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Original Article

Linking nuclear energy, human development and carbon emission in BRICS region: Do external debt and financial globalization protect the environment?

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A B S T R A C T

Nuclear energy has the potential to play an influential role in energy transition efforts than is now anticipated by many countries. Realizing sustainable human development and reducing global climate crises will become more difficult without significantly increasing nuclear power. This paper aims to probe the role of nuclear energy, external debt, and financial globalization in sustaining human development and environmental conditions simultaneously in BRICS (Brazil, Russia, India, China, and South Africa) countries. This study applied a battery of second-generation estimation approaches over the period from 1990 to 2019. These methods are useful and robust to cross-countries dependencies, slope heterogeneity, parameters endogeneity, and serial correlation that are ignored in conventional approaches to generate more comprehensive and reliable estimates. The empirical findings indicate that nuclear energy and financial globalization contribute to human development, whereas external debt inhibits it. Similarly, financial globalization accelerates ecological deterioration, but nuclear energy and external debt promote environmental sustainability. Moreover, the study reveals bidirectional feedback causalities between human development, carbon emissions and nuclear energy consumption. The study offers useful policy guidance on accomplishing sustainable and inclusive development in BRICS countries.

1. Introduction

There is a strong sentiment among academics, economists, and policymakers to look well beyond economic growth in the modern globalized era, mutating their attention from optimizing the economic productivity of countries to societal welfare. Inclusive growth is a prerequisite for economic development accomplished by ensuring equitable access to markets, services, and a fair regulatory climate as a means of people's health and wellbeing [1,2]. The human development index (HDI) has become a significant criterion for determining national progress focusing on human beings and their capabilities.[1] Despite the claim of some studies that the HDI does not encapsulate all facets of human growth, such as ecological concerns and inequalities [3,4], it is a commonly used alternative for the gross domestic product [5]. Besides this, various economic activities are viewed as one of the major sources of carbon dioxide

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[1] The United Nations Development Programme (UNDP) first adopted HDI in 1990 as a cumulative measure of populace's average longevity, education and income. http://www.hdr.undp.org/en/reports/global/hdr1990.

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(CO_2) emissions [6,7]. Ecological destruction poses a grave risk for human survival worldwide, and countries are now confronted with a growing challenge to achieve sustained growth essential for the citizens' wellbeing by transitioning to alternative energy sources [8]. Moreover, from an environmental standpoint, the advancement of human development aids in CO_2 emission reduction.

The carbon mitigating function of human capital is linked to technological research and education promoting environmental and pro-environmental practices and encouraging the use of alternative energy for a healthier lifestyle [9]. Energy usage is among the most important factors that make life easier for humans, and the socioeconomic stability of any country relies on its availability. The mounting carbon emissions and global warming adversities have advanced the prominence of targeting nuclear energy option that has cropped up as viable alternatives to fossil fuels with the potential to address energy safety and climate change.

Nuclear energy has gained prominence through many economies as part of the energy policy reform due to its cost-effective nature and tool for combating climate change. Several types of renewable energy such as nuclear, wind and solar energy are painstaking as successfully emission-free, have flashed interest globally. Increased cleaner energy usage in 2018 put forth a noteworthy influence on environmental pollution, thwarting 215 Million ton (Mt) of emissions [10]. Countries are increasing the share of nuclear energy output to expand carbon-free and cost-effective energy supply, minimize reliance on volatile imported fossil energy, reduce the negative impacts of fossil energies, and improve access to easy and clean energy. Therefore, nuclear energy can play an important role in energy, human development, and environmental policies that currently account for more than 10% of global electricity generation and are expected to increase by 25% of world power in 2050 [11]. Nuclear energy can help many countries move towards a more sustainable energy system. External debt accumulation and financial globalization can provide the necessary resources for the energy transition process, affecting nuclear energy initiatives, pollution levels, and human development. However, the inefficient use of debt reduces resources available for productive investments due to debt servicing costs, limiting economic and human development. Similarly, using external debt for financing growth in energy-dependent countries can increase energy consumption, such as infrastructure and industry investment [12,13]. Besides, financial globalization has led the world economy increasing interdependencies and generates societal benefits in advanced and emerging economies during the last couple of decades. Generally, it is observed that financial openness can aid growth mobility across countries in the context of capital flows, advanced technology exchange, and human capital progress [14].

Based on the preceding debate, it is apparent that improved human development and a low carbon environment are the ultimate sustainable and inclusive development objectives that necessitate clean energy transition. Nuclear energy might benefit energy transition initiatives and a more sustainable energy supply. Without a significant increase in nuclear power, achieving sustainable human growth and minimizing the global climate crisis would become more challenging. However, prior research has mostly concentrated on the effects of nuclear energy consumption on carbon emissions and economic growth; its impacts on human development are not documented in the literature. Due to a lack in this area, the increased investment in nuclear energy, rapid growth of debt stock, and increasing financial openness motivate this study to investigate their impacts on human development and CO_2 emissions simultaneously in BRICS countries.

The BRICS economies that comprise 42% of the world's population and 23% of the global gross domestic product are among the top ten global energy users, with about 40% of global energy use and releasing 43% of global carbon emissions [15], posing serious environmental and health challenges. BRICS countries are directing alternative energy sources to reduce environmental costs and secure energy, accounting for about 42% of renewable energy use and 16% of total world nuclear capacity [16]. Due to the relative benefits, these countries are increasing investment in nuclear energy technologies, and particularly China and Russia are working for international collaboration to enhance the nuclear electricity capacities globally.

Against this backdrop, the BRICS countries are an ideal case study for probing the effects of nuclear energy usage, external debt accumulation and financial openness on human development and CO_2 emissions. This study will provide additional understanding and useful insights to policymakers unearthing nuclear energy and capital flow associated advantages in implementing development, environmental, and energy policies. This study contributes to the literature in several ways. First, this study is a pioneering attempt to analyze the impacts of nuclear energy consumption on human development in BRICS countries. Second, we consider both social and environmental indicator to quantify their association with nuclear energy. Investigating this nexus would help explain how much nuclear energy can be used as a policy instrument for improving human development and mitigating CO_2 emissions in the BRICS region. Third, this research is the first to incorporate external debt and financial globalization amid nuclear energy's impact on human development and CO_2 emissions. This linkage will help policymakers regulate these economies' debt and capital inflows based on environmental and social consequences. Fourth, this study applies the most robust panel econometric approaches, including cross-sectional augmented autoregressive distributed lag (CS-ARDL), common correlated effects mean group (CCEMG) and augmented mean group (AMG) for the analysis. These methods address core panel data problems such as cross-sectional dependence, slope heterogeneity, parameters endogeneity, and serial correlation to generate reliable estimates.

The remainder of the study is designed as follows. Section 2 presents the review of current literature; Section 3 explains the data and methodology, including empirical model, variable description, and proposed method; Section 4 debates the observed results; Section 5 reports the paper's conclusion with policy implications.

2. Literature review

This section organizes the literature into three subsections addressing the linkages between nuclear energy consumption, external debt, and financial globalization with human development and the environment. The first subsection concludes the nexus between nuclear energy consumption, human development, and CO_2 emissions; the second subsection analyze the nexus between external debt, human development, and CO_2 emissions; and the third subsection scrutinizes the nexus between financial globalization, human development, and CO_2 emissions.

