore, their outcomes will be erroneous. Thus, this study employed the bootstrap LM panel co-integration, which is the innovation of Westerlund (2007), which is computed as follows:

$$LM_N^+ = \frac{1}{NT^2} \sum_{i-1}^{N} \sum_{t-1}^{T} \hat{w}_i^{-2} s_{it}^2 \quad (6)$$

where: $\hat{w}_i$ represents the error terms' long-term variance; sample size denoted as N; s_{it}^2 denotes the residuals' partial sum procedure and the period is denoted as T.

3.3.4. Panel estimator approach

This study utilized the Fully Modified OLS, Dynamic-OLS and fixed effect OLS for the sole purpose of comparison. According to Pedroni (2004), the main causes for concern in evaluating dynamic cointegrated panels are heterogeneous concerns with variations in averages between cross-sections and variations in cross-sectional modification to the cointegrating equilibrium. Pedroni's FMOLS model incorporates individual intercepts and accommodates heterogeneous serial correlation characteristics of the error procedures among specific cross-sections, and hence addresses these concerns appropriately. However, specific intercepts in the FMOLS approach allows for heterogeneous serial-correlation among different cross-sections. Kao and Chiang (2001) developed the DOLS estimator to panel data setups, premised upon Monte Carlo simulation findings; the DOLS estimate was shown to remain impartial in finite samples , particularly in comparison to both the OLS and the FMOLS estimators. The DOLS estimator additionally accounts for endogeneity by boosting lead and lag differences to minimize endogenous

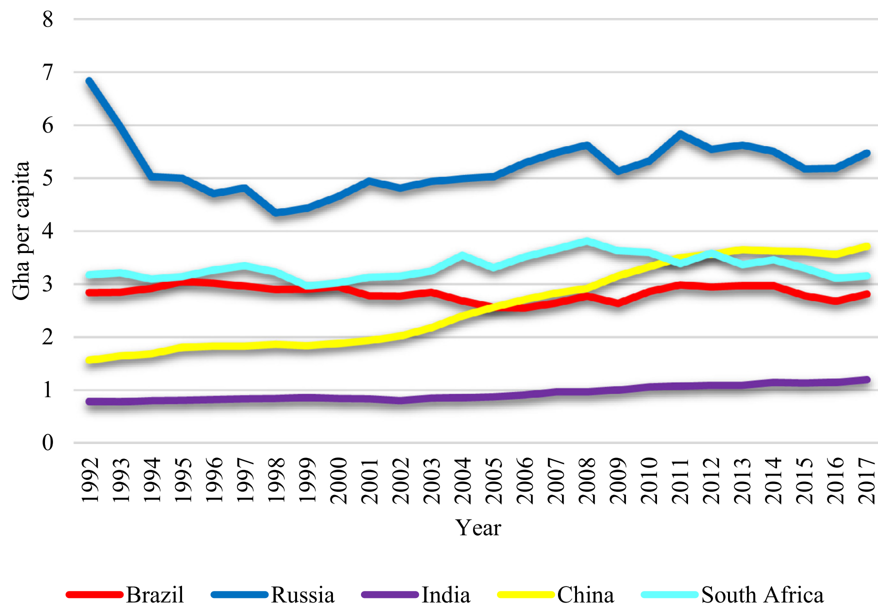

Fig. 2. Ecological footprint.

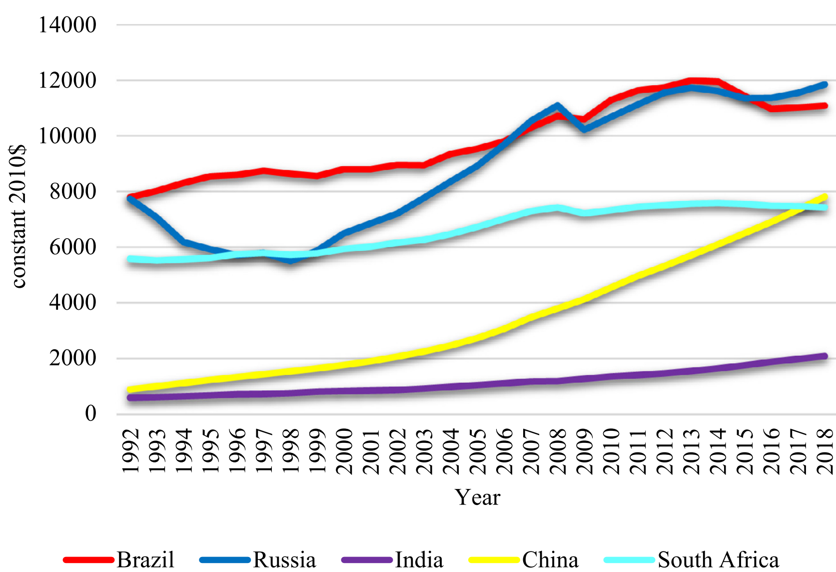

Fig. 3. GDP per capita.

feedback. The DOLS is computed as follows:

$$y_{it} = \alpha_i + \beta_i X_{it} + \sum_{k=-Ki}^{Ki} \gamma_{ik} \Delta X_{it-k} + \in_{it} \quad (7)$$

where; the leads and lags are denoted by K_i and -K_i correspondingly.

The estimates of the FMOLS is computed as follows

$$\hat{B}GFM = N^{-1} \sum_{i=1}^{N} \hat{B}FM, i \quad (8)$$

where: $\hat{B}FM$, i indicates the ith term of the FMOLS estimator.

3.3.5. Method of moments quantile regression

Given the constraints of prior estimator (FMOLS and DOLS) techniques, a panel quantile regression approach was used to investigate the distributional and heterogeneous influence across quantiles (Sarkodie and Strezov, 2019). The foundational work of Koenker and Bassett (1978) established the panel quantile regression technique. It is common to use quantile regression models to estimate the conditional median or various quantiles of the endogenous variable under certain conditions of the exogenous variables, as opposed to regular least-squares regression models, which yield estimates of the conditional mean the response under certain conditions of the exogenous variables. Quantile regressions seem to be more robust to estimates that contain outliers and they may also be used to evaluate the weak connection between conditional means between two parameters (Binder and Coad, 2011). It is indeed important to note that in this research, we utilized the methods of Moments-Quantile-Regression (MMQR) approach that takes fixed-effects into account, which Machado and Silva (2019) developed. This approach allows the conditional heterogeneous covariance effects of ecological footprints factors to be identified. This approach also permits the individual-effect to impact the overall distribution rather than adjusting means amongst the other. This method is also useful in the sense that the model has endogenous explanatory variables

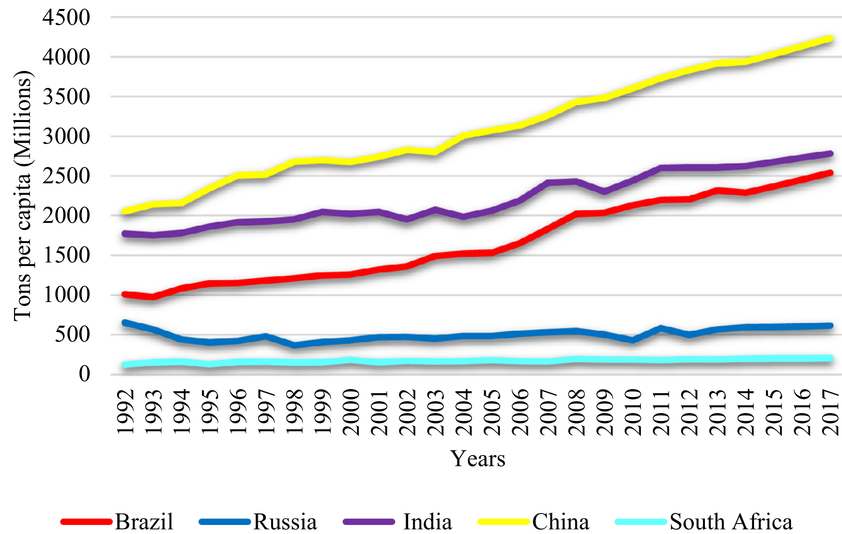

Fig. 4. Biomass energy consumption.

