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An empirical re-investigation for verifying the pollution haven hypothesis concerning the foreign direct investment-carbon intensity nexus: Contextual evidence from BRICS

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ABSTRACT

Since the BRICS countries make noteworthy contributions to global economic outputs and also account for around half of the total volume of carbon dioxide emitted worldwide, greening the economic growth processes and facilitating clean energy transition across these emerging nations have significant relevance at the global scale. Therefore, this study aims to assess the long-run determinants of carbon intensity levels of economic output and energy use in the context of the BRICS countries over the period spanning from 1998 to 2021. Specifically, this analysis is conceptualized to examine the non-linear carbon intensity-influencing impacts of incoming foreign direct investment through the lens of the widely-acclaimed pollution haven hypothesis, while controlling for other major macroeconomic factors. In this regard, advanced panel data estimators that are robust to negating issues related to cross-sectional dependence, heterogeneous slope coefficients, and endogeneity are utilized. In a nutshell, the results ultimately verify the pollution haven hypothesis by confirming the inverted U-shaped nexus between foreign direct investment inflows and carbon intensity levels of economic output. On the other hand, incoming foreign direct investment is found to monotonically increase, albeit at a decreasing rate, the carbon intensity levels of energy use. Besides, more renewable energy deployment and technological progress are identified as carbon intensity-inhibiting factors while institutional quality improvement, financial development, and international trade are responsible for amplifying carbon intensity levels, especially those related to economic output production. Hence, based on these findings, several policies are recommended for the BRICS countries to gradually green their economic growth processes and successfully undergo the clean energy transition so that their future carbon intensity levels can be contained to a large extent. These findings are expected to guide the BRICS nations in enhancing compliance with the pledges they made by signing the 2030 Sustainable Development Goals agenda of the United Nations.

1. Introduction

The BRICS bloc features the leading emerging market economies of Brazil, Russia, India, China, and South Africa, and it is regarded as a hub of global economic activities courtesy of its deeply integrated globalization ties with the world economies. Besides, the BRICS encompasses more than one-quarter of the global land area and comprises almost half of the world's population. Further, in terms of output production, the BRICS nations collectively account for a quarter of global economic output (World Bank, 2023). Moreover, in respect of energy trade, the BRICS nations are large-scale exporters (Russia) and importers (China and India) of fossil fuels, and they collectively consume around two-fifths of the total volume of energy consumed worldwide (Udeagha and Ngepah, 2023a). On the other hand, the BRICS members have also attracted significant amounts of foreign investments by implementing sound financial globalization policies. Notably, over the last two decades, the influx of Foreign Direct Investment (FDI) has quadrupled in value which, in turn, has significantly helped these emerging nations grow over time (UNCTAD, 2023). Thus, it is evident from the above-mentioned statistical facts that the BRICS nations, as a whole, play critically important roles in facilitating global economic well-being.

However, this current study is particularly motivated on the basis of how these emerging countries, alongside boosting economic output, have persistently jeopardized environmental well-being worldwide, particularly by accounting for more than 46% of the aggregate volume

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Nomenclature

BRICS	Brazil, Russia, India, China, South Africa
CD	cross-sectional dependence
CIEO	carbon Intensity of economic output
CIEU	carbon Intensity of energy use
CO_2	carbon dioxide
DCE	dynamic common correlated effects
DCE-IV	dynamic common correlated effects-instrumental variable
FDI	foreign direct investment
G7	group of seven
PHE	pollution halo effect
PHH	pollution haven hypothesis
SDG	sustainable development goals
SH	slope heterogeneity
UNCTAD	United Nations Conference on Trade and Development

of Carbon dioxide (CO_2) discharged globally (Iqbal et al., 2023). As shown in Fig. 1, it is apparent that between 2000 and 2020, the yearly shares of CO_2 discharged by the BRICS in global CO_2 emissions have progressively increased year-on-year (from 26 % to more than 46 %). In this regard, it is also worth noting that the BRICS nations are five of the leading CO_2-emitting countries in the world; precisely, China, India, and Russia are ranked among the top-4 annual emitters of CO_2 (Zhang et al., 2019; World Bank, 2023). Consequently, from these concerning environmental standpoints, it is important to figure out what the BRICS nations have done wrong which led to their abject failure in abating their emission levels. Simultaneously, it is also of immense significance for these nations to understand what future policies can help them to contain their yearly CO_2 emission discharge rates and become carbon neutral over time. Moreover, these policy implications are not only relevant for improving their environmental statuses but are also deemed imperative for establishing environmental sustainability at the global scale.

In general, although reducing CO_2 emission levels is pertinent, concentrating only on abating the annual emission figures is a less holistic approach to designing policies that are essential in proactively tackling CO_2 emission-related environmental problems. In this regard, alongside reducing CO_2 emissions, it is equally important to emphasize the necessity of reducing carbon intensity levels which would provide the scope to blend environmental, economic growth, and energy consumption objectives within the policymaking process. For instance, in the context of reducing the level of Carbon Intensity of Economic Output (CIEO), it is presumed that reducing this intensity level can green the economic growth generation initiatives which, in turn, can slash down the volume of CO_2 discharged for producing one currency unit of economic output. Particularly, from the point of view of the BRICS, it is acknowledged that the rapid growth of the economies of this bloc is a major factor that has amplified and aggravated CO_2 emissions and environmental conditions, respectively (Udeagha and Breitenbach, 2023a). Thus, reducing CIEO levels is deemed important for these nations so that their future economic growth performances can be decoupled from environmental devastations. Besides, as the BRICS nations have endorsed the 2030 Sustainable Development Goals (SDG) agenda of the United Nations, reducing CIEO is imperative for them in achieving the underlying SDG-targets in order by simultaneously executing economic and environmental development policies.

On the other hand, in the context of reducing the level of Carbon Intensity of Economic Use (CIEU), it is deemed a more appropriate environmental quality indicator that emphasizes the need for greening the energy sector so that the level of carbon emissions associated with the use of one unit of energy resource can be diminished. In this matter, it is particularly essential for the BRICS nations to plunge their CIEU figures because the chronic state of fossil fuel dependency in these nations is known to be a key barrier that has hampered the attainment of their carbon emission-abatement objective. Notably, in 2000 the mean share of fossil fuels in the total energy consumption profiles of the BRICS nations was around 72.23 %, which later rose by almost five percentage points by the end of 2020 (World Bank, 2023). Under such a scenario, the task of reducing CO_2 emission levels without stressing the urgency of undergoing green transitions within the energy sectors of the BRICS nations is likely to be extremely challenging. Moreover, identifying credible means for reducing CIEU rates can enhance the prospects of the BRICS countries regarding the realization of the targets associated with SDG-7 (emphasizing clean energy transition) and SDG-13 (emphasizing CO_2 emission reduction and climate change resilience development).

Against this backdrop, this study aims to explore the determinants of carbon intensity levels, of both output production and energy use, in the context of the BRICS nations over the 1998–2021 period. More specifically, this study is particularly focused on ascertaining the carbon intensity-influencing impacts of FDI influx under the lens of the Pollution Haven Hypothesis[1] (PHH). Since FDI received by the BRICS bloc have more or less risen four-fold within the selected period of analysis (UNCTAD, 2023), it would be interesting to understand how such external financial inflows, apart from promoting economic growth, have impacted the carbon intensity levels of the BRICS countries. Hence, the policy outcomes from this study are likely to assist in designing action plans relevant for decarbonizing the economies of these emerging nations, especially via the adoption of sustainable (or green) financial globalization policies. Furthermore, this study also probes into the carbon intensity-influencing effects associated with renewable energy transition, institutional quality improvement, financial development, urbanization, local technological development, and international trade. Thus, the findings are expected to have paramount significance for the BRICS nations in designing a holistic blueprint for plunging their respective carbon intensity figures in the future.