2.1. Nuclear energy, human development, and CO_2 emission nexus

Energy is essential to all facets of human life, affecting health, education, and living standards. It is widely recognized that access to better energy resources directly affects several areas of development, including the healthcare and education sectors, by raising economic status, which improved socioeconomic developments and led to socioeconomic stability in developing economies. Admitting that nuclear energy is of great interest to academics and policymakers in achieving sustainable energy targets for human wellbeing, nuclear energy impact on human development are not documented in the scientific literature. Instead, nuclear energy has helped the economic development of several countries and regions. For example, Mbarek et al. [17] found that nuclear energy is a huge driver of economic development in both developed and developing countries. Similarly, Wang and Lee [18] demonstrated that nuclear energy usage has progressively contributed to the economic growth of China. Moreover, the recent studies of Wang et al. [19] validated the favorable impacts of renewable energy on human development for BRICS countries. Pîrlogea [1] provided similar results for six European countries.

Nuclear energy is conceded a low-carbon transitional power generation component to reduce carbon emissions from fossil fuel combustion in producing electricity. Hassan et al. [20] unearthed that nuclear energy sources greatly reduce carbon pollution in BRICS. Lau et al. [21] confirmed that nuclear energy improves air quality and that growing nuclear energy investment is critical for improving energy efficiency and achieving economic sustainability. Pao and Chen [22] proposed that nuclear energy is the ultimate solution and most economical source to mitigate carbon emissions, even though renewable energy sources can be substituted for fossil fuel energy sources in G-20. The recent studies by Adebayo et al. [23], Majeed et al. [24], and Ozturk [25] revealed that renewable energy improves air quality and is the ultimate solution to reduce energy-related emissions. Similarly, Danish et al. [8] suggested that an immediate expansion in nuclear energy lessens environmental pollutants, indicating that additional nuclear energy power in the energy grid would be advantageous for carbon reduction for OECD economies. In contrast, Sarkodie and Adams [26] observed the adversative impacts of nuclear energy on environmental quality due to inefficiency in operations and global restrictions on the infrastructural development required for nuclear waste management. Similarly, Azam et al. [27] discovered that nuclear energy has a positive association with CO_2 emissions, indicating that its increased use induces environmental damage in high-carbon emitting countries in the long run. At the same time, Azam et al. [28] claimed that nuclear energy does not contribute to carbon mitigation, having an insignificant association with CO_2 emissions.

2.2. External debt, human development, and CO_2 emissions nexus

Several academics have emphasized the connection between debt and economic development, the research on the direct impacts of external debt on human development is scarce. A recent study by Osakede and Adeleke [29] showed that government borrowing negatively affects human development and education in 49 African states. Wang et al. [19] concluded that public debt is harmful to HDI in BRICS countries. The negative moderating effects of public debt between renewable energy and HDI showed reducing renewable energy's positive impacts. Fosu [30] identified that any restriction on the government debt imposed will adversely affect the government spending in health and education sectors which will harm the development aspects in Sub-Saharan African countries. This debt stocks public investment can intensify the economic activities requiring more energy that may affect environmental quality. However, there is a dearth of research on external debt impact on CO_2 emissions. Sun and Liu [12] deduced that private debt significantly impacted China's energy consumption among all the debt indicators. Akam et al. [31] investigated the effects of external debt on the environment in four African countries and disclosed that increased foreign debt does not contribute to environmental sustainability rather degrades the environment. Katircioğlu and Celebi [32] found a positive short-term effect but negligible long-term effects of external debt on air pollution in Turkey.

2.3. Financial globalization, human development, and CO_2 emission nexus

Globalization is a widely discussed predictor in environmental and economic academia; quite a few studies have considered the impacts of financial globalization on human development and the environment. In this line, Tang et al. [33] revealed that globalization contributed positively to human development through the economic growth channel by increasing income and further signified social and economic globalization as dominating force of human development. According to Simplice [34], trade globalization promoted human development while financial globalization has reduced human development in African countries. The survey study of Singh, [35] suggested that financial globalization can only improve HDI with the global demand growth by rapid expansion in the global economy and using effective policies by the government to improve income distribution by creating more jobs. Furthermore, Huang et al. [36] investigated the influence of human capital on ecological footprint in the context of G-7 and E-7 countries over the period from 1995 to 2018. Their findings explored that human capital mitigates the environmental pollution in G-7 countries in the mode of globalization. Similarly, the literature on globalization and environment linkage has reported mixed findings for instance. Suki et al. [37] reported that economic globalization has polluted effects on the environment, whereas political and social globalization enhances the environment in Malaysia. Likewise, Wang et al. [38] divulged that financial globalization contributes to environmental pollution in Belt and Road initiative countries. In contrast, Awosusi et al. [39] recent study revealed that globalization aids BRICS states in mitigating environmental deterioration. The recent study conducted by Miao et al. [40] in newly industrialized countries revealed that financial globalization significantly contributes to a more sustainable environment and helps to improve ecological integrity. However, Jahanger et al. [9] disclosed an insignificant association of globalization with environmental degradation in Latin American and Caribbean countries.

To sum up the review of recent studies, it is evident that nuclear energy's impact on human development is not documented in the literature, and there is no consensus among academics on its impacts on CO_2 emission. Similarly, only a few studies have examined the influence of financial globalization and external debt on human development and the environment reporting rambling results. Therefore, this study intends to fill the highlighted research gap by simultaneously examining the significance of nuclear energy, external debt, and financial globalization in enhancing environmental quality and human development from the context of the BRICS using advanced panel estimation techniques.

3. Model, data and methodology

3.1. Empirical model

The present study addressed whether nuclear energy, external debt, and financial globalization boost human development and sustain the environment. Before discussing economic modeling, we will discuss the theoretical basis that guides our selection of variables for this study. The improvement of human development and the environment are two important pillars for sustainable and inclusive development. Energy is vital to sustainable development, and the energy sector is in the process of transition to simultaneously ensure population access to energy, enhance people's living standards and reduce negative environmental impacts [41]. To this end, nuclear energy is identified as the best option for protecting the environment, providing access to modern energy, and promoting energy safety. Through economic growth channels, nuclear energy consumption may affect people's income and accessibility to health and education. Moreover, it minimizes the negative impacts of fossil energy on environmental quality and human wellbeing by maintaining an efficient energy supply and reducing energy poverty by providing modern affordable energy. Thus, evaluating nuclear energy's effects on human development and the environment is required to formulate suitable climate and development policies.

The external debt may considerably impact human development and the environment via economic growth and energy consumption channels. The government debt exercising on public sector spending and adding up debt to investments in alternative energy sources could prompt human development. Similarly, the government can finance environmental protection programs with external debt, such as research scholarships for green energy advancement and environmental technologies to upgrade ecological quality. However, high public debt may incur high debt service payments, obstruct social expenditures, lower employment, and exacerbate poverty, all of which harm human development and increase CO_2 emissions. Moreover, financial globalization facilitates unrestricted capital flows among countries by integrating worldwide money and financial markets and building an international financial system. This increased capital flow and investment can result in trade recoveries, technological advancements, labor interchange, GDP growth, employment, and income distribution, directly impacting human health, schooling, and living standards. Similarly, a developed financial structure and sufficient financial resources encourage the introduction of modern manufacturing practices and the procurement of innovative technologies that are far more energy-efficient and ecologically responsible [42]. Although a developed financial system improves access to capital and motivates economic development with a high standard of living, it also results in higher energy usage, harming human development and the environment.