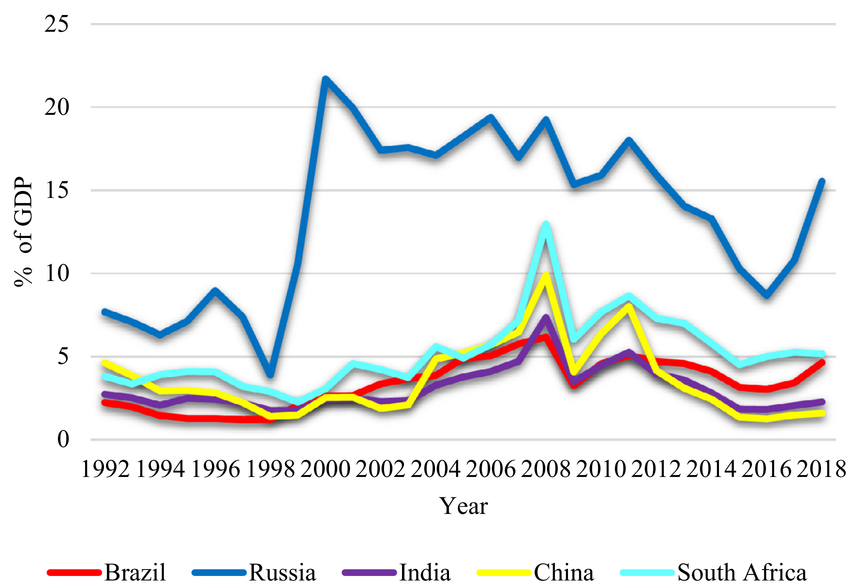

Fig. 5. Natural resources.

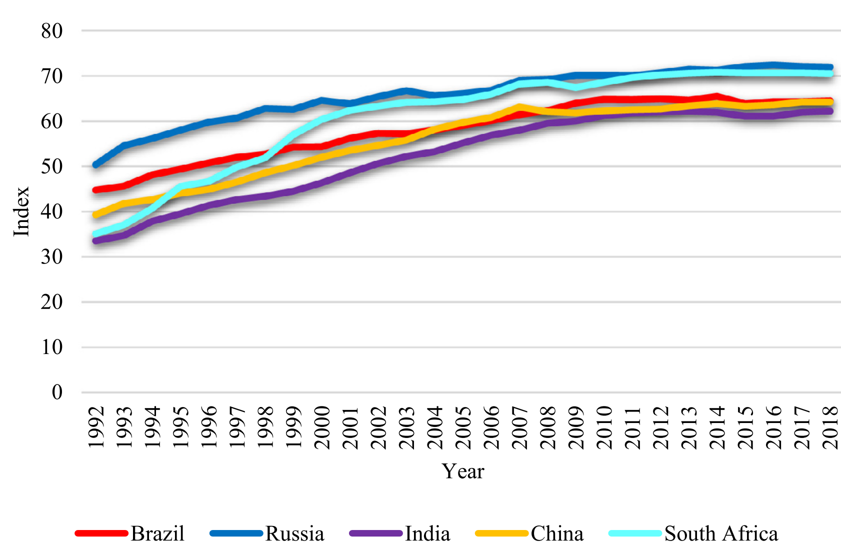

Fig. 6. Globalization.

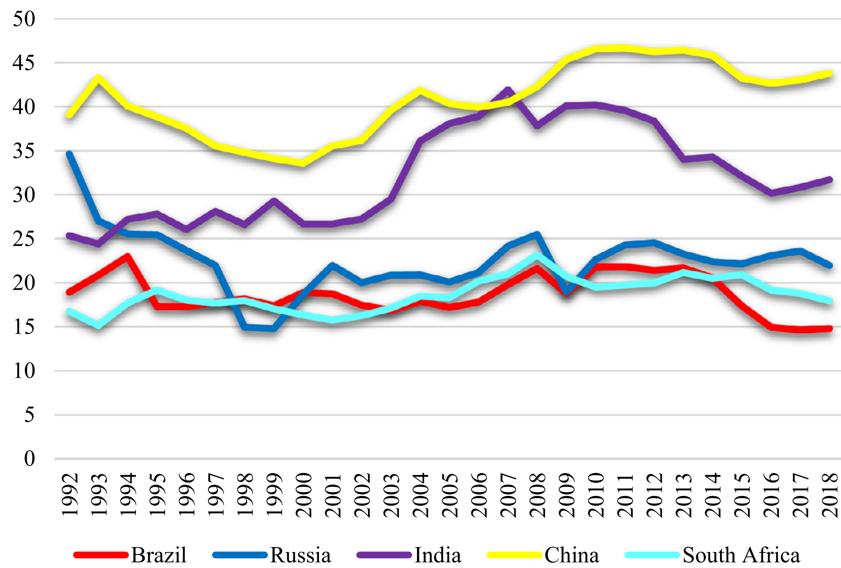

Fig. 7. Gross capital formation.

and is entrenched in individual-effect. The estimated model of conditional quantiles $Q_y\left(\delta|\hat{X}_{it}\right)$ is computed as follows:

$$Y_{it} = \dot{a}_i + \ddot{X}_{it}\Phi + \left(\dot{\lambda}_i + \mathcal{Z}'_{it}\Psi\right)\breve{U}_{it} \quad (9)$$

where: the probability, $þ\left\{\dot{\lambda}_i + \mathcal{Z}'_{it}\Psi > 0\right\} = 1$, and the parameters $(\Phi, \dot{\lambda}_i\mathcal{Z}'_{it}\Psi)$ are to be accessed. $(\dot{a}_{i,}\dot{\lambda}_i)$, i = 1,2,3 up to *n*, describes the discrete *i* fixed effects whereas $\mathcal{Z}'$ denotes k-vector of recognized modules of $\ddot{X}$, and are distinguishable alterations with j as follows:

$$\mathcal{Z}_j = \mathcal{Z}_j\left(\ddot{X}\right), j = 1, 2, \ldots\ldots, k$$

$\ddot{X}_{it}$ and $\breve{U}_{it}$ are identically dispersed beyond individuals *i* and time period (t). Based on (51), the standardized momentum conditions $\breve{U}_{it}$ are orthogonal to $\ddot{X}_{it}$. Thus, Eq. (10) recommendation is as follows:

$$Q_y\left(\dot{\delta}|\hat{X}_{it}\right) = \dot{a}_i + (\dot{\boldsymbol{\lambda}}_i\boldsymbol{\rho}_i q(\dot{\delta})) + \ddot{X}_{it}\Phi + \mathcal{Z}'_{it}\Psi q(\dot{\delta}) \quad (10)$$

Based on the Eq. (10), $\ddot{X}_{it}$ depicts the vector of the determinants of ecological footprint (GDP, BIO, NR, GLO and GCF). The quantile distribution of Y_{it} is denoted as $Q_y\left(\dot{\delta}|\hat{X}_{it}\right)$; ECF is a constrain on the placement of the regressor $\ddot{X}_{it}$. $\dot{a}_i\left(\dot{\delta}\right) \equiv \dot{a}_i + \lambda_i q(\dot{\delta})$; the scalar to uncover quantile-$\dot{\delta}'$ fixed effects across individuals *i*. $q\left(\dot{\delta}\right)$ denotes the sample quantile. This is determined by addressing optimization as described below.

$$Min_q = \sum_i \sum t\eta_{\dot{\delta}}(Rit - (\dot{\lambda}_i + \mathcal{Z}'_{it}\gamma)q) \quad (11)$$

where; $\eta_{\dot{\delta}}(\ddot{R}) = (\delta \grave{-} 1)\ddot{R}I\left\{\ddot{R} \leq 0\right\} + T\ddot{R}I\{R \ddot{>} 0\}$ denotes the checked function.