Further, in terms of contributions, this study is particularly motivated to bridge two major gaps in the extant literature. First, there has been a lack of empirical investigation using carbon intensity as the environmental quality indicator in the context of the BRICS bloc. Though some existing works have shed insights into how China's carbon intensity levels are determined (Lin and Wang, 2023; Xue et al., 2023), not much evidence is available regarding this issue in the context of the other members of the BRICS. Besides, previous studies have also not used panel data concerning these emerging nations for exploring the macroeconomic influencers of their carbon intensity levels. By contrast, the existing studies have predominantly considered CO_2 emissions as the indicator of environmental quality in the BRICS countries (Chishti and Sinha, 2022; Caglar et al., 2022; Udeagha and Ngepah, 2023b,c). Hence, these studies have specifically recommended environmental development policies while overlooking the scopes of designing interactive policies that can reverse the surging CO_2 emission trajectories of the BRICS nations by simultaneously greening their economic growth mechanisms and cleaning their fossil fuel-dominated energy sectors.

Second, the existing studies have mostly tried establishing the static impact of FDI influx on environmental quality by estimating linear estimation models (Khan et al., 2023). However, this linear modelling approach suffers from a potential bias in terms of overlooking the possible dynamic associations between FDI influx and environmental quality. Nevertheless, it is imperative to explore this nexus using non-linear models to check whether the environmental quality-inflicting impacts of FDI inflows change as FDI receipt figures persistently increase over time. Accordingly, in the context of the BRICS nations, this study

[1] The concept of the PHH is elaborately discussed in section 3.1. "For more information regarding this hypothesis", see Udeagha and Breitenbach (2023b) and Firoj et al. (2023).

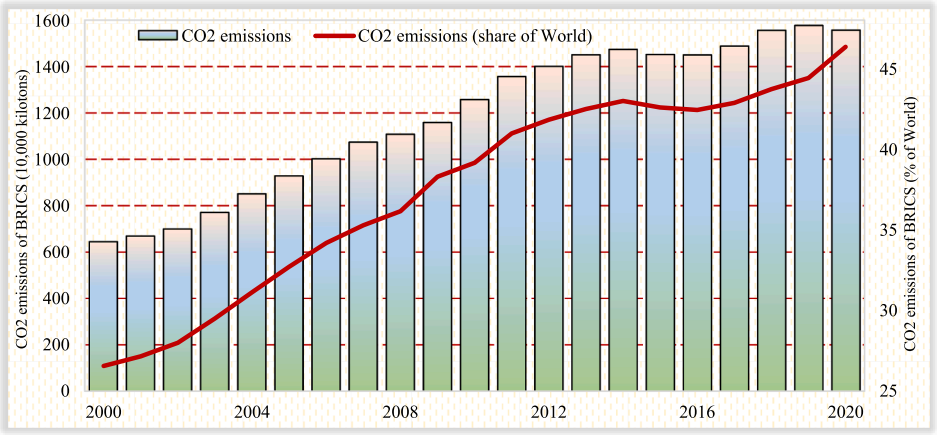

Fig. 1. Carbon emission trends concerning the BRICS countries.
Source: World Bank (2023).

tries to bridge these aforementioned voids in the environmental economics literature by utilizing a non-linear model for assessing the nexus between carbon emission intensity and FDI inflows under the theoretical framework of the PHH.

In the upcoming section, the annual trends in the levels of CIEO, CIEU, and FDI inflow are analyzed. Subsequently, the literature review is presented followed by a discussion on the empirical models and estimation techniques employed in this study. Next, the analytical findings are reported while the last section contains the concluding remarks along with policy insights.

2. Some stylized facts on carbon intensity and FDI inflow trends in BRICS nations

Figs. 2 and 3 respectively display the trends in CIEO and CIEU levels of the BRICS nations, both for the individual members of this bloc as well as for the members as a whole. Overall, contrasting trends can be identified. For instance, it is evident that over the 1998–2021 period, the CIEO levels of the BRICS nations have on average declined while the corresponding mean levels of CIEU have gone up (as indicated by the dashed green line plots). Firstly, these trends imply that the BRICS nations, as a whole, have managed to reduce the volume of CO_2 discharged per unit of economic output produced; consequently, it can be assumed that these nations have somewhat managed to green their economic output production processes as time progressed. Secondly, it is understandable from these trends that carbon emissions per unit of energy consumed have on average increased over time, whereby it can be said that the BRICS nations have intertemporally become more reliant on fossil fuels for managing their energy demands. The surging CIEU trends, therefore, corroborate the fact that in the last two decades or so the mean fossil fuel share in the energy consumption profiles of these nations rose by almost five percentage points (World Bank, 2023). However, in this regard, the declining CIEO trends are somewhat puzzling; nevertheless, it can be an indication of the BRICS nations managing to boost their energy productivity levels in the aforesaid period. As a result, despite becoming more fossil fuel dependent, more productive employment of energy resources is likely to have assisted these nations in greening their economic outputs.

Fig. 4 presents the trends in annual net receipts of FDI by the BRICS nations over the 1998-2021 period (once again both for the individual members of this bloc as well as for these nations as a whole). These trends endorse that on average the BRICS nations have become more financially globalized till 2015 (as indicated by the green dashed line plot), whereby it is evident that these nations have persistently pulled more volumes of FDI into their respective economies. However, since 2015, the annual net FDI receipt figures have on average declined which can particularly be attributed to the declining trends in China's annual net FDI influx levels. It is worth noting that China is also a leading source of FDI for the global economies which can be one of the reasons behind the nation's recent declining net FDI receipt trajectories. Nevertheless,

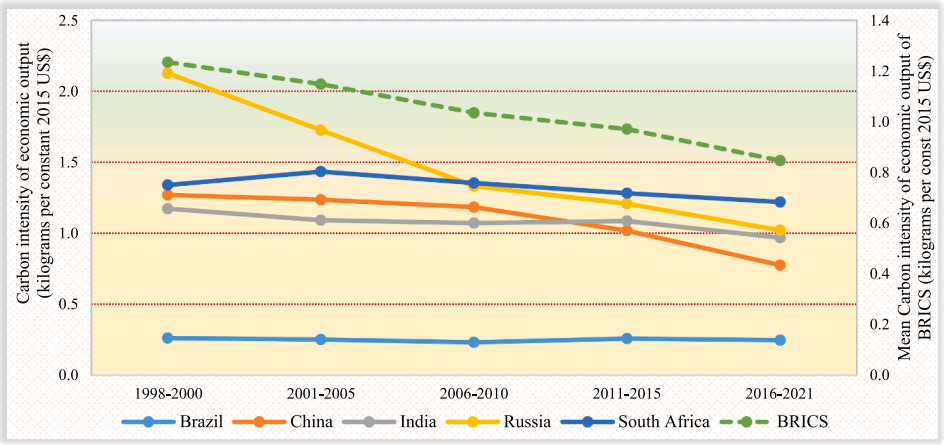

Fig. 2. The CIEO trends in the BRICS countries.
Source: Author's computation using data from World Bank (2023).

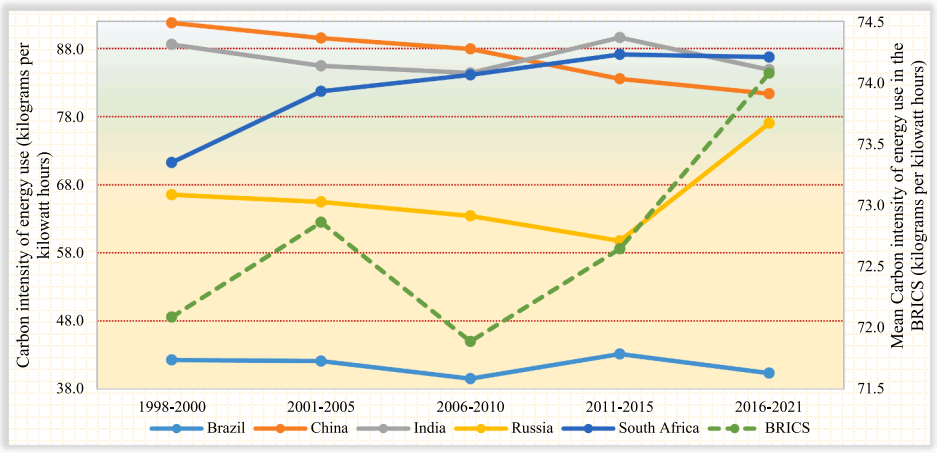

Fig. 3. The CIEU trends in the BRICS countries.
Source: Author's computation using data from World Bank (2023) and IEA (2023).