Based on this discussion and the related literature, we estimated two models in chorus because reducing carbon emissions and boosting human development are vital for inclusive and sustainable development. To avoid non-normal distribution, scaling issues and establish homoskedasticity, the data is transformed into a logarithmic form. The two multivariate log-transform models for human development and CO_2 are given as follow:

$$Ln\ (HDI_{it}) = \alpha_0 + \alpha_1 Ln\ (NEC_{it}) + \alpha_2 Ln\ (EXTD_{it}) + \alpha_3 Ln\ (FGLOB_{it}) + \alpha_4 Ln\ (REC_{it}) + \alpha_5 Ln\ (EG_{it}) + \alpha_6 Ln\ (CO_{2,it}) + \varepsilon_{it} \tag{1}$$

$$Ln\ (CO2_{it}) = \beta_0 + \beta_1 Ln(NEC_{it}) + \beta_2 Ln(EXTD_{it}) + \beta_3 Ln(FGLOB_{it}) + \beta_4 Ln\ (REC_{it}) + \beta_5 Ln(EG_{it)} + \beta_6 Ln\ (HDI_{it}) + \varepsilon_{it} \tag{2}$$

Where, HDI, CO_2, NEC, EXTD, FGLOB, REC, and EG represent human development index, carbon emissions, nuclear energy consumption, external debt, financial globalization, renewable energy consumption, and economic growth, respectively. The subscript "i" symbolizes individual cross-section ($i = 1, 2, ...5$), and the subscript "t" denotes the time ($t = 1990, ..., 2019$). α_0, β_0 are the intercept terms and ε_{it}, μ_{it} are stochastic disturbance terms of models. $\alpha_1 - \alpha_6$, and $\beta_1 - \beta_6$ are the elasticity of the coefficients.

3.2. Variables and data sources

The data adopted in this research are for the five BRICS countries during 1990–2019. The study utilizes the most ubiquitous proxies of human development index and carbon emissions to quantify human welfare and environmental quality, respectively that serves as dependent variables. The explanatory factors include nuclear energy consumption, external debt, financial globalization, renewable energy consumption and economic growth. Table 1 defines and describes the variables in detail and provide data sources. Moreover, Table 2 displays the variables' descriptive statistics and correlation matrix in logarithmic form.

3.3. Estimation strategy

3.3.1. Testing cross-sectional dependence and slope heterogeneity

The cross-sectional dependence (CSD) and slope heterogeneity are two significant issues to be controlled in panel data econometrics to ensure equitable results and choose appropriate unit root and cointegration tests. The global emergent economic complexities and the socioeconomic integration create common factors and interdependence effects among countries leading to CSD in model residuals and variables. Similarly, country-specific distinctions result in slope heterogeneity revealing parameters of interest vary across cross-sectional units. This paper applies Pesaran [43], Frees [44] and Friedman [45] tests for verifying residuals CSD and the Breusch and Pagan [46] Lagrange Multiplier (CDLMBP) and the Baltagi et al. [47] bias-corrected scaled LM (CDLMBC) tests to determine CSD in variable series, as the panel time series is greater than the cross-sections. The test statistics for $CDLM_{BP}$ and $CDLM_{BC}$ under the null assumption of cross-sectional independence are computed as:

$$CDLM_{BP} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}^{2} \tag{3}$$

$$CDLM_{BC} = \sqrt{\frac{1}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\widehat{\rho}_{ij}^{2}-1\right)\right) - \frac{N}{2(T-1)} \tag{4}$$

Where $\widehat{\rho}_{ij}^{2}$ represents the cross-countries correlation of residuals for i and j countries obtained from panel's individual Ordinary Least Squares (OLS) regression. To validate that the models have heterogeneous slopes Pesaran and Yamagata [48] slope homogeneity test is utilized. The two test statistics ($\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$) of this method under the null hypothesis of homogeneous slope coefficients can be formulated as follow:

$$\tilde{\Delta} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right) \tag{5}$$

$$\tilde{\Delta}_{adj} = (N)^{\frac{1}{2}}\left(\frac{2k(T-K-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - 2k\right) \tag{6}$$

Where $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ represent the standardized dispersion and biased-adjusted dispersion statistics, respectively. $\tilde{S}$, and k denotes the modified Swamy test and number of repressors, respectively.

3.3.2. Testing for stationarity

The standard panel unit root statistics established under the assumption of cross-sections independence and homogeneity suffer from size bias and control properties. To this end, this research implemented the novel stationarity approaches of Pesaran [49], cross-sectional Im-Pesaran-Shin (CIPS) and cross-sectional augmented Dickey-Fuller (CADF). These statistical tests consider

Table 1
Description of variables and sources of data.

Variables	Symbol	Definition	Sources
Human development index	HDI	The human development index summarizes three key aspects: a healthy life, good education, and better living standards.	Human development reports United Nations Development Programme
Carbon dioxide emissions	CO_2	Million tons per capita	Statistical Review of World Energy British Petroleum
Nuclear energy consumption	NEC	Million tons of oil equivalent	Statistical Review of World Energy British Petroleum
External debt	EXTD	Percentage of gross national product	World Development Indicators World Bank
Financial globalization	FGLOB	The integration of financial markets and systems (KOF index)	KOF Index Swiss Economic Institute
Renewable energy consumption	REC	Million tons of oil equivalent	Statistical Review of World Energy British Petroleum
Economic growth	EG	Gross domestic product per capita (constant 2010 US$)	World Development Indicators World Bank

CSD and slope heterogeneities across the dataset by augmenting each cross-sectional entity with cross-sectional averages of lagged and first difference values of analyzed variables. The test statistics of CADF and CIPS regression under the null hypothesis of homogenous non-stationarity are computed by Eqs. (7) and (8), respectively:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \delta_i \bar{y}_{it-1} + \lambda_i \Delta \bar{y}_{it} + \varepsilon_{it} \tag{7}$$

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i(N,T) \tag{8}$$

Where $\bar{y}_{it-1}$ and $\Delta\bar{y}_{it}$ are the cross-sectional average estimates of the lagged variable and first difference for each cross-section, respectively. Moreover, $t_i(N,T) = CADF$ represents the test statistics of OLS regression for i_{th} cross-section.

3.3.3. Panel cointegration test

When the variables are nonstationary at their level, a panel cointegration study is used to verify whether the selected variables have a long-run dynamic linkage. This work employs Westerlund [50] error correction oriented second-generation cointegration procedure to examine the long-run cointegration association among subjected variables. This test overcomes the heterogeneity and cross-section dependency nuisances in BRICS panel data and thus is preferable over traditional cointegration approaches. This error correction panel-oriented test statistics under the null assumption of no cointegration can be expressed as follows:

$$\Delta y_{it} = \delta_i' d_t + \partial_i y_{i,t-1} + \lambda_i' y_{i,t-1} + \sum_{j=1}^{pi} \partial_{ij} \Delta y_{i,t-1} + \sum_{j=-qi}^{pi} \gamma_{ij} \Delta x_{i,t-1} + \varepsilon_{it} \tag{9}$$

Where d_t refers to the deterministic component and ∂_i is the error correction term that defines the adjustment pace whereby the system adapts to its equilibrium position for the i_{th} country.