4. Findings and discussion

4.1. Cross-sectional dependence tests

Pesaran (2015) cross dependence test was utilized to detest the occurrence of shock-dependency amongst the cross-sections. The outcome of the Pesaran CSD is presented in Table 3. From the results in Table 3, the tests significantly reject the null hypothesis, indicating that there is no cross-sectional dependency (CSD) in our country-based panel data analysis. Taking into consideration these CD shocks was consequently critical in the panel's methodology. Furthermore, the slope homogeneity test was also utilized solely to corroborate the outcome of the CSD test. Table 4 displayed the outcome of the slope homogeneity test and confirmed the slope coefficients are heterogeneous. Also, the slope homogeneity test affirmed that BRICS have varying levels of development and technical progress. The next phase of our analysis is to ensure that each variable remains stable (stationary test).

Table 3
Pesaran (2015) Cross-sectional dependency test results.

Variables	Statistic	*P*-value
ECF	8.2681*	0.000
GDP	15.5132*	0.000
BIO	13.9906*	0.000
NRR	11.0300*	0.000
GLO	5.8078*	0.000
GCF	12.6393*	0.000

* depict significance level of 0.01.

Table 4
Slope homogeneity test results.

Test	Value	*P*-value
$\tilde{\Delta}$	8.915*	0.000
$\tilde{\Delta}_{adjusted}$	10.714*	0.000

* depict significance level of 0.01.

4.2. Panel stationary tests (unit root)

This present study employed the CIPS and CADF approach to achieve its aims. The outcomes for the CIPS and CADF tests are presented in Table 5. At level, the empirical outcomes indicate that ECF_{it}, GDP_{it}, BIO_{it}, NRR_{it}, GLO_{it} and NRR_{it} have root problems within the cross-section over the period of concern (1992–2018). However, the outcomes also show that at first difference [I(I)], all variables are free from root issues, indicating that all observed variables are stationary at first difference. Upon establishing the stationary properties, the co-integration approach can now be instigated.

Table 5
Unit root test results.

Variable	CIPS		CADF	
	Level	First-difference	Level	First-difference
ECF	−2.456	−4.568*	−2.531	−3.091*
GDP	−2.795	−3.128*	−1.912	−2.982*
BIO	−4.106	−5.334*	−3.359	−3.048*
NRR	−1.333	−4.435*	−0.829	−3.836*
GLO	−2.685	−5.387*	−2.255	−3.279*
GCF	−2.336	−4.676*	−1.917	−3.501*

* depict significance level of 0.01.

Table 6
Westerlund (2007) bootstrap panel co-integration test results.

Statistic	Value	Z-value	Robust P-Value
G_t	−2.485	1.287	0.700
G_a	−1.542	4.301	0.000*
P_t	−5.819	0.412	0.100
P_a	−5.015	2.644	0.000*

* depict significance level of 0.01.

4.3. Panel cointegration tests

The results of the ECM-based bootstrapped co-integration test of Westerlund (2007) outcome are presented in Table 6. The null hypothesis of no co-integration in the presence of serial correlation, heterogeneity and cross-section dependence is rejected given that G_a (−1.542, p < 0.01) and P_a (−5.015, p < 0.01). Thus, this is evidence of a cointegrating association between ECF_{it}, GDP_{it}, BIO_{it}, NRR_{it}, GLO_{it} and NRR_{it}. Furthermore, the ECM for our model is calculated as $\frac{P_a}{T} = \frac{-5.105}{27} = -0.1891$. Therefore, a disequilibrium in the short run will be adjusted at 18.91% in the long run on an annual basis. After establishing the co-integration association, the effect of the determinants of ecological footprint can be investigated.

4.4. Panel estimation results

The outcomes of these estimators (FMOLS, DOLS and FE-OLS) are summarized in Table 7. An examination of the coefficients produced by the estimator reveals that they are relatively similar to each other, despite the fact that they all differ with regard to statistical significance. A positive and significant association is evident between GDP and ECF. This shows that a percentage increase in GDP will cause the rate of ecological footprint to increase by 0.4758%, 0.6777% and 0.7391% with respect to FMOLS, DOLS and FE-OLS, respectively. This outcome is anticipated considering that emerging nations, like the BRICS economies, have dominated the globe's economic expansion during the last two decades. For example, between 1992 and 2018, the GDP per capita of Brazil rose significantly from US$7792 to US$11,080, while Russia experienced a surge in its GDP from US$7737 to US$11,844, India continued to increase from US$595 to US$2,086, China increased from US$887 to US$7807, and South Africa rose from US$5586 to US$7434. As a result, the quality of the environment in the BRICS economies has deteriorated in their pursuit of achieving tremendous economic expansion; this outcome concurs with the findings of Akinsola et al. (2021) for Brazil and Yang et al. (2021) for the BICS economies, Kihombo et al. (2021a,b) for the WAME economies, Alola et al. (2021b) for China, and Udemba et al. (2021) for the G7 economies.

However, biomass is found to be negative and significantly associated with ecological footprint for all estimators. The coefficients for FMOLS, DOLS, and FE-OLS regarding biomass and ecological footprint are −0.7482; −0.2074 and −0.1588, respectively. Our results demonstrate that biomass energy operates as a renewable energy solution, which contributes to minimizing pollution by decreasing ecological footprint in the BRICS economies. This energy source is abundant in the BRICS nations, and its combustion is ecologically sustainable. This outcome aligns with the studies of Wang (2019), who confirmed that biomass energy consumption improves the environmental quality in the BRICS economies, while the studies of Solarin et al. (2018) and Gao and Zhang (2021) contradicted this finding.

Table 7
Panel estimation outcome.

Regressors	FMOLS		DOLS		FE-OLS	
	Coefficient	T-Stat	Coefficient	T-Stat	Coefficient	Z-Value
GDP	0.4758*	−5.6163	0.6777*	18.6821	0.7391*	14.2361
BIO	−0.7482*	−5.0628	−0.2074*	−2.8568	−0.1588*	−2.1472
NRR	0.1464*	3.2677	0.0345**	2.2813	0.2588*	6.9966
GLO	−0.5911*	−3.1059	−0.7580*	−13.0285	−0.5715*	−2.7074
GCF	0.2992*	1.8872	0.1726*	2.7030	0.4820*	6.7407

*, ** and *** depict significance level of 0.01, 0.05 and 0.1 respectively.

