



Human Capital Development, Foreign Investment, and Renewable Energy: Pathways to Environmental Sustainability in BRICS Economies

Fatima Farooq¹, Muhammad Faheem², Said Zamin Shah³ & Momina Sardar Gul⁴

¹Associate Professor, School of Economics, Bahauddin Zakariya University, Multan, Pakistan,

Email: fatimafarooq@bzu.edu.pk

²Assistant Professor, School of Economics, Bahauddin Zakariya University, Multan Pakistan,

Email: faheem@bzu.edu.pk

³Department of Economics, Islamia College University Peshawar, KP, Pakistan, Email: szshah@icp.edu.pk

⁴M.Phil Economics, University of Peshawar, Email: momina1891@gmail.com

ARTICLE INFO			ABSTRACT
Article History:			<i>This study explores the effect of human capital, foreign direct investment (FDI), renewable energy, and gross domestic product (GDP) on environmental sustainability in BRICS countries over the period 2000–2023. Using the DCCE estimator to account for cross-sectional dependence and heterogeneity, the results show that human capital and renewable energy significantly lower CO₂ emissions, highlighting their key role in environmental sustainability. In contrast, FDI and GDP growth contribute to higher CO₂ emissions, suggesting that economic expansion and foreign investment, in their current forms, may undermine environmental quality in the BRICS region. These results offer important policy implications. First, investment in human capital should be prioritized, with a focus on education, environmental awareness, and clean technology skills. Second, BRICS countries must accelerate the shift to renewable energy through supportive policies, infrastructure development, and incentives. Third, governments should encourage green FDI by imposing environmental standards and offering incentives for sustainable projects. Fourth, growth strategies must integrate environmental concerns, emphasizing low-carbon sectors and sustainable practices. Lastly, regional cooperation among BRICS nations can facilitate shared innovation and joint climate action. Aligning economic development with sustainability goals is crucial for ensuring long-term ecological resilience in these emerging economies.</i>
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Corresponding Author:			
Muhammad Faheem			
Email:			
faheem@bzu.edu.pk			



Introduction

Although issues of the environment are human-induced, the fall of environmental standards is one of the central problems for the world over the last decade (Tanveer et al., 2025). Developed countries are contributing to environmental pollution on a large scale by disturbing the natural functioning of ecosystems. BRICS countries have made significant progress through active government policies and environmental resource consumption. Countries like China, Brazil, Russia, South Africa, and India, are remarkable contributors in the economy and policy exchange of the world. These are the most industrialized states and contribute about 25% share of GDP and 50% share of population to the world (Wei et al., 2024). On the other side, they are also sharing a major part of carbon dioxide emissions with the world. For BRICS, environmental sustainability is one of the top priorities in policymaking due to more dependency on fossil fuels for economic expansion. Multiple countries have joined the Paris Agreement (2015) to implement policies to limit greenhouse gas emissions to less than 2°C, but a nonstop increase in pollution level is a major concern for economies that are highly dependent on fossil fuels for their growth (Udeagha and Npukah, 2023; Farooq et al., 2025). To avoid catastrophic and extreme climate events, the level of greenhouse gas must be reduced (Masood et al., 2023; Asghar et al., 2024; Sajid et al., 2025). To deal with this issue, countries are focusing on green growth projects and fintech for an eco-friendly globe. Protection of the environment is crucial because it is a common medium for the whole world. A low level of pollution is required for the preservation of ecosystems, biodiversity, and natural areas that is possible by environmental policy restrictions. The ecosystem, with its natural commodities, is capable of reducing global warming by absorbing extra carbon dioxide in the atmosphere. Therefore, environmental legislation benefits pollution reduction strategies by raising awareness about climate change and its consequences. According to the Porter hypothesis, environmental regulations can control pollution costs by increasing green growth (Porter and Linde, 1995), but results of this hypothesis are inconsistent in different sample countries (Lena et al., 2022).