3.3.4. Panel long and short-run estimation

This study estimated the model's long and short-run coefficients using the CS-ARDL robust modeling technique suggested by Chudik and Pesaran [51]. The adoption of the CS-ARDL model was driven by the larger panel's time function of the study than the cross-sectional component since it is the most suited in such instances. The CS-ARDL procedure presents numerous advantages over conventional econometrics models simultaneously compensates for slope heterogeneity across countries and cross-country dependency, regardless of whether the related variables are nonstationary, I(0), I(1), or mixed order integrated. Additionally, the CS-ARDL technique corrects for unobserved common factors, serial correlation, and common correlation-bias, is resilient to managing endogeneity produced by reverse causal relationships between model variables, and addresses small sample size and omitted variables biases. Moreover, the key benefit of the CS-ARDL mechanism is that it normalizes the causes of unobserved common factors by implementing the Pesaran [52] correlated effects procedure in the context of panel ARDL models considering the lagged explained variable as weakly exogenous variate under the error correction framework. The CS-ARDL algorithm augments the conventional ARDL approach by adding cross-section means of the dependent variable and other covariates as substitutions of unobserved factors and their lags values to capture the cross-sectional correlation. Therefore, the panel CS-ARDL pattern can be developed as follow:

$$y_{i,t} = \alpha_i + \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}' x_{i,t-j} + \sum_{j=0}^{K} \phi_{ij}' \bar{Z}_{i,t-j} + \varepsilon_{it} \tag{10}$$

Where $\bar{Z} = (\bar{y}_i, \bar{x}_i)'$ represents the cross-sectional means of the explained variable $(\bar{y}_i)$ and other model covariates $(\bar{x}_i)$. K denotes the lag length of cross-section means. The error correction (ECM) specification of CS-ARDL can be written below as:

$$\Delta y_{i,t} = \alpha_i + \xi_i\left(y_{i,t-1} - \varpi'_i x_{i,t-1}\right) + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta'^{*}_{ij} \Delta x_{i,t-j} + \sum_{j=0}^{K} \phi'_{ij} \overline{Z_{i,t-j}} + \sum_{j=1}^{p-1} \psi_j \overline{\Delta y_{t-j}} + \sum_{j=0}^{q-1} \zeta_j \overline{\Delta x_{t-j}} + \varepsilon_{it} \tag{11}$$

To test the robustness and further signify the findings of CS-ARDL, this study applied Pesaran [52] CCEMG and Eberhardt and Bond [53] AMG estimation methods. These frameworks, like the CS-ARDL, address the issue of CSD subjected to numerous unseen common shocks, parameter endogeneity, unit root, and panel slope heterogeneity. The CCEMG estimator utilizes the linear arrangements of the cross-sectional mean of observable dependent and explanatory variables with the common hidden effects. The AMG assessment tool introduces a common dynamic effect in panel data models to accommodate cross-sectional dependency.

3.3.5. Panel causality test

The empirical analysis is also utilized the causality test of Dumitrescu and Hurlin [54] to identify the causality path among observed variables. The DH causality test offers a higher predictive ability than the standard Granger causality test under cross-country dependence and heterogeneity. The proposed linear model of this test under the homogenous non-causality null

Table 2
Summary of descriptive statistics and pairwise correlation matrix.

Panel A: Descriptive Statistics							
	LnHDI	$LnCO_2$	LnNEC	LnEXTD	LnFGLOB	LnREC	LnEG
Mean	0.656160	3.020218	0.714467	1.361052	1.619579	−0.162012	3.637452
Std. Dev.	0.093410	0.463730	0.623504	0.185347	0.145342	1.049230	0.408181
Skewness	−0.503548	0.433112	−0.459946	0.379159	−1.513155	0.178245	−0.830161
Kurtosis	2.665278	2.203134	4.240568	3.001449	5.775461	2.138862	2.213805
Jarque-Bera	7.039255	8.658367	14.90756	3.594052	105.3858	5.429023	21.09231
Panel B: Pairwise Correlation Matrix							
	LnHDI	$LnCO_2$	LnNEC	LnEXTD	LnFGLOB	LnREC	LnEG
LnHDI	1						
$LnCO_2$	−0.056801	1					
LnNEC	0.575261	−0.620919	1				
LnEXTD	−0.248430	−0.452065	0.015641	1			
LnFGLOB	0.741880	0.062817	0.472293	0.204695	1		
LnREC	0.145101	0.240781	0.034823	−0.327874	0.186793	1	
LnEG	0.903277	0.294312	0.265942	0.300063	0.660113	0.030788	1

assumption that considers no individual causality is expressed as:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{k} \lambda_i^{(k)} y_{i,t-k} + \sum_{k=1}^{k} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \tag{12}$$

In the above equation $\beta_i^{(k)}$ and $\lambda_i^{(k)}$ signifies the coefficient estimates of lag explanatory and explained variable, k defines the lag length expected to be unchanged for panel units.

4. Empirical results analysis and discussion

The results of cross-sectional dependence and slope homogeneity tests are summarized in Table 3. The significance of CSD results provides robust evidence against the null hypothesis (H_0) of cross-sectional independence for all variables and residuals of the models indicating that a spillover effect from any shock or changes exists among BRICS countries. Similarly, the statistical significance of delta and adjusted delta unveiled that the slope coefficients are heterogeneous, strongly rejecting the null hypothesis (H_0) of slope homogeneity.

Table 4 highlights the results of the CIPS and CADF at the level and first difference. These findings suggest that the null hypothesis (H_0) of unit root cannot be rejected at level series. However, the data series pose stationarity at the 1% significance level after taking the first difference, evidencing standard first order I(1) integration of all analyzed variables.

The Westerlund error-correction-based cointegration test results for the specified models calculated in Table 5 provide sample evidence to reject the null hypothesis (H_0) of no cointegration. The significance of the bootstrap group statistics (Gt, Ga) for both models based on robust p-values unveiled that the series are cointegrated, confirming long-run relationships among modeled variables and allowing us to forecast the long-run elasticities estimation using regression analysis.

The CS-ARDL long and short-run regressions results for both models are provided in Table 6. The short-run results for Eq. (1) indicate that any positive change in LnNEC, LnFGLOB, LnREC and LnEG enhances the LnHDI, whereas the growth of $LnCO_2$ emissions adversely impacts LnHDI and LnEXTD has insignificant effects. The short-run elasticities estimation for Eq. (2) specifies that any additional change in LnNEC, LnEXTD, LnREC, and LnHDI improves environmental quality and increases in LnFGLOB and LnEG degrade the environment. The error correction term (ECT_{t-1}) coefficients reported in Table 6 are negative and statistically significant for both models in equations (1) and (2). These statistics indicate that LnHDI reacts to its long-run equilibrium state by a 27.6% adjustment speed within a year, and $LnCO_2$ adjusts with a speed of 7.5% per year towards the long-run equilibrium level in response to the changes in the explanatory variables.

The long-run dynamics of CS-ARDL estimations show similar results as of the short run for nuclear energy, financial globalization, renewable energy, economic growth, CO_2 emissions, and human development for both models except external debt in Eq. (1) show opposite coefficient signs. The significant long-run coefficients of nuclear energy indicate a favorable impact on human development and the environment. Particularly, a 1% increase in nuclear energy positively affects human development by 0.012% and decreases CO_2 emissions by 0.014%. These predictions indicate that nuclear energy reduces environmental risks and serves as a green and sustainable energy source for BRICS countries. This conclusion, along with the predictions of Hassan et al. [20], and Lau et al. [21], shows that nuclear energy usage in BRICS countries leads to economic development, environmental protection, and increased human development. Besides, nuclear energy helps meet the energy demand by producing secure electricity in transition from brown energy sources towards sustainable and eco-friendly energy, reducing the adverse impacts of energy use on human wellbeing and the environment. It further helps to reduce the reliance on energy imports and other fossil fuels and reduces the current account deficits of these countries that stimulate economic progress and human development and promote a clean environment.