Similar to GDP, the association between NR and ecological footprint was found to be positive at different levels of significance. As shown in Table 7, the coefficients for NR are 0.1464, 0.0345 and 0.2588 with regard to FMOLS, DOLS and FE-OLS, respectively. The BRICS economies are endowed with aplethora of natural resources, which they primarily use to generate revenues in foreign currency. The repercussions of exploring these natural resources could contribute to deforestation and other environmentally hazardous practices. This outcome is in agreement with the studies of Jiang et al. (2020), Hassan et al. (2019), Langnel et al. (2021), Nathaniel and Adeleye (2021) and Ahmed et al. (2020). This outcome is enlightening, indicating that the exploitation and consumption of natural resources are unsustainable in the BRICS economies. For instance, the top producer of coal in the world is China, with India in second place and Russia and South Africa occupying the sixth and seventh places, respectively. According to Awosusi et al. (2021a,b), the consumption of coal in South Africa contributes to environmental degradation. Also, Shahbaz et al. (2015) discovered that coal consumption contributes to environmental degradation in China and India. Kanat et al. (2021) confirmed a similar outcome in the case of Russia.

As expected, globalization negatively affects the ecological footprint in BRICS economies. One percent increase in globalization will produce decreases in the rate of ecological footprint by 0.5911%, 0.7580% and 0.5715% with respect to FMOLS, DOLS and FE-OLS, respectively. This outcome aligns with the research of Saud et al. (2020), Yang and Usman (2021), Ansari et al. (2021), Alola et al. (2021a,b), Salari et al. (2021) and Usman et al. (2020). Therefore, this outcome indicates that globalization brings about environmental betterment in BRICS economies. Furthermore, the adverse effect of globalization on ecological footprint shows that the pollution haven hypothesis (PHH) is invalid in the cases of the BRICS economies.

Finally, the empirical findings of GCF and ECF disclosed a positive and significant association. Increases of 0.2992%, 0.1726% and 0.4820% in ecological footprint will result from a 1% increase in gross capital formation. This finding was supported by the study of Zhang et al. (2021) and shows that gross capital formation is not sustainable in the BRICS economies.

Table 8 provides a summary of the outcomes of the method of moments Quantile regression (MMQR). Also, the quantile plot of the heterogeneous effect of GDP, biomass energy, natural resources, globalization and gross capital formation on ecological footprint is depicted in Fig. 8. The analysis covers nine quantiles (0.1–0.9). The results indicate that there is a positive impact between GDP and ECF in all quantiles. According to Table 8, the

Table 8
Outcomes of the MMQR.

	Location	Scale	Lower Quantile			Middle Quantile			Higher Quantile		
Variables			0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
GDP	0.9697*	0.0388	0.9029*	0.9212*	0.9483*	0.9563*	0.9691*	0.9809*	0.9895*	1.0125*	1.0275*
BIO	−0.6071*	−0.0559*	−0.5111*	−0.5374*	−0.5764*	−0.5879*	−0.6064*	−0.6234*	−0.6357*	−0.6688*	−0.6906*
NRR	0.1227*	0.0008	0.1241*	0.1236*	0.1231*	0.1229*	0.1226*	0.1224*	0.1223*	0.1217*	0.1215*
GLO	−0.9336*	−0.2045*	−0.5823*	−0.6785*	−0.8213*	−0.8634*	−0.9309*	−0.9933*	−1.0384*	−1.1594*	−1.2388*
GCF	0.2240*	0.0337	0.1659*	0.1818*	0.2055*	0.2124*	0.2236*	0.2338*	0.2413*	0.2613*	0.2744*

Note: * represents 1% level of significance.

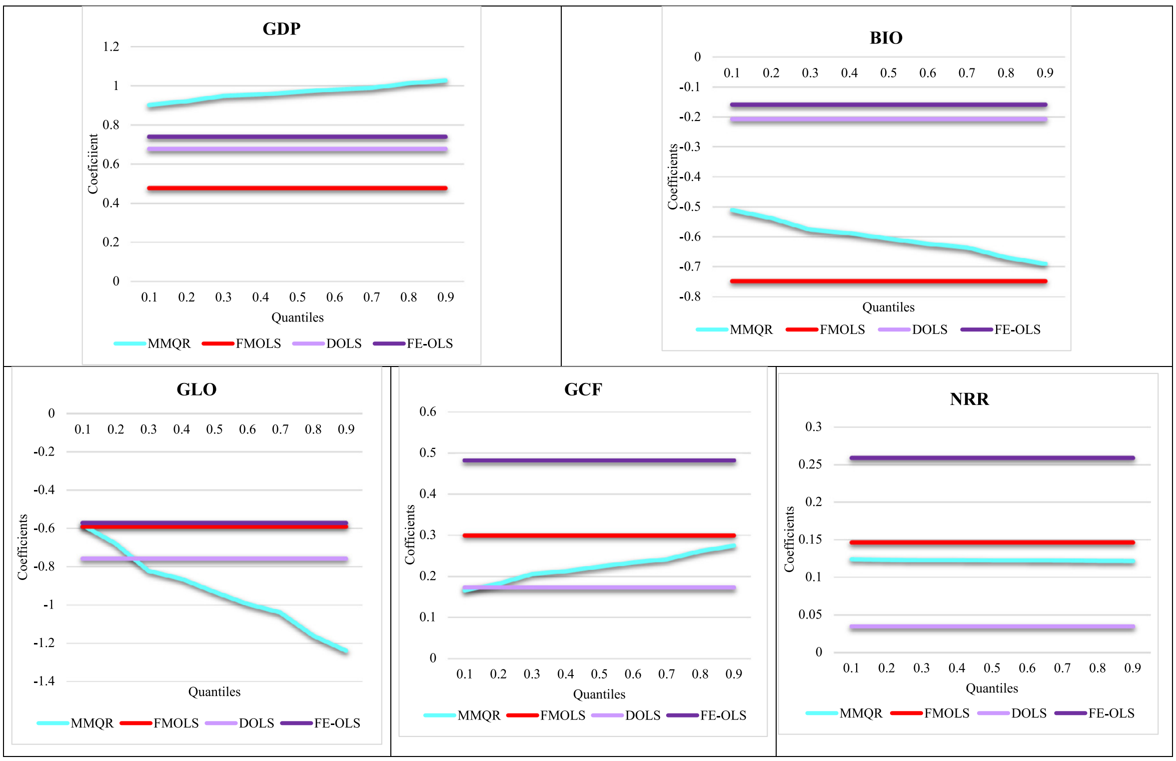

Fig. 8. Graphical representation of coefficient estimates for all variables across all quantiles, obtained from all 4 estimator.

increase in ecological footprint is evidently caused by GDP, and the ecological footprint increases from 0.9029 to 1.0275 as the quantile rises. Primary output rises slowly in the early phases of economic expansion and accelerates in the later phases. As a result, an increase in these economic activities has an undesirable effect on ecological footprint.

In contrast with the preceding cases, the environmental impact of biomass is negative and significant across all quantiles (0.1–0.9). The magnitude of the impact of biomass energy consumption increases as the quantiles increase. Increasing biomass energy usage in the energy mix suggests that non-renewable energy consumption is declining, which is applicable for the BRICS economies. The indirect effect of biomass energy may have an obvious resolution, like the necessity to develop technical innovation, notably in the generation of renewable energy, in order to enhance the production quality while also reducing production costs. Moreover, it indirectly circumvents the problem of rising environmental degradation. This outcome contradicts the claim of Solarin et al. (2018), suggesting that biomass is like fuels (fossil fuels) that emit air pollution, which reduces the quality of the environment, thereby calling for a reduction in the usage of biomass energy. This study finding also contradicts the outcomes of Wang et al. (2020), who suggested that increasing usage of biomass will result in an increase in ecological footprint in the G-7 economies.