Human capital is a vital parameter in the process of production (Feng and Cheng, 2016; Farooq et al., 2025). Improved human capital guarantees better social, environmental, and economic status. Human capital can be general human capital, task-specific human capital, and firm-specific human capital. They can be accumulated by experience, education, firm and task-related training, skills, and knowledge (Kwon, 2009). Human capital is a vital factor influencing both the environment and economic welfare (Khan et al., 2021). Environmental pollution is linked with human activities. HC can help in achieving environmental sustainability without hindering economic progress. It contributes to improving environmental performance through modernization and unique pollution-free applications in transport, firms, and households. It also contributes to economic progress by following the rules of the state, promoting equality, and having a low crime ratio. HC helps in minimizing energy consumption by providing understanding about energy security and pollution challenges. HC can reduce carbon dioxide emissions by more energy efficiency (Kwon, 2009) through better working conditions. Educated human capital can promote technological innovation and clean production for effective management of the environment. Education, skill, training, competency, knowledge, and experience can enhance the productivity of human capital. Better education and skills help HC to curb environmental pollutants to control global warming (Ireland and Clausen, 2019). There are two approaches regarding HC and environment. One is 'promotion perspective' confirming that HC can lessen carbon emission level by firm innovation (Yin et al., 2021). Another approach is the 'inhibition perspective,' claiming that HC increases pollution levels by hampering innovation in firms (Khan et al., 2020). The relation can fluctuate from region to region. Human beings impact the world environment by production and consumption activities.

There has been a growing attention in the association amid environmental sustainability and foreign direct investment, much of it around green FDI (Farooq et al., 2025). On the contrary, Green FDI is an investment with social goals and determining economic returns, environmental protection, and sustainability. This dual focus is especially important as the growth in China's traditional FDI has traditionally been accompanied by environmental degradation because of increased CO₂ emissions and other pollutants (Hu et al., 2018; Ali et al., 2022; Ly-My et al., 2023). However, the potential for FDI to promote environmental sustainability through green innovation and adopting cleaner technologies is also realized (AlMazrouie & Nobanee, 2020; Ali et al., 2022; Yuan & Yin, 2024). The empirical studies concerning the environmental impact of FDI present mixed results. However, green innovation can dampen the adverse effects on such economies and enhance environmental quality (Ali et al., 2022). Like in China, Yuan and Yin (2023) have also found that green FDI significantly alleviates local air pollution, particularly in areas where environmental policies are very important. This implies that the environmental outcomes of FDI are very context-dependent and mediated by issues similar to nearby rules and the nature of FDI, whether inexperienced subjects or mergers and acquisitions (Ly-My et al., 2023; Xiao et al., 2023). In addition, the impact of FDI on green economic growth will be moderated by the role of environmental regulations. The results show that stringent environmental regulations in China can help increase the optimistic possessions (Hu et al., 2018). That demonstrates the need for regulatory frameworks that safeguard FDI for sustainable development. The interplay between FDI, green innovation, and environmental sustainability has also been examined in South Asia. Previous studies find that although FDI would result in environmental quality degradation, combining green innovation can greatly improve ecological sustainability (Brohi & Suzuki, 2023).

Environment plays a significant role in sustainable growth. BRICS countries contribute a major part to the global economy, population, foreign exchange (Udeagha and Ngepah, 2023; Sibte-Ali et al., 2025) and CO₂ emissions. To address the environmental issues, there is an urgent need for green growth, fintech, and green finance in BRICS. BRICS nations are promoting their investment in green growth with investment in fintech and human capital to lessen the level of environmental effluence (Lisha et al., 2023). FDI invests in environmental regulations and green infrastructure to foster economic development. Human capital developed through skills and education drives the fintech advancement, promoting investment in green and sustainable projects. With more green growth, economic expansion takes place, attracting more FDI and creating opportunities for the growth of human capital. Efficient environmental policy and regulations to ensure green technologies improve the role of fintech and human capital in sustainable growth.