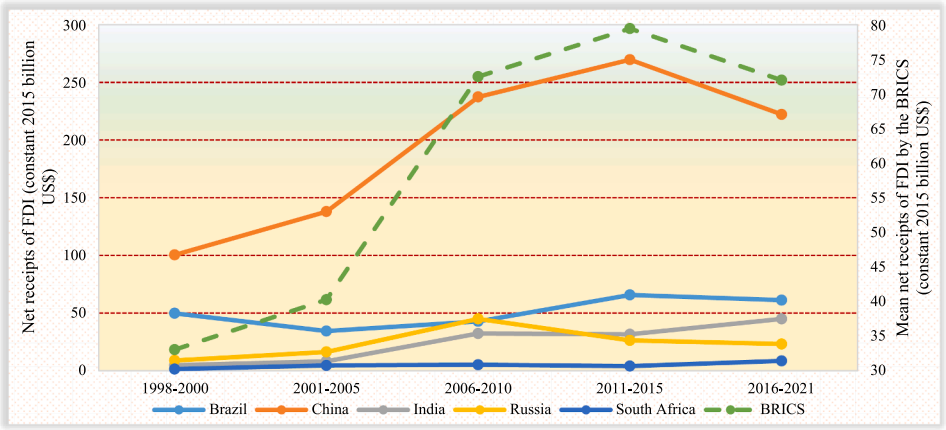

Fig. 4. The net FDI receipt trends in the BRICS countries.
Source: Author's computation using data from World Bank (2023).

as per the estimates provided by the United Nations Conference on Trade and Development (UNCTAD), inflows of FDI into the BRICS bloc have quadrupled (UNCTAD, 2023) which further endorses that these emerging nations, over time, have become more financially globalized with the other world economies.

3. Literature review

3.1. Theoretical perspectives of the FDI inflows-carbon emissions nexus

Globalization is regarded as an economic growth-stimulating factor that connects the world economies through trade and financial investment, in particular (Dabwor et al., 2022). However, while promoting economic expansion, globalization imposes environmental impacts that either enhance or degrade the level of environmental well-being. Especially in the context of financial globalization, resulting in cross-border flows of FDI, the associated environmental impacts within the host economy can be explained by the concept of the PHH. This hypothesis argues that incoming FDI is accompanied by unclean technological transfers that lead to the expansion of pollution-intensive industries operating in the FDI-hosting economies (Saqib and Dincă, 2023). Consequently, the volume of CO_2 emissions in the host nations can be expected to surge.

Contrastingly, if FDI inflows involve the dissemination of clean technologies, it is likely to stimulate the expansion of less pollution-intensive industries of the host economies and, thereby, help in abating their carbon emission levels (Mahmood, 2023). Under such circumstances, the carbon emission-plunging impact of incoming FDI is referred to as the Pollution Halo Effect (PHE) that invalidates the PHH. Apart from transfers of unclean and clean technologies, the PHH is said to hold if foreign investors exploit weak environmental regulations in developing countries, in particular (Zhou et al., 2019). Notably, in developed economies with strong environmental legislation, it is difficult to get away by investing in pollution-intensive industries. Thus, investors in these countries are often motivated to invest in developing countries that are yet to enforce strong environmental protection laws. In these countries, environmental regulations are relatively easier to breach which, in turn, allows the expansion of pollution-intensive industries by facilitating investment of foreign funds. On the flip side, incoming FDI into developed economies is likely to be clean whereby the PHH may not hold due to the existence of the PHE.

Furthermore, although the PHH assumes the environmental impacts of incoming FDI to be static (or monotonic), it can be hypothesized that the nexus between FDI receipts and environmental quality is dynamic (or non-monotonic). For instance, in the initial stages, traditional technologies embodied within FDI are most likely to be unclean. As a result, the economic output production processes within the FDI-receiving countries are anticipated to be highly pollution-intensive; additionally, the fossil fuel dependency level is also expected to be on the higher side. Consequently, incoming FDI may lead to higher levels of CIEO and CIEU.

Under the above scenarios, the PHH can be verified. On the other hand, in the latter stages, newly-developed technologies embodied within FDI are likely to be cleaner due to emphasizing the need for greening economic activities and transitioning from fossil fuels to renewable energy in order to evade the atrocities linked with rising atmospheric CO_2 emission levels. In this regard, incoming FDI may result in lower levels of CIEO and CIEU whereby the PHE would exist to invalidate the PHH. From the above viewpoints, the intertemporal nexus concerning FDI inflows and carbon intensity levels can be hypothesized to exhibit an inverse U-shape. Fig. 5 summarizes the theoretical arguments explaining the contrasting impacts of FDI inflows on carbon emission-related environmental quality indicators.

3.2. Empirical evidence regarding the FDI inflows-carbon emissions nexus

The empirical literature in the context of the relationship between financial globalization and environmental quality has mostly been assessed in terms of the responses of CO_2 emission levels to a rise in the level of net FDI receipts. Among these, while several studies have verified the PHH and accused financial globalization of imposing detrimental impacts on the environment, some have presented empirical evidence that nullified the authenticity of the PHH to establish the environmental quality-improving impacts of financial globalization. Among the previous studies that have supported the PHH in the context of the BRICS nations, Gyamfi et al. (2022) considered data from the 1990–2019 period and found that although per capita CO_2 emission figures of these emerging nations are inelastic to changes in FDI influx shares of their real economic output levels, the PHH can still be confirmed by the predicted positive nexus between these variables. Based on their findings, the authors highlighted the relevance of attracting clean FDI in realizing the carbon emission-abating objective of the BRICS countries. Likewise, using annual data from 2000 to 2020, Wen et al. (2022) claimed that the PHH holds in the context of the BRICS nations as these emerging countries attract pollution-intensive FDI that boost their annual discharges of CO_2 in the long run.

Besides, conducting similar experiments using data for the individual BRICS nations, Udeagha and Ngepah (2022) concentrated on South Africa to assess how incoming FDI affects this Sub-Saharan African nation's short- and long-run CO_2 emission figures. Utilizing data from 1960 to 2020, the authors concluded that incoming FDI is responsible for boosting CO_2 emissions in South Africa (thus, the PHH was validated); however, the results affirmed that the CO_2 emission-surging impact is short-lived, and it does not sustain in the long-run. Notably, in the long run, the impact of incoming FDI on South Africa's CO_2 emission levels was found to be statistically inconclusive. Contrarily, in another study on the Chinese economy, Zheng et al. (2022) verified the existence of the PHH for both the short-run and long-run scenarios. Accordingly, the authors tried to portray that unclean FDI has persistently flown into China to drive up the nation's CO_2 discharge levels. Furthermore, among the existing studies featuring the non-BRICS nations, the PHH was verified by the positive influence of FDI influxes in CO_2 emission levels of selected European countries (Christoforidis and Katrakilidis, 2021) and Turkey (Bekun et al., 2023).

On the other hand, among the preceding studies that have condemned the authenticity of the PHH (thus, implicitly approving the PHE), Caglar et al. (2022) performed empirical analysis using data from the BRICS nations and concluded that for these nations to achieve their Paris Accord-related commitments, it is essential for these nations to be more financially globalized so that influx of FDI can help them in plunging their long-run CO_2 emission figures. Thus, this statement nullified the existence of the PHH in the context of the BRICS while affirming the presence of the PHE. In the same sense, Balsalobre-Lorente et al. (2022) asserted that incoming FDI not only reduces CO_2 emission levels directly but also indirectly cuts down emissions by neutralizing the CO_2 emission-boosting impacts associated with energy consumption across the BRICS countries. Besides, for the BRICS member Brazil, Polloni-Silva et al. (2021) utilized data from 592 Brazillian municipalities and recorded evidence regarding more FDI inflows contributing to fewer discharges of CO_2; thus, this finding respectively affirmed the PHE and PHH. Likewise, in the context of the other BRICS-member India, Rej et al. (2023) verified the PHE, both for the cases of the short-run and the long-run.