Across all quantiles, natural resources have a positive and significant association with ecological footprint in the BRICS economies. As the quantiles increase, the degree to which natural resources impact ecological footprint continues to slightly decrease. Thus, the exploitation of natural resources contributes to environmental deterioration, highlighting the unsustainable role of exploitation operations. The findings from the study of Hassan et al. (2019) and Ahmed et al. (2020) for Pakistan and China, respectively, agree with our findings, although the empirical outcomes of Ulucak and Khan (2020) for the BRICS economies contradict our findings by disclosing that natural resources reduce the rate of ecological footprint. Expanding the volume of extractive operations can contribute to economic growth, but these operations also negatively affect the environment. The justification for this outcome is that the use of coal, natural gas, oil and natural extraction could contribute to the imbalance in the ecosystem, deforestation, soil erosion, and loss of biodiversity. Consequently, measures aimed at increasing natural resource efficiency while simultaneously reducing the damage caused to the ecosystem are required.

The outcome for globalization revealed that its impact on ecological footprint is negative across all quantiles; moreover, the degree of impact continues to increase as the quantiles increase. This outcome confirms that globalization may mitigate ecological footprint in the BRICS economies. This finding has significant

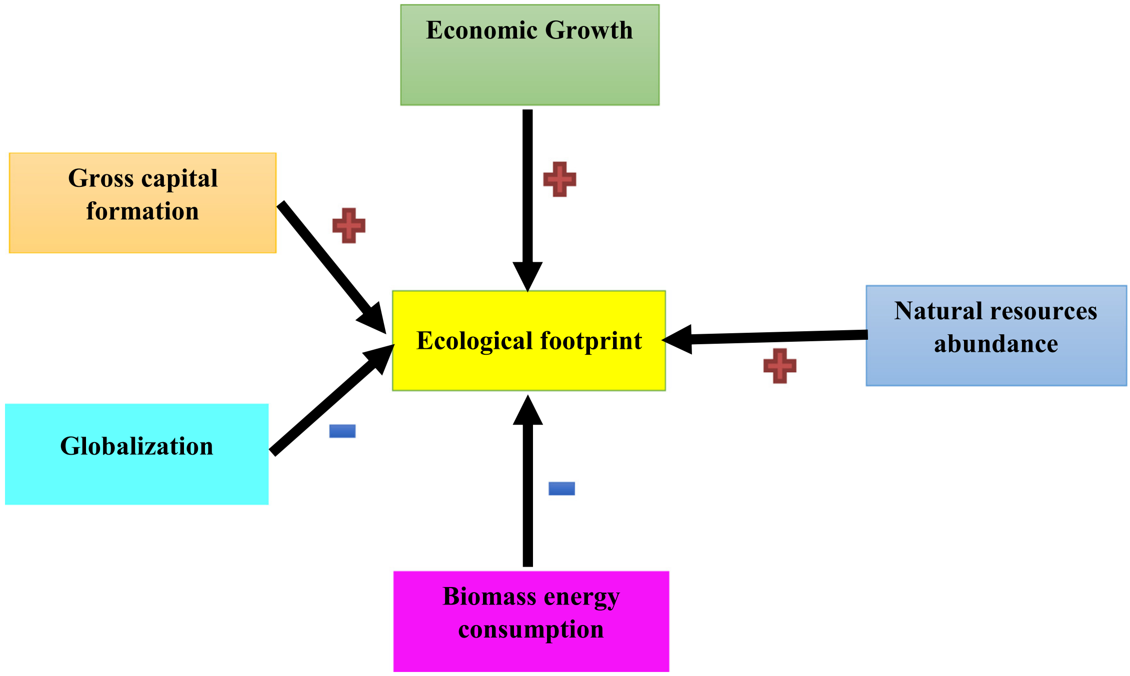

Fig. 9. Graphical findings of FMOLS, DOLS, FE-OLS, and MMQR.

policy ramifications, which aligns with the research of Saud et al. (2020), who established an adverse role of globalization on environmental degradation. Our outcomes are also in line with the recent empirical investigation of Yang and Usman (2021), who found a negative association between globalization and ecological footprint in 10 selected nations. Social and environmental sustainability are required for the globalization process (Shahbaz et al., 2018); however, the BRICS economies have only been able to meet this requirement to a certain extent, which provides justification for this outcome. Another probable explanation might be that some industrial or manufacturing operations had been transferred to other nations through either foreign direct investment, free trade or both, thereby easing the strain on these nations' ecosystems and natural resources. Therefore, globalization gains more influence in the BRICS economies when compared with industrialization. Finally, gross capital formation impacts on ecological footprint are positive across all quantiles. Specifically, it is clear that upper quantiles of gross capital formation show a higher effect on ecological footprint when compared with the lower and middle quantiles. This outcome is not consistent with Nathaniel and Adeleye (2021) research, who established a positive and insignificant association between gross capital formation and ecological footprint in 44 African economies. The rationale for this outcome is that companies with a larger capital stock are more likely to engage in an expansionary drive that includes more manufacturing operations and the utilization of various energy-generating operations. Thus, the major goal of the long-run fiscal investment in these economies is to achieve economic expansion, which is at the expense of the environmental quality of these economies, although the justification for these economies is that they are still in the developing phase. This finding also provides an insight into the negative effect of GDP on these economies, as shown in Fig. 9.

5. Conclusion and policy recommendation

Environmental concerns have remained a topic of significant interest in the literature as the globe continues to experience global warming. Despite the fact that various researchers have examined the factors that influence environmental pollution, most empirical investigations have employed aggregate renewable energy consumption or traditional panel estimation methods. In contributing to the literature on environment and energy, the current research explored the role of biomass energy usage, natural resources abundance, globalization and gross capital formation in the growth-environment nexus for the BRICS economies. Different preliminary analyses and panel sensitivity tests were used in this work to discover the characteristics of the considered dataset over the period from 1992 to 2018, while a number panel conventional estimation approaches were used with quantile regression to verify the robustness of the estimations. The study employed the CIPS and CADF stationary test and uncovered that all series are stationary at first difference. Using the Westerlund co-integration test, the presence of a co-integration association between ecological footprint, economic growth, biomass energy usage, natural resources abundance, globalization and gross capital formation was found in the BRICS economies.. Furthermore, this study also utilized the MMQR approach. This approach allows for the heterogeneity interconnection at several levels of conditional quantiles distribution (usually 0.1–0.90 quantiles) of ecological footprint, which is not possible when using traditional mean regressions. This is important for a stronger and more detailed evaluation of the empirical connection.

The FMOLS, DOLS and FE-OLS estimators confirmed that GDP, natural resource abundance and gross capital formation increase ecological footprint, while biomass energy usage and globalization reduce ecological footprint in the BRICS economies. Based on the empirical evaluation, an increase in GDP by one percent will increase ecological footprint by 0.48%, 0.68% and 0.74% with respect to FMOLS, DOLS and FE-OLS, respectively. Also, an increase in the usage of biomass energy by 1% will reduce ecological footprint by 0.75%, 0.21% and 0.16% with respect to FMOLS, DOLS and FE-OLS, respectively. An increase of NRR by 1% will raise ecological footprint by 0.15%, 0.03% and 0.26% with regard to FMOLS, DOLS and FE-OLS, respectively. One percent increase in globalization will produce a decrease in the rate of ecological footprint by 0.59%, 0.76% and 0.57% with respect to FMOLS, DOLS and FE-OLS, respectively. An increase of gross capital formation by 1% will raise ecological footprint by 0.30%, 0.17% and 0.48% with regard to FMOLS, DOLS and FE-OLS, respectively.

The findings of the MMQR revealed a positive impact between GDP and ECF in all quantiles. The environmental impact of biomass is negative and significant across all quantiles (0.1–0.9).