The long-run coefficients of external debt appear to be negative and significant for both human development and CO_2 emissions. More specifically, a 1% augmentation in external debt will lead to reduce the human development and environmental pollution level by 0.0002%, and 0.0696% respectively. These results accentuate that external debt impairs the growth of human development for BRICS economies due to the detrimental impact on public spending and per capita income growth. The possible reason is the government's external debt services for repayment with high interest, which exerts a crowding-out effect on public expenditure in social sectors of education and healthcare and also causes governments to increase tax revenue, discouraging investors from influencing their investment quality. These findings are similar to Wang et al. [19]. The allocation of debt funds to different sectors can negatively affect human development and create disparities, leading to economic inequality. However, the significant negative coefficients of external debt indicate that the economic and environmental authorities of BRICS countries utilize external debt funds efficiently by financing environmental protection and other alternative energy projects. As the significance of external debt impacts on human development is quite low, it can be inferred that this can be offset by the favorable external debt impacts on environmental quality following certain debt thresholds by BRICS countries. Moreover, allocating debt funds in clean energy projects such as nuclear and renewables and spending on sanitation, water, and environmental protection will result in more sustainable and inclusive development—these outcome conflicts with the study of Katircioğlu and Celebi [32].

The regression estimates of financial globalization display positive effects on both human development and CO_2, revealing that a 1% increase in financial openness boosts the human development of BRICS countries by 0.109% while degrading the atmospheric quality by 0.419%. The positive effects on human development could be attributed to the swift capital flows providing more investment opportunities and easy access to the financial system. It confirms the comparative advantage of financial services provided by these countries' financial and money markets, providing a good return on investment to domestic investors by opening to the global market. Moreover, the high flow of foreign direct investment can be another reason for this positive effect that helps to increase the per capita income. This finding parallels with Tang et al. [33], but opposes Simplice [34]. Moreover, the positive impact of financial globalization shows that foreign investors lean to use polluted technologies and manipulate natural resources via low-cost production practices. Besides, it also results in higher energy usage in the production process, which is harmful to the environment. The environmental regulations to ensure the best possible use of financial integration that aligns with the sustainability targets are most important in this scenario. These results correspond to Wang et al. [38].

Furthermore, the regression coefficients of renewable energy appear to be positive signs for human development and negative for CO_2 emission. Explicitly, a 1% augmentation in renewable energy consumption will lead to increase the human development level by 0.0036%, and reduce the 0.0022% environmental pollution in the long-run. These results signify that usage of renewable energy has assisted human development in the BRICS economies. This effect is analogous to Balsalobre-Lorente et al. [2], Jahanger et al. [9], Ozturk [25], Huang et al. [36], Shinwari et al. [55], Usman et al. [56]. It can be justified that development in BRICS is strongly based on renewable technologies, which ultimately accelerate economic growth and improve human capital. The predominant fossil fuel dependence in these economies has traditionally levied damaging impacts on human development. In contrast, the diluting effects of renewable energy use on ecological damage are supported by the studies of Usman et al. [13], and Sarkodie et al. [26]. This result implies that renewable energy can effectively replace other fossil fuels, bringing environmental and health benefits to the community. Contrary to the conclusion of Lau et al. [21], these results suggest that more resources should be devoted to renewables making them more cost-effective. In addition, the long-run results for economic growth conclude significant positive association with both human development and environment; that is, a 1% positive change in the economic growth of BRICS countries supports human development by 0.174% and degrades environment by 0.926%. In addition to potential of environmental cost, it is undeniable that economic expansion benefits people with higher income through better access to education and health services in emerging economies. This result validates the findings of Wang et al. [19], Usman et al. [57]. High-income earners can service more capital on education, health, food, clothing, and housing quality that increase average life expectancy and reduce population's mortality ratio. However, these countries seem to be sacrificing the environment due to productivity growth by massive brown production. The inefficient and unnecessary use of resources and excessive fossil fuel utilization for economic growth causes environmental degradation. This result endorses empirical evidence depicted by Adebayo et al. [23].

The estimated results present a negative effect of CO_2 emissions on human development, supporting the notion that carbon emissions harm human development endeavors and wellbeing in BRICS. The study supports the conservation hypothesis suggesting that BRICS countries can implement energy conservation and environmentally friendly policies to diminish the detrimental impacts of carbon emissions on human wellbeing with achieving sustainable economic growth. This conclusion is similar to Tran et al. [5]. Finally, the negative coefficient indicates that the increase in human development decreases environmental adversities. Human development helps educate people, raise awareness about

Table 4
CIPS and CADF findings.

Variables	CIPS		CADF	
	Level	1st Difference	Level	1st Difference
LnHDI	−0.627	−3.157*	−1.317	−2.627*
$LnCO_2$	−1.967	−3.767*	−0.350	−2.363*
LnNEC	−2.027	−4.738*	−1.101	−4.228*
LnEXTD	−1.494	−4.150*	−1.659	−3.613*
LnFGLOB	−2.028	−5.588*	−2.065	−4.538*
LnREC	−2.077	−3.914*	−1.924	−2.965*
LnEG	−2.006	−2.906*	−1.146	−3.354*

Note: * indicates $P < 0.01$; and 10%, 5%, & 1% critical values are −2.21, −2.33, & −2.57, respectively.

Table 3
CSD and slope homogeneity tests results.

Panel A: CSD tests in panel time-series data							
Tests	LnHDI	$LnCO_2$	LnNEC	LnEXTD	LnFGLOB	LnREC	LnEG
$CDLM_{BP}$	230.783*	201.425*	178.318*	36.088*	225.477*	209.372*	245.852*
$CDLM_{BC}$	49.282*	42.717*	37.550*	5.747*	48.096*	44.494*	52.652*

Panel B: CSD tests in panel data models (Residuals)		
Tests	Eq. (1) (Dependent variable: LnHDI)	Eq. (2) (Dependent variable: $LnCO_2$)
Pesaran [51]	0.417**	−2.317**
Frees [52]	1.643*	1.250*
Friedman [53]	28.226*	14.053*
Panel C: Slope homogeneity test		
Δ	11.295*	8.739*
Adj Δ	13.190*	10.205*

Note: *, & ** indicate $P < 0.01, 0.05$, respectively.

Table 5
Westerlund cointegration test.

Statistics	Model 1 (Dependent variable: LnHDI) Value	Z-value	Robust P-value	Model 2 (Dependent variable: $LnCO_2$) Value	Z-value	Robust P-value
Gt	- 1.101*	8.218	0.000	- 2.166*	−0.023	0.000
Ga	- 1.577*	4.359	0.006	- 1.935*	7.334	0.000
Pt	- 1.171	3.312	0.657	- 2.870	1.702	0.890
Pa	- 1.935	3.366	0.318	- 3.402	2.601	0.720

Note: * indicates P < 0.01.

Table 6
CS-ARDL Long-run and short-run findings.

Variables	Long-run results Coefficient	t-stat	p-value	Short-run results Coefficient	t-stat	p-value
Eq. (1): Dependent variable HDI						
LnNEC	0.0125*	3.1594	0.0003	0.0134*	8.1064	0.0010
LnEXTD	−0.0002***	1.9259	0.0793	0.0044	0.4631	0.6433
LnFGLOB	0.1095*	9.0321	0.0000	0.1071*	8.0423	0.0000
LnREC	0.0036*	5.9853	0.0000	0.0034***	1.5099	0.0910
LnEG	0.1741*	32.3188	0.0000	2.1293**	2.2378	0.0233
$LnCO_2$	−1.8621**	−4.7284	0.0104	- 1.3106*	−5.1066	0.0080
ECT(-1)				−0.2761*	7.7864	0.0000
Eq. (2): Dependent variable CO_2						
LnNEC	−0.0142*	−17.4686	0.0000	- 0.0128*	- 7.3657	0.0000
LnEXTD	−0.0696**	−1.3323	0.0182	−0.8412*	−8.4061	0.0000
LnFGLOB	0.4199*	6.5622	0.0000	0.3336***	1.9293	0.0537
LnREC	−0.0022***	−2.0932	0.0550	- 0.0011**	−1.1866	0.0235
LnEG	0.9269*	14.0741	0.0000	2.4149***	1.8728	0.0560
LnHDI	−2.2123*	−6.7838	0.0000	−5.2943**	−1.6902	0.0114
ECT(-1)				−0.0752**	−2.6743	0.0332

Note: *, **, *** indicate P < 0.01, 0.05, 0.1, respectively.