Among the similar studies conducted using data from non-BRICS nations, Taşdemir and Özçelik (2023) compiled data from 13 countries located in the Middle East and North Africa and found evidence in support of the PHE-induced decline in CO_2 emissions levels upon receiving FDI, only in the context of selected countries in which human capital is less developed and governance quality is poor. Besides, in the context of South Korea, Kim and Seok (2023) claimed that the PHH is likely to become invalid if the South Korean economy is sufficiently developed. This finding implied that as an economy becomes well-developed, it can attract clean FDI whereby its CO_2 emission levels can be expected to fall over time. Meanwhile, from the viewpoint of developed economies, Chien et al. (2023) concentrated on the Group of Seven (G7) nations and concluded that in developed countries with high levels of CO_2 emissions, incoming FDI assists in reducing their emission figures whereby the PHE can be deemed valid (synonymous with the invalidity of the PHH).

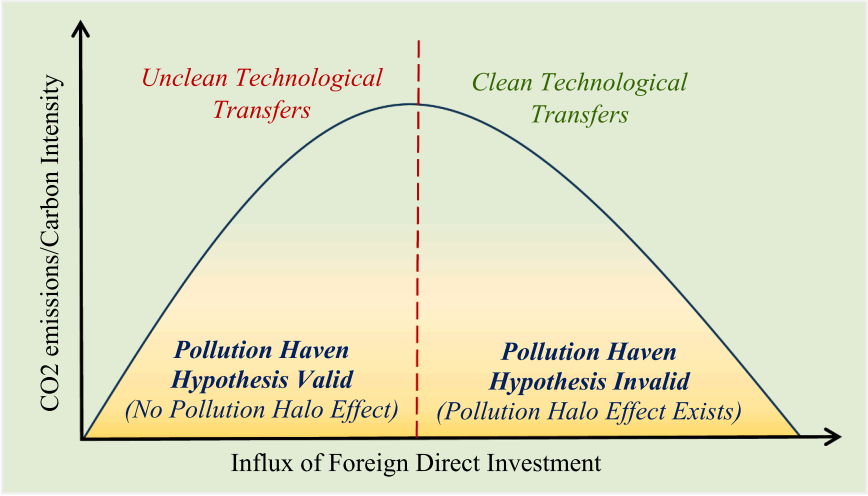

Fig. 5. The non-linear nexus between FDI inflows and environmental quality.

3.3. Literature gaps and contributions

The review of the empirical literature presented in Section 3.2 affirms that the preceding studies have (a) primarily focused on CO_2 emission levels to proxy environmental quality, and (b) though a few studies have attempted to assess the quadratic association between CO_2 emissions and incoming FDI, no information is available regarding the non-linearity concerning carbon intensity and FDI receipts in the context of BRICS bloc. Therefore, considering these major literature gaps, this study bridges them by exploring the non-linear impacts of FDI influx on CIEO and CIEU figures of the BRICS nations using data from 1998 to 2021.

4. Models and econometric methods

4.1. Build-up empirical models

Considering the objective of understanding whether incoming FDI imposes non-linear environmental impacts within the BRICS nations, this study employs an augmented version of the conventionally used Stochastic Impact by Regression on Population, Affluence, and Technology environmental model introduced by Ehrlich and Holdren (1971). Accordingly, the carbon intensity levels of the BRICS nations are expressed as quadratic functions of incoming FDI and its squared term, while controlling for key macroeconomic variables as follows:

$$\textbf{Model } 1: \ \mathrm{LnCIEO}_{i,t} = \alpha + \beta_1 \mathrm{LnFDI}_{i,t} + \beta_2 \left(\mathrm{LnFDI}_{i,t}\right)^2 + \beta_3 \mathrm{RECS}_{i,t} + \beta_4 \mathrm{IQL}_{i,t} + \beta_5 \mathrm{FINDEV}_{i,t} + \beta_6 \mathrm{LnURBAN}_{i,t} + \beta_7 \mathrm{LnTP}_{i,t} + \beta_8 \mathrm{TOPEN}_{i,t} + \varepsilon_t \quad (1)$$

$$\textbf{Model } 2: \ \mathrm{LnCIEU}_{i,t} = \alpha + \beta_1 \mathrm{LnFDI}_{i,t} + \beta_2 \left(\mathrm{LnFDI}_{i,t}\right)^2 + \beta_3 \mathrm{RECS}_{i,t} + \beta_4 \mathrm{IQL}_{i,t} + \beta_5 \mathrm{FINDEV}_{i,t} + \beta_6 \mathrm{LnURBAN}_{i,t} + \beta_7 \mathrm{LnTP}_{i,t} + \beta_8 \mathrm{TOPEN}_{i,t} + \varepsilon_t \quad (2)$$

In Model 1, the dependent variable LnCIEO stands for the natural log-transformed level of CIEO which is calibrated in terms of the volume of CO_2 discharged for producing one currency unit of economic output. Notably, a rise in the value of this variable may be interpreted as a successful attempt made by the BRICS nations in making their economic output production processes less polluted and vice-versa. On the other hand, Model 2's dependent variable LnCIEU stands for the natural log-transformed level of CIEU which is measured in terms of the volume of CO_2 discharged per unit of energy combusted. Thus, a rise in the value of this variable may either indicate more use of green (clean) energy or portray greater efficiency in the overall use of energy resources. Hence, it is apparent that both these carbon intensity indicators, unlike the conventional environmental proxy CO_2 emission levels, help in capturing the extent of CO_2 emitted relative to output produced and energy resources consumed. As a result, changes in these carbon intensity levels shall not only guide in environmental policymaking purposes but simultaneously lead to the conceptualization of green growth and clean energy transition policies.

The descriptions of the explanatory variables along with their justifications for inclusion in the model are given below:

- The variable LnFDI refers to the natural log-transformed net value of FDI[2] flowing into the BRICS nations which provides the extent by which these nations are financially globalized both within the bloc and worldwide. As per the theoretical foundations of the PHH, if a rise in FDI inflows accounts for a rise in carbon intensity (i.e., if $\beta_1 > 0$), then the validity of the PHH can be confirmed and vice-versa. In this regard, the squared term of this variable (denoted by LnFDI^2) is included in the models to capture whether FDI influxes non-linearly impact the carbon intensity levels of the BRICS nations. Notably, for the assumption of plausible non-linear associations between incoming FDI and carbon intensity to hold, the predicted signs of the elasticity parameters β_1 and β_2 have to be opposite, yet statistically significant in both cases. Precisely, the positive and negative signs of β_1 and β_2 respectively shall affirm the inverted U-shaped nexus between net FDI receipts and levels of CIEO and CIEU.
- Among the covariates controlling for the FDI inflows-carbon intensity nexus, RECS refers to the renewable energy's share of total final energy consumption levels of the BRICS nations. Notably, this particular variable indicates the state of fossil fuel intensiveness of the energy sectors in these emerging countries. Since renewable energy is a cleaner energy source (Rasoulinezhad and Taghizadeh-Hesary, 2022; Sharif et al., 2023), more deployment of renewable energy while reducing fossil fuel employment, in tandem, can be expected to make economic growth processes less polluted and thereby assist in making the energy systems greener. Thus, a rise in the share of renewables can be hypothesized to plunge the CIEO and CIEU figures (i.e., β_3 can be expected to be negative).
- The variable IQL refers to institutional quality which is proxied by a composite index that is generated by using the principal component analysis and goal post techniques and by employing data regarding six indicators of governance (voice and accountability, rule of law, political stability, regulatory quality, corruption control, and effectiveness of government). Since good governance is related to better quality institutions (Muhammad and Khan, 2023), higher values of the composite institutional quality index would indicate strong quality institutions and vice-versa. Given the understanding that institutions that are bounded with strong laws, especially those related to environmental protection, have better scopes for restricting employment of unclean energy resources so that the economic output generation initiatives can be greened; thus, institutional quality improvement can be expected to reduce the CIEO and CIEU figures of the BRICS nations (i.e., β_4 is likely to be negative).
- FINDEV denotes financial development which is measured in terms of private sector borrowings' share of the real national output. Traditionally, the roles of a well-developed financial sector in stimulating economic growth (or affluence) by amplifying factor productivity and enlarging capital stock are duly acknowledged in the literature (Yang, 2019). Likewise, in the contemporary era, financial development is said to be associated with green finance which is thought of as a mechanism for greening economic output, especially by facilitating the clean energy transition process (Taghizadeh-Hesary and Yoshino, 2020; Zhou et al., 2022). From these viewpoints, financial development can be assumed to curb the CIEO and CIEU figures, as well (i.e., β_5 can be expected to be negative). Moreover, the inclusion of this variable in the model is justified by the importance of promoting green finance in respect of enabling the BRICS nations to achieve the climatic pledges they made by signing the 2030 SDG agenda of the United Nations (Nawaz et al., 2021).
- LnURBAN refers to urbanization which is calibrated in terms of the natural log-transformed size of the urban population of the respective BRICS nations; this variable captures the rate of urbanization in these emerging economies. Notably, controlling for urbanization within the carbon intensity determining models is relevant from the theoretical viewpoint of the '*urban heat island effect*' that links urbanization with higher CO_2 emission-led environmental pollution (Rahaman et al., 2022). Besides, considering the fossil fuel-intensive structures of the BRICS nations, a rise in the size of their urban populations can be expected to boost energy demand which, in turn, may amplify their fossil fuel employment levels. Consequently,

[2] Net FDI refers to the difference between inward and outward FDI of the respective BRICS countries.

urbanization can be hypothetically linked with higher carbon intensity levels (i.e., β_6 is likely to be positive).