Also, across all quantiles, natural resources have a positive and significant association with ecological footprint in the BRICS economies. It was found the impact of globalization on ecological footprint is negative across all quantiles. Finally, the impacts of gross capital formation on ecological footprint were positive across all quantiles. As illustrated in Fig. 8, the estimates of the MMQR for GDP, BIO, NRR, GLO and GCF are quite different in terms of their dynamics. The coefficients of GDP and GCF are highest at higher quantiles and lower quantiles, their coefficients are at their lowest. While the coefficients of BIO and GLO decrease from the lowest to the highest quantiles, for NRR, the value of the coefficient does change across all quantiles.

5.1. Policy recommendation

Given the empirical evidence, the following recommendations are proposed for these economies: reducing emissions necessitates a shift in energy policies away from fossil fuels and toward renewable energy alternatives. This will almost certainly result in a decrease in revenue surplus due to an increase in operating expenditure. This can be offset by levying a charge on dirty industries that depend on fossil fuels. Once the pollution tax diminishes the appeal of polluting companies, they will strive to transition to greener and alternative sources of energy. It seems that governments will need to make significant investments in sustainable energy alternatives.

These economies should develop a circular economy that is effective whereby the concept of the 3R's (reduction, reuse and recycle) can be employed by all industries (especially the dirty ones). Therefore, the level of material consumed during production and pollution may be significantly lowered. This necessitates a coordinated action at multiple levels. At the company level, implementing process synthesis, cleaner production, and eco-design at various phases in the life-cycle could accomplish optimal dematerialization. At the level of clustered industries, comprehensive facilitation of industrial symbiosis such as exchange of by-products among various companies or industries solely to reduce waste and the usage of the material is recommended. However, the Chinese government has been prominent among the BRICS economies fostering eco-industrial parks (EIP). The specifications for the national eco-industrial park have been established to assist in the development of EIP professionals towards the development of the eco-industry. The Chinese experience can also be disseminated within other BRIC nations, allowing for developing increasingly country-specific norms. The circular economy should become a critical tool for domestic economic development at the regional level because it stimulates the establishment of economic operations with assessment mechanisms that emulate natural ecosystems such as the process of converting natural resources into manufactured products and the manufacturing byproducts are utilized as resources for other industries. There should be a regulation backing the implementation of this approach, like suitable economic measures (such as financial subsidies, taxation, pricing, and so on), a fair incentive and punishment framework, as well as research and development.

The current state of biomass energy usage in BRICS nations reveals that this energy source is mostly utilized by the household sector, making it much less difficult for the government to improve at this level. Clean and efficient biomass alternatives are relatively expensive; thus, governments should support their usage in this sector by offering subsidized rates. Bioenergy is a major source of energy in emerging economies, but it requires modernization with respect to efficiency, cost, and sustainability. Several bioenergy alternatives, such as agro-residues, rice husks, and MSW offer significant possibilities for reducing the ecological footprint. The efficiency of the production process and the amount of fossil fuel utilized to create biomass are two factors that influence the decrease in ecological footprint. As a result, the governments of the BRICS should take measures regarding the innovation of biomass so as to improve conversion efficiency.

Since the research has found that NR positively influences ECF, sustainable strategies must be adopted in the assessment of NR in the BRICS. The necessity for "green exploration" necessitates reforms and the implementation of mineral pollution, soil, and water regulations in the BRICS. This would minimize not only the damage to the environment but also maintain the long-term sustainability of the ecosystem. The use of clean and cheaper natural resources such as hydropower, solar, biomass, and, wind, among others, will enable resource recycling, biodiversity protection, and a reduction in ECF with less depletion of NR. Forests should be safeguarded even more by enforcing sanctions on offenders.

This study contains numerous limitations that can be addressed in future studies. Firstly, owing to the lack of available data, this research could not address the environmental consequences of various kinds of biomass energy generation. Secondly, our research examines the impact of the usage of biomass energy on the BRICS' ecological footprint, which comprises five emerging economies. Future studies might build on this work by evaluating the ecological effect of the usage of biomass energy in other emerging nations or groups, therefore expanding the insight into the biomass energy-ecological footprint nexus.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Abbas, Q., Nurunnabi, M., Alfakhri, Y., Khan, W., Hussain, A., Iqbal, W., 2020. The role of fixed capital formation, renewable and non-renewable energy in economic growth and carbon emission: a case study of Belt and Road Initiative project. Environ. Sci. Pollut. Res. 27 (36), 45476–45486.

Adebayo, T.S., Awosusi, A.A., Odugbesan, J.A., Akinsola, G.D., Wong, W.K., Rjoub, H., 2021b. Sustainability of energy-induced growth nexus in Brazil: do carbon emissions and urbanization matter? Sustainability 13 (8), 4371.

Adebayo, T.S., Awosusi, A.A., Oladipupo, S.D., Agyekum, E.B., Jayakumar, A., Kumar, N.M., 2021a. Dominance of fossil fuels in Japan's national energy mix and implications for environmental sustainability. Int. J. Environ. Res. Public Health 18 (14), 7347.

Adebayo, T.S., Kalmaz, D.B., 2021. Determinants of CO2 emissions: empirical evidence from Egypt. Environ. Ecol. Stat. 28 (2), 239–262.

Adebayo, T.S., Kirikkaleli, D., 2021. Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools. Environ. Dev. Sustain. 1–26.

Adebayo, T.S., Ramzan, M., Iqbal, H.A., Awosusi, A.A., Akinsola, G.D., 2021c. The environmental sustainability effects of financial development and urbanization in Latin American countries. Environ. Sci. Pollut. Res. 1–14.