Table 7
Robustness results (CCEMG and AMG).

Regressors	CCEMG Coefficient	p-value	AMG Coefficient	p-value
Eq. (1): Dependent variable HDI				
LnNEC	0.2270*	0.0000	0.0529**	0.0349
LnEXTD	−0.9277**	0.0142	−0.7138***	0.0917
LnFGLOB	0.8220*	0.0030	0.6067**	0.0181
LnREC	0.0115**	0.0160	0.0576***	0.0565
LnEG	0.1554**	0.0270	0.5703**	0.0209
$LnCO_2$	−0.3654***	0.0921	−0.6234***	0.0620
Eq. (2): Dependent variable CO_2				
LnNEC	−0.0016**	0.0200	−0.0014*	0.0000
LnEXTD	−0.0118**	0.0100	−0.0435**	0.0300
LnFGLOB	0.9564**	0.0405	0.8957**	0.0423
LnREC	−0.0026***	0.0940	−0.0036*	0.0000
LnEG	0.18303*	0.0000	0.1741**	0.0163
LnHDI	−0.03807*	0.0000	−0.0306**	0.0218

Note: *, **, and *** indicate P < 0.01, 0.05, and 0.1, respectively.

environmental protection and meet the country's environmental sustainability goal. The high living standard with improved education and income level improve environmental quality by moving towards more green and sustainable production, consumption, and transportation activities. Moreover, the use of more clean energy in BRICS countries can also cause favorable impacts of HDI on the environment. The results of this study are analogous to the conclusion of Tran et al. [5]. Fig. 1 shows the graphical presentation of the estimated findings of the study.

The findings of CCEMG and AMG estimation used to check the robustness of CS-ARDL estimates are illustrated in (Table 7). The long-run estimates of the CCEMG and AMG model reveal similar results alongside CS-ARDL estimates possessing the same signs and significances. The results confirm that nuclear energy, external debt, financial globalization, renewable energy, and economic growth enhance human development while CO_2 emission harms human development in BRICS countries. Moreover, these results reconfirmed that renewable and nuclear energy, human development, and external debt are beneficial in improving the environmental quality, while financial globalization degrades the environment.

The pairwise DH panel causality outcomes are depicted in Table 8. The empirical findings reveal both bidirectional and unidirectional causality amongst the variables. The results confirm bidirectional feedback causality between human development to nuclear energy, and between economic growth and carbon emissions, demonstrating that policies targeting these variables might affect each other. However, unidirectional causality running from human development to external debt and renewable energy implies that any alterations made in policies aiming at human development will not affect external debt levels and renewable energy usage. In contrast, external debt and renewable energy consumption policies will affect the human development. Moreover, this study observes a one-way causal connection from financial globalization to human development, indicating that any change in financial liberalization policy will not affect human development. In contrast, policies aiming at the human development will affect the financial liberalization in BRICS economies.

Table 8 further reveal bidirectional feedback causalities between CO_2 emission to nuclear energy, human development, and economic growth, indicating that any policy adjustment aiming at these variables might affect each other. In addition, CO_2 emissions

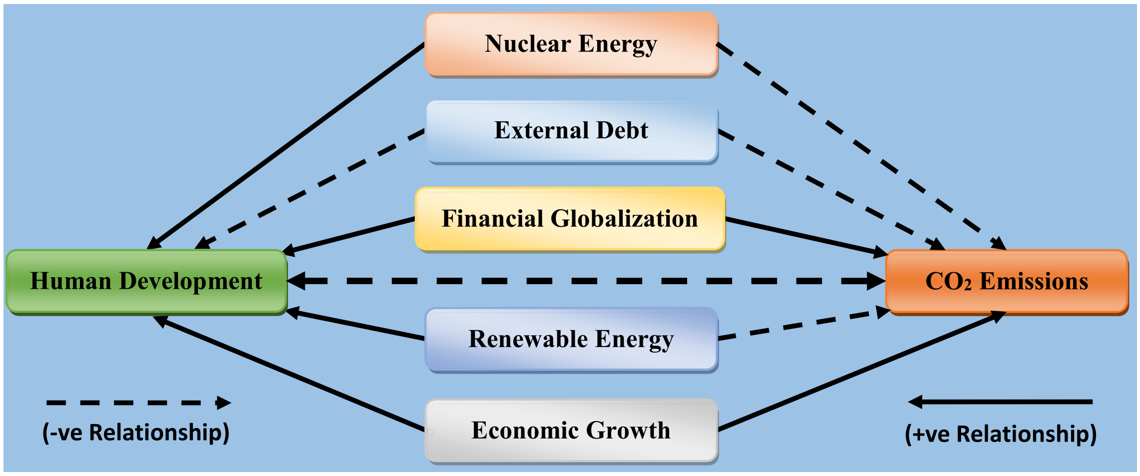

Fig. 1. Graphical presentation of empirical findings.

Table 8
Pairwise Dumitrescu-Hurlin panel causality results.

	LnHDI	$LnCO_2$	LnNEC	LnEXTD	LnFGLOB	LnREC	LnEG
LnHDI	———	10.7094	3.2789	7.9312	10.1342	5.7063	9.6276
		3.5636	−0.7237	1.9605	3.2317	0.6610	2.9394
		0.0004*	0.0140**	0.5020	0.0012*	0.2051	0.0033*
LnCO2	17.9784	———	4.3324	5.4726	5.5120	5.6353	6.4780
	7.7578		−0.1159	0.5419	0.5647	0.6204	1.1220
	0.0000*		0.0000*	0.4025	0.5723	0.0140**	0.0000*
LnNEC	12.9917	15.9076	———	10.299	10.4346	10.1017	22.0137
	4.8804	6.5629		3.3269	3.4050	3.1731	10.0862
	0.0153**	0.0000*		0.0009*	0.0007*	0.1020	0.0000*
LnEXTD	5.6969	3.0824	4.8836	———	4.9768	3.9220	5.5159
	0.6713	−0.8371	0.2021		0.2559	−0.3587	0.5669
	0.0499**	0.5878	0.8398		0.7980	0.7198	0.5707
LnFGLOB	4.6343	9.2063	5.3304	1.5979	———	4.0402	3.3362
	0.0583	2.6963	0.4599	−1.6937		−0.2912	−0.6907
	0.9535	0.0626***	0.6456	0.0903***		0.7709	0.4897
LnREC	18.6864	8.9418	19.0232	7.8537	8.9772	———	9.3237
	8.0796	2.5102	8.2721	1.8883	2.5304		2.7285
	0.0120**	0.6200	0.0030*	0.0590***	0.0114**		0.0064*
LnEG	8.6982	9.6333	4.6099	6.5509	5.0744	9.9120	———
	2.4031	2.9427	0.0442	1.1641	0.3122	3.0647	
	0.0163**	0.0222**	0.9647	0.2444	0.7549	0.0022*	

Note: 1st, 2nd, & 3rd value indicates W-stat, Z-stat & P-value, respectively; *, **, *** indicate $P < 0.01, 0.05, 0.1$, respectively.

show one-way causality to financial globalization, which means that any changes in environmental policies will not affect financial globalization. In contrast, any adjustment in financial globalization policy will affect the environmental quality in BRICS countries. However, no causality is observed between $LnCO_2$ and LnEXTD. Overall, these causality results complement the long-run estimation of CS-ARDL.