- The variable LnTP refers to technological progress which is proxied by natural log-transformed counts of patents applied by residents of the BRICS nations. Since designing state-of-the-art technologies, through investment in research and development projects, is pertinent for green economic output and cleaning the energy sector (Zhang et al., 2022; Qi et al., 2022), technological progress can be assumed to lower down carbon intensity levels in the BRICS nations (i.e., β_7 is likely to be negative). However, if technological progress induces the discovery of unclean technologies, especially those related to more fossil fuel employment-led economic output production, then it may rather increase the carbon intensity figures of the BRICS nations (i.e., β_7 is likely to be positive).
- Lastly, the variable TOPEN refers to trade openness that proxies for the extent of trade globalization across the BRICS countries. It is measured in terms of international trade's (sum of exports and imports) share of national output. Considering the theoretical concept of '*net emissions-embodied in traded goods*,' it is quite expected that if trade-related industries are fossil fuel intensive, then more openness to international trade can be linked with higher levels of carbon intensity (i.e., β_8 can be assumed to be positive). Contrastingly, if trade-related industries are reliant on renewable energy and employ energy-efficient machinery, a rise in the level of international trade openness can be associated with lower carbon intensity levels (i.e., β_8 is likely to be negative).

4.1.1. Data

Since data regarding the concerned variables for the BRICS nations are unavailable before and beyond the 1998-2021 period, the data set considered in this study uses annual frequency data within this timeframe. However, to account for some gaps in the series of the data, the linear interpolation technique is utilized to fill them. Table 1 displays the measuring scales of the variables and reports the data sources, as well. Besides, in Table 2, the summary statistics and pairwise correlation among these variables are presented while in Table 3 the Variance Inflation Factor (VIF) outputs are shown.

Table 1
Units and sources of data.

Symbol	Variable	Unit	Source
LnCIEO	Carbon intensity of economic output	Kilotons/ constant 2015 US$	Author's computation using data from World Bank (2023)
LnCIEU	Carbon intensity of energy use	Kilotons/ kilowatt hours	Author's computation using data from World Bank (2023) and IEA (2023)
LnFDI (LnFDI^2)	Net receipts of FDI (squared term)	Constant 2015 US$	World Bank (2023)
RECS	Renewable energy's "share of total energy consumption level"	Percentage	World Bank (2023)
IQL	Institutional Quality	Index (0=poorest quality; 100=best quality)	Author's computation using data from World Bank (2023)
FINDEV	Financial development	Percentage	World Bank (2023)
LnURBAN	Urbanization	Number of urban residents	World Bank (2023)
LnTP	Technological progress	Number of patents	World Bank (2023)
TOPEN	Trade openness	Percentage	World Bank (2023)

4.2. Econometric methods

Firstly, the issue of dependency across cross-sections is tested using the technique recommended by Juodis and Reese (2022). This technique for assessing Cross-sectional Dependence (CD) is different from the conventionally employed CD-testing methods in the sense that it assumes weak dependence across cross-sections; consequently, the statistical significance of the test statistic predicted using this test confirms the issue of CD for the respective variable. Secondly, to ascertain the existence of heterogeneous slope coefficient-related concerns, the method recommended by Bersvendsen and Ditzen (2021) is employed. This recently introduced Slope Heterogeneity (SH)-testing method controls for the CD-related concerns in the data and predicts test statistics assuming slope coefficients to be homogeneously distributed across different cross-sectional units. Thus, the statistical significance of these test statistics shall verify the existence of SH in the concerned model.

Thirdly, to check whether the concerned variables are integrated (i.e., whether these variables are stationary and whether their respective series is mean-reverting), the unit root analysis is performed using the method recommended by Herwartz and Siedenburg (2008). This method is a CD-adjusted panel unit root estimation approach that neutralizes small sample bias through modifications and wild bootstrapping mechanisms (Sinha et al., 2020). Notably, for each variable, at either the level or the first difference, the method of Herwartz and Siedenburg (2008) predicts a single test statistic assuming that the series in question does not revert to its mean level (i.e., the concerned series of variables is non-integrated/non-stationary). Fourthly, for testing the existence of long-run associations among the variables of concern (i.e., for checking whether the series of the respective model's variables co-move in the long run), the CD-adjusted panel cointegration method recommended by Westerlund and Edgerton (2008) is employed in this study. Besides, this method is also robust to the presence of unknown structural break-related concerns in the data; hence, it is suitable for identifying the location of these breaks, as well (Chau et al., 2023). The test statistic predicted using this cointegration estimator assumes no cointegration among the concerned variables within the specified model.

Finally, the panel regression analysis is performed to explore how positive changes to the levels of net FDI influxes, the share of renewable energy in the total final energy consumption portfolio, institutional quality, financial development, urbanization, technological progress, and international trade openness impact the long-run carbon intensity figures of the BRICS nations. In this context, two CD- and SH-adjusted panel regression methods are used in this study. First, the Dynamic Common Correlated Effects (DCE) panel regression technique proposed by Chudik and Pesaran (2015) is employed. This method emerged to account for the limitations of the static common correlated effects estimator of Pesaran (2006) which is inappropriate to estimate models in which (i) the lagged level of the outcome (dependent) variable is considered as a covariate, and (ii) variables are weakly exogenous (Chudik and Pesaran, 2015). However, though the method of Pesaran (2006) is suitable for handling data sets that suffer from CD- and SH-related concerns, it is still inappropriate to use this method unless sufficient lags and cross-sectional averages are augmented into the model (as in the case of the DCE estimator).

The DCE estimator offers three estimation procedures; however, in the context of this study, the Cross-sectional Augmented Distributed Lag model is chosen which is efficient in estimating the long-run coefficients without estimating the coefficients for the short-run (Chudik et al., 2016). Although the DCE estimator of Chudik and Pesaran (2015) has several advantages, it is ideally suited for large panel data sets. Nevertheless, this estimator has provision for utilizing jackknife bias correction and recursive mean adjustment methods for accounting for finite sample bias in small panel data sets. Furthermore, it is assumed that augmenting the lagged-outcome variable as a covariate may generate endogeneity concerns stemming from reverse causation issues. Under

Table 2
Summary statistics and correlation.

Panel A: Summary statistics

Variable	LnCIEO	LnCIEU	LnFDI	RECS	IQL	FINDEV	LnURBAN	LnTP	TOPEN
Minimum	-15.325	-10.184	0.205	3.180	0.000	16.823	17.060	4.928	16.439
Maximum	-13.013	-8.588	9.703	50.050	100.0	182.868	20.599	14.171	69.393
Mean	-13.959	-9.572	2.333	23.438	43.860	64.849	18.938	9.248	43.650
Std. Dev.	0.662	0.308	1.432	16.823	23.051	37.231	1.051	2.087	12.404
Skewness	-1.169	-0.566	1.274	0.226	0.123	1.369	-0.273	0.611	-0.251
Kurtosis	2.821	2.853	2.705	1.396	2.659	3.019	2.012	3.006	2.094
Observations	120	120	120	120	120	120	120	120	120

Panel B: Matrix of correlation

	LnCIEO	LnCIEU	LnFDI	RECS	IQL	FINDEV	LnURBAN	LnTP	TOPEN
LnCIEO	1.000								
LnCIEU	0.798	1.000							
LnFDI	-0.311	-0.275	1.000						
RECS	-0.719	-0.417	0.143	1.000					
IQL	-0.146	0.049	-0.114	0.166	1.000				
FINDEV	0.067	0.329	0.165	-0.216	0.149	1.000			
LnURBAN	-0.144	0.130	0.192	0.359	-0.329	0.497	1.000		
LnTP	0.086	0.140	0.184	-0.222	-0.453	0.661	0.770	1.000	
TOPEN	0.698	0.649	0.037	-0.628	-0.004	0.385	-0.066	0.171	1.000

Table 3
Outputs from VIF analysis.