Adebayo, T.S., Soylu, Ö.B., Kirikkaleli, D., 2020. The imperativeness of environmental quality in China amidst renewable energy consumption and trade openness. Sustainability 13 (9), 5054.
Ahmed, Z., Asghar, M.M., Malik, M.N., Nawaz, K., 2020. Moving towards a sustainable environment: the dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. Resour. Policy 67, 101677.
Ahmed, Z., Wang, Z., Mahmood, F., Hafeez, M., Ali, N., 2019. Does globalization increase the ecological footprint? Empirical evidence from Malaysia. Environ. Sci. Pollut. Res. 26 (18), 18565–18582.
Ahmed, Z., Zhang, B., Cary, M., 2021. Linking economic globalization, economic growth, financial development, and ecological footprint: Evidence from symmetric and asymmetric ARDL. Ecol. Indic. 121, 107060.
Ajmi, A.N., Inglesi-Lotz, R., 2020. Revisiting the Kuznets curve hypothesis for Tunisia: carbon dioxide vs. Ecological footprint. Energy Sources B 1–14.
Akinsola, GD., Awosusi, AA., Kirikkaleli, D., Umarbeyli, S., Adeshola, I., Adebayo, TS., 2021. Ecological footprint, public–private partnership investment in energy, and financial development in Brazil: a gradual shift causality approach. Environ. Sci. Pollut. Res. 29 (6), 6719–6732.
Alola, A.A., Adebayo, T.S., Onifade, S.T., 2021b. Examining the dynamics of ecological footprint in China with spectral granger causality and quantile-on-quantile approaches. Int. J. Sustain. Dev. World Ecol. 1–14.
Alola, A.A., Eluwole, K.K., Lasisi, T.T., Alola, U.V., 2021a. Perspectives of globalization and tourism as drivers of ecological footprint in top 10 destination economies. Environ. Sci. Pollut. Res. 1–11.
Ansari, M.A., Haider, S., Masood, T., 2021. Do renewable energy and globalization enhance ecological footprint: an analysis of top renewable energy countries? Environ. Sci. Pollut. Res. 28 (6), 6719–6732.
Awosusi, A.A., Adebayo, T.S., Kirikkaleli, D., Akinsola, G.D., Mwamba, M.N., 2021a. Can CO 2 emissions and energy consumption determine the economic performance of South Korea? A time series analysis. Environ. Sci. Pollut. Res. 1–16.
Awosusi, A.A., Adebayo, T.S., Oladipupo, S.D., Agyekum, E.B., Jayakumar, A., Kumar, N.M., 2021b. Dominance of fossil fuels in Japan's national energy mix and implications for environmental sustainability. Int. J. Environ. Res. Public Health 18 (14), 7347.
Aydin, M., 2019. The effect of biomass energy consumption on economic growth in BRICS countries: A country-specific panel data analysis. Renew. Energy 138, 620–627.
Ayobamiji, A.A., Kalmaz, D.B., 2020. Reinvestigating the determinants of environmental degradation in Nigeria. Int. J. Econ. Policy Emerg. Econ. 13 (1), 52–71.
Balsalobre-Lorente, D., Shahbaz, M., Sinha, A., 2019. Foreign direct investment–CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. J. Cleaner Prod. 217, 603–614.
Bilgili, F., Koçak, E., Ü, Bulut., Kuşkaya, S., 2017. Can biomass energy be an efficient policy tool for sustainable development? Renew. Sustain. Energy Rev. 71, 830–845.
Binder, M., Coad, A., 2011. From average joe's happiness to miserable jane and cheerful john: using quantile regressions to analyze the full subjective well-being distribution. J. Econ. Behavior Org. 79 (3), 275–290.
Bui, Q., Kongbuamai, N., Yousaf, H.M.A.U., Liu, Y., 2020. The impact of tourism and natural resources on the ecological footprint: a case study of ASEAN countries. Environ. Sci. Pollut. Res. 27 (16), 19251–19264.
Gao, J., Zhang, L., 2021. Does biomass energy consumption mitigate CO2 emissions? The role of economic growth and urbanization: evidence from developing Asia. J. Asia Pac. Econ. 26 (1), 96–115.
Güngör, H., Kirikkaleli, D., Adebayo, T.S., 2021. Consumption-based carbon emissions, renewable energy consumption, financial development and economic growth in Chile. Bus. Strategy Environ..
Gyamfi, B.A., Ozturk, I., Bein, M.A., Bekun, F.V., 2021. An investigation into the anthropogenic effect of biomass energy utilization and economic sustainability on environmental degradation in E7 economies. Biofuels, Bioprod. Biorefin. 15 (3), 840–851.
Hadj, T.B., 2021. Nonlinear impact of biomass energy consumption on ecological footprint in a fossil fuel–dependent economy. Environ. Sci. Pollut. Res. 1–14.
Hassan, S.T., Xia, E., Khan, N.H., Shah, S.M.A., 2019. Economic growth, natural resources, and ecological footprints: evidence from Pakistan. Environ. Sci. Pollut. Res. 26 (3), 2929–2938.
He, K., Ramzan, M., Awosusi, A.A., Ahmed, Z., Ahmad, M., Altuntą s, M., 2021. Does globalization moderate the effect of economic complexity on CO2 emissions? Evidence from the top 10 energy transition economies. Front. Environ. Sci. 555.
Houshfar, E., Skreiberg, Ø., Todorović, D., Skreiberg, A., Løvås, T., Jovović, A., Sørum, L., 2012. NOx emission reduction by staged combustion in grate combustion of biomass fuels and fuel mixtures. Fuel 98, 29–40.
Jiang, P., Majeed, A., Ahmad, M., Umar, M., Khan, Z., Muhammad, S., 2020. The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: an advanced panel data estimation. Resour. Policy 69, 101817.
Kanat, O., Yan, Z., Asghar, M.M., Ahmed, Z., Mahmood, H., Kirikkaleli, D., Murshed, M., 2021. Do natural gas, oil, and coal consumption ameliorate environmental quality? Empirical evidence from Russia. Environ. Sci. Pollut. Res. 1–17.
Kao, C., Chiang, M.H., 2001. On the estimation and inference of a cointegrated regression in panel data. Nonstationary panels, panel cointegration, and dynamic panels. Emerald Group Publishing Limited.
Kihombo, S., Ahmed, Z., Chen, S., Adebayo, T.S., Kirikkaleli, D., 2021a. Linking financial development, economic growth, and ecological footprint: what is the role of technological innovation? Environ. Sci. Pollut. Res. 1–11.
Kihombo, S., Vaseer, A.I., Ahmed, Z., Chen, S., Kirikkaleli, D., Adebayo, T.S., 2021b. Is there a tradeoff between financial globalization, economic growth, and environmental sustainability? An advanced panel analysis. Environ. Sci. Pollut. Res. 1–11.
Kirikkaleli, D., Adebayo, T.S., 2021. Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. Sustain. Dev. 29 (4), 583–594.
Kirikkaleli, D., Adebayo, T.S., Khan, Z., Ali, S., 2021. Does globalization matter for ecological footprint in Turkey? Evidence from dual adjustment approach. Environ. Sci. Pollut. Res. 28 (11), 14009–14017.
Koenker, R., Bassett, G. Jr., 1978. Regression quantiles. Econometrica: J. Econometric Soc. 33–50.
Kongbuamai, N., Bui, Q., Yousaf, H.M.A.U., Liu, Y., 2020. The impact of tourism and natural resources on the ecological footprint: a case study of ASEAN countries. Environ. Sci. Pollut. Res. 27 (16), 19251–19264.
Langnel, Z., Amegavi, G.B., Donkor, P., Mensah, J.K., 2021. Income inequality, human capital, natural resource abundance, and ecological footprint in ECOWAS member countries. Resour. Policy 74, 102255.
Lu, W.C., 2020. The interplay among ecological footprint, real income, energy consumption, and trade openness in 13 Asian countries. Environ. Sci. Pollut. Res. 27 (36), 45148–45160.
Machado, J.A., Silva, J.S., 2019. Quantiles via moments. J. Econometrics 213 (1), 145–173.
Marti, L., Puertas, R., 2020. Analysis of the efficiency of african countries through their ecological footprint and biocapacity. Sci. Total Environ. 722, 137504.
McCoskey, S., Kao, C., 1998. A residual-based test of the null of co-integration in panel data. Econometric Rev. 17 (1), 57–84.
Nathaniel, S.P., Adeleye, N., 2021. Environmental preservation amidst carbon emissions, energy consumption, and urbanization in selected african countries: implication for sustainability. J. Cleaner Prod. 285, 125409.
Nathaniel, S.P., Yalçiner, K., Bekun, F.V., 2021. Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS. Resour. Policy 70, 101924.
Oladipupo, S.D., Adebayo, T.S., Adeshola, I., Rjoub, H., 2021. Wavelet analysis of impact of renewable energy consumption and technological innovation on CO2 emissions: evidence from Portugal. Environ. Sci. Pollut. Res. 1–18.
Ozturk, I., Bilgili, F., 2015. Economic growth and biomass consumption nexus: Dynamic panel analysis for Sub-Sahara African countries. Appl. Energy 137, 110–116.
Pedroni, P., 2004. Panel co-integration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econom. Theory 20 (3), 597–625.
Pendrill, F., Persson, U.M., Godar, J., Kastner, T., 2019. Deforestation displaced: trade in forest-risk commodities and the prospects for a global forest transition. Environ. Res. Lett. 14 (5), 055003.
Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. J. Appl. Econometrics 22 (2), 265–312.
Pesaran, M.H., 2015. Testing weak cross-sectional dependence in large panels. Econometric Rev. 34 (6–10), 1089–1117.
Pesaran, M.H., Yamagata, T., 2008. Testing slope homogeneity in large panels. J. Econometrics 142 (1), 50–93.
Qayyum, U., Anjum, S., Sabir, S., 2021. Armed conflict, militarization and ecological footprint: Empirical evidence from South Asia. J. Cleaner Prod. 281, 125299.
REN21, J., 2019. Renewables 2019: global status report. Retrieved from: https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf.
Rjoub, H., Adebayo, T.S., 2021. A new perspective into the impact of renewable and nonrenewable energy consumption on environmental degradation in Argentina: a time–frequency analysis. Environ. Sci. Pollut. Res. 1–17.
Rjoub, H., Adebayo, T.S., Awosusi, A.A., Panait, M., Popescu, C., 2021. Asymmetric impact of international trade on consumption-based carbon emissions in MINT Nations. Energies 14 (20), 6581.
Sabir, S., Gorus, M.S., 2019. The impact of globalization on ecological footprint: empirical evidence from the South Asian countries. Environ. Sci. Pollut. Res. 26 (32), 33387–33398.
Salari, T.E., Roumiani, A., Kazemzadeh, E., 2021. Globalization, renewable energy consumption, and agricultural production impacts on ecological footprint in emerging countries: using quantile regression approach. Environ. Sci. Pollut. Res. 1–15.