5. Conclusion and policy implications

The efficacy of nuclear energy and growing financial openness in achieving societal sustainability and carbon mitigation goals has become a major concern in the global debate about the sustainability transition pathway. This study simultaneously examines the impacts of nuclear energy usage, external debt and financial globalization on human development, and carbon emissions in the BRICS spanning from 1990 to 2019. The long-run results of CS-ARDL, CCEMG, and AMG estimation reveal that nuclear energy, financial globalization, renewable energy, and economic growth positively impact human development while externeal debt and carbon emissions hamper human development in BRICS. Additionally, nuclear energy, external debt, human development, and renewable energy aids in the advancement of environmental quality while financial globalization and economic growth impair BRICS environmental quality.

Several policy implications for BRICS countries are proposed based on the empirical findings. First, the productive use of electricity fosters living standards by promoting health and educational quality. The policymakers of BRICS countries need to implement clean energy portfolios (nuclear and renewable) by limiting fossil fuels with the carbon tax and incentives to domestic firms and foreign sectors to promote green technologies investments. Nuclear energy growth and investment in BRICS countries are paramount to attaining sustainable development, a carbon-neutral economy, and a better living society for humans. Nuclear energy must be included in policies and actions promoting human capital and low-emission energy systems. The government should encourage license renewals, new reactor building, and innovative nuclear technologies, such as twice-through fuel cycle and small modular reactors technologies. These nations should also assist nuclear energy research, pilot programs, and educational efforts emphasizing nuclear energy's benefits, including climate stability and human development. Moreover, these nations should collaborate to establish nuclear energy initiatives and share best practices via funding, technology transfer, and capacity development to help address nuclear energy nonproliferation, security, human and environmental safety challenges.

Second, with the possible benefits of external debt, BRICS policymakers should identify certain debt thresholds above which external debt is harmful to human welfare by restricting debt stock proportions. The government should guarantee that foreign debts are invested in productive sectors of education, health, green energy and cleaner production by focusing on research and development and avoiding corruption in the borrowed capital to achieve the desired economic, human, and environmental targets. Additionally, policymakers should use debt financing to facilitate consumption and investment in alternative energies such as nuclear and other renewables. Regulating debt funding through alternative energy technologies would decrease the problems of investing in low-carbon technologies that benefit future generations and reduce environmental impacts. Likewise, strengthening the government's capacity to finance clean energy projects, the government must confiscate legal and regulatory barriers to private sector investment and reduce the debt burden.

Third, as financial globalization benefits human development, the BRICS economies should be more integrated into the global economy. Governments should promote trade and financial openness that facilitate foreign capital inflows. The increase in foreign capital inflows leads to the growth of national financial markets, providing more funds for ecological investment and the relocation and production of green tech. The government should provide fiscal incentives to overseas investors to bring better foreign investment, increase competition, expand jobs, and eventually boost human development. However, BRICS countries must follow international sustainable environmental protocols in hunting foreign capital projects enforcing stringent environmental regulations. Projects with obsolete technologies should be limited by imposing dumping duties, and efficient capital goods should be encouraged by providing tax benefits, leading to more export capacity, more employment, and facilitating sustainable production via environmental awareness.

Future research can determine whether the existing results can subsist in the country-specific empirical study and extend to countries with similar human development indices such as high indexed or low indexed. Additionally, instead of overall external debt, alternative debt proxies such as private debt and public debt can also be utilized in environmental assessment impacts. Moreover, this study investigates the only symmetric influence of nuclear energy, external debt, financial globalization, renewable energy, and economic growth on human development and carbon emissions; in the future, scholars can investigate the asymmetric effect of studied regressors on human development and carbon emission.

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.

References

[1] C. Pîrlogea, The human development relies on energy. Panel data evidence, Procedia Econ. Financ. 3 (2012) 496–501.
[2] D. Balsalobre-Lorente, L. Ibáñez-Luzón, M. Usman, M. Shahbaz, The environmental Kuznets curve, based on the economic complexity, and the pollution haven hypothesis in PIIGS countries, Renew. Energy 185 (2022) 1441–1455.
[3] J. Hickel, The sustainable development index: measuring the ecological efficiency of human development in the anthropocene, Ecol. Econ. 167 (2020), 106331.
[4] S.A. Sarkodie, S. Adams, P.A. Owusu, T. Leirvik, I. Ozturk, Mitigating degradation and emissions in China: the role of environmental sustainability, human capital and renewable energy, Sci. Total Environ. 719 (2020), 137530.
[5] N. Tran, Q. Van, Tran, L.T.T. Van, Do, L.H. Dinh, H.T.T. Do, Tradeoff between environment, energy consumption and human development: do levels of economic development matter? Energy 173 (2019) 483–493.
[6] T.S. Adebayo, S.D. Oladipupo, I. Adeshola, H. Rjoub, Wavelet analysis of impact of renewable energy consumption and technological innovation on CO2 emissions: evidence from Portugal, Environ. Sci. Pollut. Res. (2021) 1–18.
[7] B. Yang, M. Usman, 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 (2021) 893–910.
[8] M. Usman, N. Hammar, Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries, Environ. Sci. Pollut. Res. 28 (12) (2021) 15519–15536.
[9] A. Jahanger, M. Usman, M. Murshed, H. Mahmood, D. Balsalobre-Lorente, The linkages between natural resources, human capital, globalization, economic growth, financial development, and ecological footprint: the moderating role of technological innovations, Resou. Pol. 76 (2022), 102569.
[10] F.F. Adedoyin, I. Ozturk, F.V. Bekun, P.O. Agboola, M.O. Agboola, Renewable and non-renewable energy policy simulations for abating emissions in a complex economy: evidence from the novel dynamic ARDL, Renew. Energy 177 (2021) 1408–1420.
[11] World Nuclear Association, Nuclear Power in the World Today, NPWT, 2021. https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx. (Accessed 20 December 2021).
[12] X. Sun, X. Liu, Decomposition analysis of debt's impact on China's energy consumption, Energy Pol 146 (2020), 111802.
[13] M. Usman, M.S.A. Makhdum, What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development, Renew. Energy 179 (2021) 12–28.
[14] M.A. Baloch, I. Ozturk, F.V. Bekun, D. Khan, Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: does globalization matter? Bus. Strat. Environ. 30 (1) (2021) 176–184.
[15] World Bank, World Development Indicator, WDI, 2020. https://databank.worldbank.org/reports.aspx?source=world-development-indicators. (Accessed 29 December 2021).
[16] BP, Statistical Review of World Energy, 69th Edition, BP, 2020. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf. (Accessed 29 December 2021).
[17] M.B. Mbarek, S. Nasreen, R. Feki, The contribution of nuclear energy to economic growth in France: short and long run, Qual. Quantity 51 (2017) 219–238.
[18] E.Z. Wang, C.C. Lee, The impact of clean energy consumption on economic growth in China: is environmental regulation a curse or a blessing? Int. Rev. Econ. Finance 77 (2022) 39–58.
[19] Z. Wang, Q. Bui, B. Zhang, C.L.K. Nawarathna, C. Mombeuil, The nexus between renewable energy consumption and human development in BRICS countries: the moderating role of public debt, Renew. Energy 165 (2021) 381–390.
[20] S.T. Hassan, Danish Salah-Ud-Din khan, M.A. Baloch, Z.H. Tarar, Is nuclear energy a better alternative for mitigating CO2 emissions in BRICS countries? An empirical analysis, Nucl. Eng. Technol. 52 (2020) 2969–2974.
[21] L.S. Lau, C.K. Choong, C.F. Ng, F.M. Liew, S.L. Ching, Is nuclear energy clean? Revisit of Environmental Kuznets Curve hypothesis in OECD countries, Econ. Modell. 77 (2019) 12–20.
[22] H.T. Pao, C.C. Chen, Decoupling strategies: CO2 emissions, energy resources, and economic growth in the Group of Twenty, J. Clean. Prod. 206 (2019) 907–919.
[23] T.S. Adebayo, E.B. Agyekum, S. Kamel, H.M. Zawbaa, M. Altuntaş, Drivers of environmental degradation in Turkey: designing an SDG framework through advanced quantile approaches, Energy Rep. 8 (2022) 2008–2021.
[24] M.T. Majeed, I. Ozturk, I. Samreen, T. Luni, Evaluating the asymmetric effects of nuclear energy on carbon emissions in Pakistan, Nucl. Eng. Technol. (2021) 1–9.
[25] I. Ozturk, Measuring the impact of alternative and nuclear energy consumption, carbon dioxide emissions and oil rents on specific growth factors in the panel of Latin American countries, Prog. Nucl. Energy 100 (2017) 71–81.
[26] S.A. Sarkodie, S. Adams, Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa, Sci. Total Environ. 643 (2018) 1590–1601.
[27] A. Azam, M. Rafiq, M. Shafique, J. Yuan, An empirical analysis of the non-linear effects of natural gas, nuclear energy, renewable energy and ICT-Trade in leading CO2 emitter countries: policy towards CO2 mitigation and economic sustainability, J. Environ. Manag. 286 (2021), 112232.