Scores	LnFDI	RECS	IQL	FINDEV	LnURBAN	LnTP	TOPEN
VIF	1.23	4.22	2.52	3.99	4.12	3.56	2.84
1/VIF	0.813	0.237	0.397	0.251	0.243	0.281	0.352
Mean VIF	3.21						

Note: Individual mean VIF scores less than 5 affirm no multicollinearity.

such a circumstance, the outcomes derived using the DCE technique are likely to be biased. Thus, an additional regression method is utilized which utilizes an instrumental variable approach within the DCE estimation setting to control for the presence of endogenous covariates within the model. In this regard, the instrumental variable-adjusted DCE method (DCE-IV from hereafter) recommended by Ditzen (2018) is also utilized in this study. Notably, the DCE-IV estimator augments lagged levels of covariates as regressors that work as instruments for correcting the impacts exerted by the endogenous covariates.

5. Findings from results

Firstly, the findings from the CD and SH tests, using the methods recommended by Juodis and Reese (2022) and Bersvendsen and Ditzen (2021), respectively, are reported in Table 4 and analyzed accordingly. Regarding the issue of CD, it is evident that the predicted test statistics are statistically significant for the variables LnCIEO, LnFDI, RECS, LnURBAN, LnTP, and TOPEN but statistically insignificant for the variables LnCIEU, IQL, and FINDEV. Nevertheless, the statistical significance rejects the null hypothesis and verifies the existence of CD-related problems in the data. Since the BRICS nations have globalization ties among themselves, these findings regarding CD can be deemed justified. On the other hand, in the context of SH, the statistical significance of the Delta and adjusted Delta statistics, for both Models 1 and 2, reject the null hypothesis and affirm the existence of SH-related concerns in the data. As the BRICS nations have significant differences in various macroeconomic aspects, the finding of the heterogeneity of the slope coefficients is quite justified.

Secondly, Table 5 displays the outputs derived from integration and cointegration analyses, using methods recommended by Herwartz and Siedenburg (2008) and Westerlund and Edgerton (2008), respectively. Notably, in the context of the integration test's outcomes, the results verify the integration order of I(1) for all concerned variables (as affirmed by the statistical significance of the test statistics at the first difference). These findings, apart from certifying the unique integration order, imply that the series of the concerned variables are mean-reverting. Hence, there is no issue utilizing these integrated variables for regression purposes (i.e., the regression outcomes are not

Table 4
Results from CD and SH tests.

Panel A: CD test of Juodis and Reese (2022)

Test Stat.	LnCIEO	LnCIEU	LnFDI	RECS	IQL	FINDEV	LnURBAN	LnTP	TOPEN
Value	-1.75*	1.53	-5.09***	3.52***	-0.68	0.92	-2.68***	5.08***	5.18***
Probability	0.081	0.127	0.000	0.000	0.499	0.359	0.007	0.000	0.000
CD exists	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes

Panel B: SH test of Bersvendsen and Ditzen (2021)

Model	Delta Statistic	Adjusted Delta Statistic	SH exits
Model 1	3.693*** (0.000)	4.671*** (0.000)	Yes
Model 2	3.290*** (0.001)	4.161*** (0.000)	Yes

Notes: The p-values are displayed within the parentheses; *** and * respectively affirm statistical significance at 1% and 10%.

Table 5
Results from integration and cointegration tests.

Panel A: Integration (or unit-root) test of Herwartz and Siedenburg (2008)

Analysis at Level, I(0)	LnCIEO	LnCIEU	LnFDI	RECS	IQL	FINDEV	LnURBAN	LnTP	TOPEN
Test Stat.	-0.514	-0.805	-0.903	-0.213	1.659	0.607	0.266	-1.175	0.878
Prob.	0.304	0.239	0.272	0.615	0.954	0.728	0.605	0.120	0.810
Integration	No	No	No	No	No	No	No	No	No
Analysis at 1st Diff., I(1)	**LnCIEO**	**LnCIEU**	**LnFDI**	**RECS**	**IQL**	**FINDEV**	**LnURBAN**	**LnTP**	**TOPEN**
Test Stat.	-2.008**	-2.873***	-2.103**	-1.344*	-1.578*	-1.643*	2.607**	-2.312***	-2.196**
Prob.	0.023	0.008	0.018	0.089	0.057	0.052	0.012	0.009	0.014
Integration	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: Cointegration test of Westerlund and Edgerton (2008)

	Considering no shift		Considering mean shift		Considering regime shift	
Model	**LM_{τ} stat.**	**LM_{Φ} stat.**	**LM_{τ} stat.**	**LM_{Φ} stat.**	**LM_{τ} stat.**	**LM_{Φ} stat.**
Model 1	-2.301**	-3.650***	-3.980***	-3.850***	-3.775***	-3.450***
	(0.012)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Model 2	-2.859***	-4.459***	-4.258***	-3.998***	-1.565*	-2.759**
	(0.008)	(0.000)	(0.000)	(0.000)	(0.056)	(0.012)

Notes: The p-values are displayed within the parentheses; ***, **, and * respectively affirm statistical significance at 1%, 5%, and 10%; For the sake of brevity, the structural break locations are not presented.

likely to be spurious). Besides, regarding the cointegration test's outcome, it is found that for both Models 1 and 2 the estimated test statistics are statistically significant. Thus, the null hypothesis can be rejected to confirm the presence of cointegrating associations among the variables of concern. Accordingly, it can be asserted that the carbon intensity levels of the BRICS nations have long-run associations with their levels of net FDI receipts, renewable energy penetration within the energy system, institutional quality, financial development, urbanization, technological progress, and trade openness. Furthermore, the confirmation of these cointegration relationships allows the estimation of the long-run carbon intensity rate-influencing effects of the concerned covariates.

Thirdly, the coefficient estimates derived from the regression analysis, using the DCE and DCE-IV panel estimators of Chudik and Pesaran (2015) and Ditzen (2018), respectively, are reported in Table 6. Overall, across the alternative regression estimators, the predicted coefficients are evidenced to be similar in sign but different in magnitude. Besides, it is evident that FDI inflows, institutional quality improvement, and financial development impose opposing impacts on the long-run CIEO and CIEU figures of the BRICS nations. However, the corresponding impacts of renewable energy transition, urbanization, technological progress, and trade openness on both carbon intensity indicators are homogeneous. Notably, the negative signs of the coefficients associated with the one-period lagged-dependent variables (i.e., L1.LnLIEO and L1.LnLIEU) show that the current year's CIEO and CIEU levels are likely to be lower and higher than the preceding year's CIEO and CIEU levels, respectively. Hence, these contrasting findings corroborate the opposing trends in annual CIEO and CIEU figures of the BRICS nations shown in Figs. 2 and 3.

Table 6
Results from regression analysis.