Saqib, M., Benhmad, F., 2021. Does ecological footprint matter for the shape of the environmental Kuznets curve? Evidence from European countries. Environ. Sci. Pollut. Res. 28 (11), 13634–13648.

Sarkodie, S.A., Strezov, V., 2019. Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci. Total Environ. 646, 862–871.

Saud, S., Chen, S., Haseeb, A., 2020. The role of financial development and globalization in the environment: accounting ecological footprint indicators for selected one-belt-one-road initiative countries. J. Cleaner Prod. 250, 119518.

Shahbaz, M., Balsalobre, D., Shahzad, S.J.H., 2019. The influencing factors of CO 2 emissions and the role of biomass energy consumption: statistical experience from G-7 countries. Environ. Model. Assess. 24 (2), 143–161.

Shahbaz, M., Farhani, S., Ozturk, I., 2015. Do coal consumption and industrial development increase environmental degradation in China and India? Environ. Sci. Pollut. Res. 22 (5), 3895–3907.

Shahbaz, M., Rasool, G., Ahmed, K., Mahalik, M.K., 2016. Considering the effect of biomass energy consumption on economic growth: fresh evidence from BRICS region. Renew. Sustain. Energy Rev. 60, 1442–1450.

Shahbaz, M., Shahzad, S.J.H., Mahalik, M.K., 2018. Is globalization detrimental to CO2 emissions in Japan? New threshold analysis. Environmental Modeling & Assessment 23 (5), 557–568.

Sikka, M., Thornton, T.F., Worl, R., 2013. Sustainable biomass energy and indigenous cultural models of well-being in an Alaska forest ecosystem. Ecol. Soc. 18 (3).

Solarin, S.A., Al-Mulali, U., Gan, G.G.G., Shahbaz, M., 2018. The impact of biomass energy consumption on pollution: evidence from 80 developed and developing countries. Environ. Sci. Pollut. Res. 25 (23), 22641–22657.

Sulaiman, C., Abdul-Rahim, A.S., 2020. Can clean biomass energy use lower CO 2 emissions in african economies? Empirical evidence from dynamic long-run panel framework. Environ. Sci. Pollut. Res. 27 (30), 37699–37708.

Sulaiman, C., Abdul-Rahim, A.S., Ofozor, C.A., 2020. Does wood biomass energy use reduce CO2 emissions in European union member countries? Evidence from 27 members. J. Cleaner Prod. 253, 119996.

Udemba, E.N., 2020. A sustainable study of economic growth and development amidst ecological footprint: New insight from Nigerian perspective. Sci. Total Environ. 732, 139270.

Udemba, E.N., 2021. Nexus of ecological footprint and foreign direct investment pattern in carbon neutrality: new insight for United Arab Emirates (UAE). Environ. Sci. Pollut. Res. 1–19.

Udemba, E.N., Ahmed, Z., Adebayo, T.S., Murshed, M., Kirikkaleli, D., 2021. Effects of economic complexity, economic growth, and renewable energy technology budgets on ecological footprint: the role of democratic accountability. Environ. Sci. Pollut. Res. 1–16.

Ullah, A., Ahmed, M., Raza, S.A., Ali, S., 2021. A threshold approach to sustainable development: Nonlinear relationship between renewable energy consumption, natural resource rent, and ecological footprint. J. Environ. Manag. 295, 113073.

Ulucak, R., 2020. Linking biomass energy and CO2 emissions in China using dynamic autoregressive-distributed lag simulations. J. Cleaner Prod. 250, 119533.

Ulucak, R., Khan, S.U.D., 2020. Determinants of the ecological footprint: role of renewable energy, natural resources, and urbanization. Sustainable Cities Soc. 54, 101996.

Ulucak, R., Ozcan, B., 2020. Relationship between energy consumption and environmental sustainability in OECD countries: The role of natural resources rents. Resour. Policy 69, 101803.

Umar, M., He, X., Adebayo, T.S., Kirikkaleli, D., 2021. Consumption-based carbon emissions in Mexico: an analysis using the dual adjustment approach. Sustain. Prod. Consum. 27, 947–957.

Usman, O., Akadiri, S.S., Adeshola, I., 2020. Role of renewable energy and globalization on ecological footprint in the USA: implications for environmental sustainability. Environ. Sci. Pollut. Res. 27, 30681–30693.

Wang, Z., 2019. Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. Sci. Total Environ. 670, 1075–1083.

Wang, Z., Bui, Q., Zhang, B., Pham, T.L.H., 2020. Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. Sci. Total Environ. 743, 140741.

Westerlund, J., 2007. Testing for error correction in panel data. Oxf. Bull. Econ. Statist. 69 (6), 709–748.

Yang, B., Jahanger, A., Ali, M., 2021. Remittance inflows affect the ecological footprint in BICS countries: do technological innovation and financial development matter? Environ. Sci. Pollut. Res. 28 (18), 23482–23500.

Yang, B., Usman, M., 2021. Do industrialization, economic growth and globalization processes influence the ecological footprint and healthcare expenditures? Fresh insights based on the STIRPAT model for countries with the highest healthcare expenditures. Sustain. Prod. Consum. 28, 893–910.

Yuping, L., Ramzan, M., Xincheng, L., Murshed, M., Awosusi, A.A., BAH, Adebayo, T.S., 2021. Determinants of carbon emissions in Argentina: The roles of renewable energy consumption and globalization. Energy Rep. 7, 4747–4760.

Zafar, M.W., Sinha, A., Ahmed, Z., Qin, Q., Zaidi, S.A.H., 2021. Effects of biomass energy consumption on environmental quality: the role of education and technology in Asia-Pacific economic cooperation countries. Renew. Sustain. Energy Rev. 142, 110868.

Zafar, M.W., Zaidi, S.A.H., Khan, N.R., Mirza, F.M., Hou, F., Kirmani, S.A.A., 2019. The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: the case of the United States. Resour. Policy 63, 101428.

Zhang, L., Li, Z., Kirikkaleli, D., Adebayo, T.S., Adeshola, I., Akinsola, G.D., 2021. Modeling CO2 emissions in Malaysia: an application of maki co-integration and wavelet coherence tests. Environ. Sci. Pollut. Res. 28 (20), 26030–26044.