[28] A. Azam, M. Rafiq, M. Shafique, J. Yuan, Does nuclear or renewable energy consumption help to control environmental pollution? New evidence from China, Renew. Energy Focus. 39 (2021) 139–147.
[29] U.A. Osakede, O.K. Adeleke, Government Borrowing, Infrastructure and Human Development in Africa: A Panel Threshold Approach, Springer, Cham, 2022, pp. 81–92.
[30] A.K. Fosu, The external debt-servicing constraint and public-expenditure composition in Sub-Saharan Africa, Afr. Dev. Rev. 22 (2010) 378–393.
[31] D. Akam, S.P. Nathaniel, A.H. Muili, S.N. Eze, The relationship between external debt and ecological footprint in SANE countries: insights from Kónya panel causality approach, Environ. Sci. Pollut. Res. (2021).
[32] S. Katircioğlu, A. Celebi, Testing the role of external debt in environmental degradation: empirical evidence from Turkey, Environ. Sci. Pollut. Res. 25 (2018) 8843–8852.
[33] S. Tang, Z. Wang, G. Yang, W. Tang, What are the implications of globalization on sustainability?-A comprehensive study, Sustain 12 (8) (2020) 3411.
[34] A. Simplice, Globalization and Africa: implications for human development, Int. J. Dev. Issues 12 (2013) 213–238.
[35] A. Singh, Financial globalization and human development, J. Hum. Dev. Capab. 13 (2012) 135–151.
[36] Y. Huang, M. Haseeb, M. Usman, I. Ozturk, Dynamic association between ICT, renewable energy, economic complexity and ecological footprint: is there any difference between E-7 (developing) and G-7 (developed) countries? Technol. Soc. 68 (2022), 101853.
[37] N.M. Suki, A. Sharif, S. Afshan, N.M. Suki, Revisiting the Environmental Kuznets Curve in Malaysia: the role of globalization in sustainable environment, J. Clean. Prod. 264 (2020), 121669.
[38] B. Wang, C. Yan, N. Iqbal, Z. Fareed, A. Arslan, Impact of human capital and financial globalization on environmental degradation in OBOR countries: critical role of national cultural orientations, Environ. Sci. Pollut. Res. (2022) 1–17.
[39] A.A. Awosusi, T.S. Adebayo, M. Altuntaş, E.B. Agyekum, H.M. Zawbaa, S. Kamel, The dynamic impact of biomass and natural resources on ecological footprint in BRICS economies: a quantile regression evidence, Energy Rep. 8 (2022) 1979–1994.
[40] Y. Miao, A. Razzaq, T.S. Adebayo, A.A. Awosusi, Do renewable energy consumption and financial globalization contribute to ecological sustainability in newly industrialized countries? Renew. Energy (2022).
[41] M. Usman, D. Balsalobre-Lorente, Environmental concern in the era of industrialization: can financial development, renewable energy and natural resources alleviate some load? Energy Pol 162 (2022), 112780.
[42] M. Khan, I. Ozturk, Examining the direct and indirect effects of financial development on CO_2 emissions for 88 developing countries, J. Environ. Manag. 293 (2021), 112812.
[43] M.H. Pesaran, General diagnostic tests for cross section dependence in panels, in: CESifo Work. Pap. No. 1229, Cent. Econ. Stud. Ifo Inst, CESifo), Munich, 2004.
[44] E.W. Frees, Assessing cross-sectional correlation in panel data, J. Econom. 69 (1995) 393–414.
[45] M. Friedman, The use of ranks to avoid the assumption of normality implicit in the analysis of variance, J. Am. Stat. Assoc. 32 (1937) 675–701.
[46] T.S. Breusch, A.R. Pagan, The Lagrange multiplier test and its applications to model specification in econometrics, Rev. Econ. Stud. 47 (1980) 239–253.
[47] B.H. Baltagi, Q. Feng, C. Kao, A Lagrange Multiplier test for cross-sectional dependence in a fixed effects panel, J. Econom. 170 (2012) 164–177.
[48] M.H. Pesaran, T. Yamagata, Testing slope homogeneity in large panels, J. Econom. 142 (2008) 50–93.
[49] M.H. Pesaran, A simple panel unit root test in the presence of cross-section dependence, J. Appl. Econom. 22 (2007) 265–312.
[50] J. Westerlund, Testing for error correction in panel data, Oxf. Bull. Econ. Stat. 69 (2007) 709–748.
[51] A. Chudik, M.H. Pesaran, Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors, J. Econom. 188 (2015) 393–420.
[52] M.H. Pesaran, Estimation and inference in large heterogeneous panels with a multifactor error structure, Econom 74 (2006) 967–1012.
[53] M. Eberhardt, S. Bond, Cross-section Dependence in Nonstationary Panel Models: a Novel Estimator, Pap. Prep. Nord. Econom. Meet., Lund, Sweden, 2009, pp. 29–31.
[54] E.I. Dumitrescu, C. Hurlin, Testing for Granger non-causality in heterogeneous panels, Econ. Modell. 29 (2012) 1450–1460.
[55] R. Shinwari, Y. Wang, A. Maghyereh, B. Awartani, Does Chinese foreign direct investment harm CO_2 emissions in the Belt and Road Economies, Environ. Sci. Pollut. Res. (2022) 1–17.
[56] M. Usman, M.S.A. Makhdum, R. Kousar, Does financial inclusion, renewable and non-renewable energy utilization accelerate ecological footprints and economic growth? fresh evidence from 15 highest emitting countries, Sustain. Cities Soc. 65 (2021) 102590.
[57] M. Usman, A. Jahanger, M.S.A. Makhdum, D. Balsalobre-Lorente, A. Bashir, How do financial development, energy consumption, natural resources, and globalization affect Arctic countries' economic growth and environmental quality? an advanced panel data simulation, Energy 241 (2022) 122515.