Model	Model 1 (Dep. Var.: LnCIEO)		Model 2 (Dep. Var.: LnCIEU)	
Estimator	DCE	DCE-IV	DCE	DCE-IV
L1.LnCI_EO	-0.895***	-0.564***		
	(0.065)	(0.140)		
L1.LnCI_EU			0.698**	1.222***
			(0.345)	(0.460)
LnFDI	0.106***	0.144**	0.119**	0.324**
	(0.026)	(0.064)	(0.049)	(0.141)
$LnFDI^2$	-0.012**	-0.019*	0.018**	0.048**
	(0.005)	(0.011)	(0.009)	(0.024)
RECS	-0.024***	-0.023***	-0.053***	-0.058***
	(0.002)	(0.002)	(0.003)	(0.006)
IQL	0.002***	0.005**	-0.003	-0.006
	(0.001)	(0.003)	(0.005)	(0.010)
FINDEV	0.009**	0.016***	0.004	0.006
	(0.004)	(0.005)	(0.006)	(0.007)
LnURBAN	0.598	0.577	0.866	0.890
	(0.537)	(0.624)	(0.7609)	(0.814)
LnTP	-0.246***	-0.236***	-0.319***	-0.316***
	(0.016)	(0.016)	(0.031)	(0.059)
TOPEN	0.006***	0.008***	0.012***	0.014***
	(0.001)	(0.001)	(0.003)	(0.004)
Constant	-18.312***	-18.005***	-26.312***	-26.632***
	(0.404)	(0.381)	(0.800)	(1.386)
Observations	115	115	115	115

Notes: The standard errors are displayed within the parentheses; *** and ** respectively affirm statistical significance at 1% and 5%.

Moreover, regarding the carbon intensity level-influencing effects associated with financial globalization, the results show that incoming FDI initially boosts but later on reduces the long-run CIEO figures of the BRICS nations. Consequently, the FDI influx-CIEO nexus depicts an inverted U-shape. On the other hand, the results affirm that incoming FDI monotonically increases, albeit at a decreasing rate, the long-run CIEU levels of the BRICS nations. Precisely, as far as the CIEO-related result is concerned, the initial positive relationship between FDI influx and CIEO validates the PHH while affirming the PHE ultimately. While, in the case of the CIEU-related result, the PHH is verified throughout. Nevertheless, these findings collectively indicate that as net FDI receipts persistently increases over time, the technologies accompanying these foreign financial influxes become greener which, in turn, helps the BRICS countries to green their economic output generation procedures and clean their energy sectors, as well. By contrast, the initial carbon intensity level-surging impact highlights the issue that foreign investors target these emerging nations for investment in pollution-intensive/fossil fuel-dependent industries, thus, turning them into pollution havens. Similarly, using CO_2 emissions as the environmental quality indicator, the PHH was verified by Gyamfi et al. (2022) and Wen et al. (2022) while Udeagha and Ngepah (2022) and Christoforidis and Katrakilidis (2021) supported this hypothesis in the context of South Africa and Turkey, respectively.

In addition, regarding the impacts associated with a higher share of renewables in the energy systems, the negative signs of the associated coefficient estimates show that more renewable energy deployment while reducing fossil fuel consumption, in tandem, is likely to reduce both CIEO and CIEU levels of the BRICS countries in the long-run. This finding corroborates the underlying theoretical notion of renewable (or clean) energy transition boosting employment of clean energy for producing economic output in these emerging nations. Besides, as

renewable energy is adopted as the preferred energy source for meeting energy demand across the BRICS nations, the fossil fuel intensiveness of their energy systems can be expected to decline. Thus, these above-mentioned arguments justify the long-run carbon intensity level-plunging impacts of rising renewable energy shares. These findings are in line with the finding of the CO_2 emission-reducing impact of renewable energy in BRICS countries by Khattak et al. (2020) and also support the green growth-promoting impact of renewable energy in the BRICS countries found by Danish and Ulucak (2020).

Further, the results show that despite improving the quality of institutions, particularly by promoting good governance within the BRICS nations, it is not possible to green the economic growth process by reducing their CIEO levels. Rather, the estimates endorse that with improvement in institutional quality, the long-run CIEO levels of the BRICS nations go up. This finding can be explained by the corresponding finding of the statistically inconclusive nexus between institutional quality improvement and CIEU levels. In this regard, the statistical insignificance of the coefficient estimates concerning Model 2 suggests that despite making institutions strong, the use of clean energy in the BRICS nations is likely to be unaffected. This scenario could be due to a lack of compliance with environmental regulations, especially those enacted to prevent fossil fuel employment. Besides, since the BRICS nations are largely reliant on fossil fuels while their renewable energy sectors are yet to be developed, the ineffectiveness of institutional quality-improving policies in reducing carbon intensity levels can be deemed justified. These findings contradict the CO_2 emission-curbing impact of institutional quality improvement found in the context of the BRICS nations by Wang et al. (2018). Therefore, these opposing findings highlight that though better-quality institutions help in reducing carbon emission levels, the process of greening economic growth gets disrupted while and objective of undergoing renewable energy transition remains doubtful; thus, the CIEO levels are likely to increase while CIEU levels are expected to stay put. Besides, the study by Wang et al. (2018) considered corruption control as the sole indicator of institutional quality as opposed to the use of five additional governance indicators in this study for predicting the composite institutional quality index. Thus, it can be said that though controlling corrupt practices is useful in achieving the environmental sustainability agenda, simultaneously improving the levels of the other indicators of good governance may not collectively facilitate this goal in the cases of the BRICS nations.

Next, the results reported in Table 6 endorse that financial development, in terms of enhancing credit extensions toward the private sector, is associated with higher CIEO levels in the long run. Contrastingly, its impact on the CIEU levels of the BRICS countries is statistically inconclusive. These findings indicate that developing the financial sectors in these emerging countries has successfully amplified private investment and has boosted the economic output levels of the BRICS nations. However, financial development is likely to have abjectly failed in sufficiently boosting investment in renewable energy sectors in these countries. This statement is duly supported by the statistics endorsing the declining trends in mean renewable energy's share of total final energy consumption levels of the BRICS nations in the last couple of decades (World Bank, 2023). As a result, amidst rising dependence on fossil fuels, that are both locally sourced and imported, financial development-led private investment can be said to have expanded the pollution-intensive industries in these countries. Consequently, the CIEO-boosting impact of financial development does not come as a surprise. Besides, the ineffectiveness of financial development policies in reducing CIEU levels is concerning because it establishes the lack of effective steps taken by the BRICS countries to scale green finance provisions whereby these nations have not been able to encourage private sector participation in clean energy development initiatives. The findings in this study partially match the results regarding financial development-led surges in annual CO_2 emission levels of the BRICS nations documented by Haseeb et al. (2018).

In addition, invalidating the notion of the '*urban heat island effect*', the results shown in Table 6 establish that urbanization is unable to explain the variations in the long-run CIEO and CIEU figures of the BRICS nations (confirmed by the statistical insignificance of the corresponding coefficient estimates). Though several preceding studies have verified the CO_2 emission-boosting impacts of urbanization for these nations (Younis et al., 2021; Voumik and Sultana, 2022), the statistically inconclusive findings in this study regarding the urbanization-carbon intensity nexus probably indicate that urbanization is unable to green the economic output production processes in the BRICS nations and also questions its ineffectiveness in stimulation clean energy transition within their energy sectors. On the other hand, the results reported in Table 6 confirm the role of technological development in reducing carbon intensity levels of the BRICS countries. Therefore, the findings endorse that technological innovation-led development of green technologies can help these nations in making more productive use of low-carbon energy resources for output generation purposes; thus, enabling these nations to reduce their long-run CIEO and CIEU figures. Similarly, in the context of the BRICS countries, previous studies have highlighted the importance of technological progress in reducing CO_2 emissions (Su et al., 2021), stimulating clean energy transition (Sharma et al., 2021), and promoting green growth (Danish and Ulucak, 2020).

Lastly, the results confirm the detrimental impact of international trade in the BRICS countries by statistically verifying the carbon intensity level-boosting impacts associated with more openness to trade. These findings indicate that the BRICS nations are net importers of carbon emissions that are embodied in traded commodities. It is worth noting that the majority of these countries are large-scale fossil fuel importers which explains why liberalizing trade barriers can account for higher levels of CIEU in the long run. In the same sense, given the understanding that fossil fuels (both locally produced and imported) are employed in the export industries in these countries, it is of no surprise that more participation in international trade-led economic expansion is likely to amplify their long-run CIEO figures. Therefore, these findings collectively imply that the trade globalization policies pursued by these emerging nations are inducing a trade-off between economic progress and environmental distress; consequently, the processes involving green growth promotion and undergoing clean energy transition are being hampered. Likewise, Chhabra et al. (2023) pointed out that international trade is responsible for degrading environmental quality by surging the CO_2 emission levels of the BRICS countries.

For robustness check, the analysis is conducted using annual per capita CO_2 emission levels as the outcome variables instead of CIEO and CIEU. Table 7 presents the results from the robustness analysis. As expected, the robustness of the findings cannot be established as the per capita yearly CO_2 emission figures of the BRICS nations are observed to be influenced by all concerned factors which was not the case earlier. Nevertheless, the results statistically endorse the long-run per capita CO_2 emission-surging impacts of net receipts of FDI, financial

Table 7
Results from robustness analysis (Dep. Var.: $LnCO_2PC$).

Estimator	DCE		DCE-IV	
	Coeff.	Std. Error	Coeff.	Std. Error
L1.$LnCO_2PC$	0.439***	0.151	0.485**	0.242
FDIN	0.085***	0.023	0.127**	0.050
$FDIN^2$	0.014**	0.007	0.018*	0.010
RECS	-0.026***	0.004	-0.029***	0.008
IQL	-0.006**	0.003	-0.011**	0.005
FINDEV	0.003***	0.001	0.005***	0.001
LnURBAN	0.674***	0.069	0.655***	0.053
LnPT	-0.254***	0.013	-0.240***	0.023
TOPEN	0.003***	0.001	0.004***	0.001
Constant	12.317***	4.399	12.085***	3.795
Observations	115		115	

Notes: ***, **, and * respectively affirm statistical significance at 1%, 5% and 10%.

development, urbanization, and international trade openness while affirming the emission-plunging impacts of higher renewable energy shares of energy systems, institutional quality improvement, and technological progress.

6. Conclusion and policies takeaways

Comprising five of the leading emerging market economies in the world, the BRICS bloc has established its importance in respect of promoting global economic well-being. However, these nations have also accounted for close to half of the annual volume of CO_2 emitted worldwide. Hence, from the perspective of ensuring a simultaneity between economic- and environmental well-being, it is essential for the BRICS nations to green their economic growth processes while cleaning their energy sectors, in tandem. Against this backdrop, this current study empirically ascertained the factors influencing the long run CIEO and CIEU figures of the BRICS countries by considering the period from 1998 to 2021. In a nutshell, the findings endorsed the PHH by verifying the inverted U-shaped nexus between net FDI receipts and the CIEO levels. On the other hand, incoming FDI was found to monotonically increase, albeit at a decreasing rate, the CIEU figures of the BRICS nations. Apart from FDI inflows, more renewable energy deployment instead of fossil fuels and technological progress were identified as carbon intensity-inhibiting factors while institutional quality improvement, financial development, and international trade were found to be responsible for amplifying the carbon intensity levelsBRICS nations, especially their CIEO figures. By contrast, urbanization failed to explain the variations in the long-run CIEO and CIEU figures of these emerging countries.

6.1. Policy implications

These aforementioned findings are taken into consideration for recommending policies that can enable these countries to comply with the pledges they made under the 2030 SDG agenda of the United Nations. Overall, the governments of the BRICS nations should develop the mindset of blending economic development, energy transition, and environmental policies so that they can reduce their carbon intensity levels to ultimately green their economic growth processes by facilitating renewable energy transition. In this regard, firstly, becoming more financially globalized over time, especially by attracting green FDI is a key financial globalization policy reform that needs to be emphasized. Thus, it can make sure that FDIs flowing into the BRICS nations are not directed at their pollution-intensive industries. This can be done by putting restrictions on investing foreign funds in industries that intensively use unclean inputs; consequently, the adoption of clean financial globalization policies can induce the PHE and thereby prevent the BRICS countries from becoming pollution havens for foreign investors. Simultaneously, these nations should diversify their FDI influx baskets by attracting certain FDIs that would accompany clean technologies, especially those relevant for boosting energy efficiency levels and speeding up renewable energy penetration rates within the energy sectors of the BRICS nations.

Secondly, focusing on the need for transitioning from the use of non-renewable to renewable energy and developing technologies for reducing carbon intensity levels, the BRICS nations should now plan to move away from fossil fuel dependency, especially reducing their imports of such unclean fuels. Rather, these countries should prioritize developing their indigenous renewable energy sectors. This is important because without expediting the renewable energy deployment processes and simultaneously withdrawing from the use of fossil fuels (i.e., without undergoing the non-renewable to renewable energy transition in full swing), it is unlikely that the BRICS nations can significantly cut down their carbon intensity levels which, in turn, would further hinder their prospects of establishing green growth. In this context, renewable energy development would require the concerned governments to scale budgetary allocations for financing state-owned renewable energy technology-related startups. Financing such programs is deemed important since traditional technologies are more suited to boosting electricity output using primary fossil fuels; thus, these obsolete technologies are regarded as unclean and should be replaced with cleaner alternatives. Simultaneously, the BRICS governments should also incentivize and encourage private participation that can complement the state-owned initiatives in speeding up the renewable energy technological development procedure. This would require the governments to make sure that the private investors in these countries are guaranteed to receive good returns on their investments in the renewable energy sector.

Thirdly, regarding the CIEO-increasing impact of institutional quality improvement, it is essential for the governments to revisit their policies concerning the promotion of good governance across the respective BRICS nations. However, simply enhancing governance quality may not be sufficient in greening the economic growth process and undergoing the clean energy transition unless fossil fuel reliance is substantially reduced. For instance, despite enacting strong laws for reducing fossil fuel consumption in order to limit CIEU and CIEO levels, the lack of scope to switch from fossil fuels to renewable energy resources is likely to prevent the reduction in carbon intensity levels via the channel of good governance-induced institutional quality improvement. Hence, it is once again apparent that designing policies that can ease the process of reducing fossil fuel reliance is of immense relevance in greening economic outputs and cleaning the energy systems of the BRICS countries.

Fourthly, the introduction of green financial schemes is imperative for the BRICS nations to gradually plunge the carbon intensity-increasing impacts associated with financial development. Since traditional policies for developing the financial sector are primarily focused on enhancing financial inclusivity and boosting private-sector borrowings, these policies have largely neglected the corresponding issue of environmental degradation that can be caused by investing the credited funds in polluted industries, in particular. Thus, in the contemporary context, greening the financial sector is more important so that private borrowings and the corresponidng investments are environmentally sustainable. In this regard, the concerned governments should waive interest on loans taken for investment in green industries, especially the renewable energy sector. At the same time, the interest rates levied on funds borrowed for investing in pollution-intensive projects should be increased so that these types of borrowings, which are not environmentally sustainable, can be contained.

Lastly, regarding international trade, the BRICS nations should reform their trade liberalization policies as well. Notably, these nations need to raise the tariff and non-tariff barriers that are imposed on fossil fuel imports. However, this action can compromise their energy security statuses. Hence, the tariff and non-tariff barriers should be gradually increased until the point that the indigenous renewable energy sectors in these countries are sufficiently developed. More importantly, the concerned government should allow tax-free, duty-free, and quota-free imports of renewable electricity and intermediate goods that are employed within the renewable energy sectors. Furthermore, the BRICS governments should also encourage their export-oriented firms to become more energy productive and less pollution-intensive.

6.2. Limitations and research directions

This study has utilized panel data concerning the BRICS countries for evaluating the factors influencing their carbon intensity levels. Thus, it is unclear whether the identified factors would homogeneously impact the respective carbon intensity figures of the individual members of the BRICS bloc. In this regard, country-specific analysis can be conducted in the future to check the robustness of the findings reported in this study. Besides, although the FDI influx-carbon intensity nexus was evaluated using a quadratic function, it is also not clear whether this nexus may change further. Thus, future studies can look to re-investigate this nexus

using a cubic function to check whether the relationship between net receipts of FDI and carbon intensity levels depicts an N-shape. Furthermore, this study has presented insights from the perspective of emerging (or underdeveloped) nations but has not explored the carbon intensity level-determining factors from the viewpoints of developed nations. Hence, a counterfactual analysis can be conducted using data from a group of developed nations for testing the homogeneity of the findings across alternate samples of underdeveloped and developed nations. Furthermore, separately investigating the carbon intensity-influencing effects of the six governance-related indicators used in this study can be interesting to understand why institutional quality improvement was found to be ineffective in abating the carbon intensity figures of the BRICS nations.

Ethics approval

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Consent to participate

Not applicable.

Consent for publication

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Data availability

Data will be made available on request.

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