Literature Review

Human capital acts as a foundation stone for the prosperity of a state. Humans are significant players in nature and can contribute in positive and negative ways to the growth of a country. Educated and skilled capital can reduce environmental pollution by advancing innovation and technology. Bayar et al. (2022) illustrated the role of human capital and institutions on the environment. Secondary data between 2000 and 2018 from EU transition economies was used in the research full stop. The study applied coin decoration analysis to obtain results. According to findings, human capital showed a negative relation with CO₂ in Slovenia, Hungary, Croatia, and the Czech Republic and a positive relation in Latvia and Lithuania. The nexus amid human capital and environmental sustainability was explored by Sibanda et al. (2023). The study employed PMG by utilizing data from 1980 to 2021 in the Southern African development community. Empirical results found that human capital upsurges environmental sustainability in the long run through human capital programs, technological advancement, research, and development in the region. 1% upsurge in human capital will lower carbon dioxide emissions by 1.627 78% in Sri Lanka (Adikari

et al., 2023). The study found a long-run relation between human capital and CO₂ emissions using ARDL between 1978 and 2019. According to Yao et al. (2021), human capital and environmental pollution are negatively linked in the long run. Findings presented that pollution level can be reduced to 12% by increase in one-year average school in China. A study investigated in 78 developing countries from 1990 to 2016 by Jahangir et al. (2023) also indicated negative influence of human capital on CO₂ in all developing countries. Using two-stage least squares GMM, a positive role of globalization on CO₂ was observed in Latin America and the Caribbean while corrupt pollution was seen in Asia and Africa. More human capital and globalization can boost levels of carbon dioxide emissions. Bano et al. (2018) studied the link between human capital and CO₂ emissions in the long and short term using analytic techniques including ARDL and VECM. The outcome of the paper demonstrated reduced environmental pollution through education in Pakistan in the long run.

Quality of environment can be improved in the long run by better GDP and human capital (Rahman et al., 2021). The study used data from 1979 to 2017 and applied DOLS, FMOLS, and PMG. The result found EKC hypothesis not proved in newly industrialized countries. Using information from 1995 to 2018, Isiksal et al. (2023) analyzed the association between CO₂ emissions and human capital in a Central Asian state. One-way causality using PMG and DH tests was found. The author's empirical finding presented that human capital with training and education has a significant influence on the environment. Li and Ullah (2022) also focused on the contribution of skilled and educated capital to the environment in BRICS. The research applied nonlinear panel ARDL between 1991 and 2019 for a valid result. According to the conclusion of the study, optimistic change in education can lower the level of environmental pollution in Russia, China, and South Africa, while negative change in education leads to a higher pollution level in Brazil.

Studies of the relationship between foreign direct investment (FDI) and environmental sustainability have produced diverse results. Gao et al. (2022) performed a panel data analysis of China data from 2004 to 2019 and concluded a positive relationship between FDI and green total factor energy efficiency. They find that FDI promotes adopting cleaner and more energy-efficient technology in host regions. Similarly, Li and Xiao (2024) tested mechanisms and intermediary effect tests on China's urban green business environment. They discovered that FDI facilitates a conducive environment for urban green business. They conducted an empirical analysis involving Chinese firms. They claimed that the influence of FDI on domestic environmental performance can possess two paths: positive if the FDI allows direct access to advanced technologies and practices. Soto (2024) extended the analysis to the Latin American case, using cointegration regression analysis from 1990 to 2022. It was found that FDI facilitates the transition of green economies in the region as FDI facilitates resource allocations and technology transfer. Using OECD-REGPAT and FDI Markets, Castellani et al. (2022) examined the regional specialization in environmental technologies in European regions from 2003 to 2014. The research also indicated how FDI helps innovation and specialization in green technologies.

As a quasi-natural experiment in China, Chen et al. (2021) use mixed impact to explore the relationship between green finance and FDI. FDI involves investment in green projects, but certain negative externalities may eliminate some benefits. Using SYS-GMM for 2003–2017, Luo et al., (2021) examined green innovation in China. While stimulating innovation, FS ventures depend on the combination of regional policies and industry capabilities. According to the Spatial Durbin Model (SDM) used by Zheng et al. (2022), it also finds that FDI spillovers are positive and negative in China's marine green economy. Using Geweke causal decomposition and Granger causality tests, Li et al. (2022) investigated green development performance in 77 developing

countries, and a non-trivial relationship was uncovered. They noted that FDI promotes green development, which calls for strong institutional frameworks. Kharb et al. (2024) studied environmental sustainability in developing countries as fixed and random effect models. However, FDI's benefits differed greatly depending on country-specific contexts and environmental policies, as found in their findings. Using DOLS and FMOLS techniques, Zamir and Mujahid (2022) explored the association of FDI with the economic growth of South Asian countries from 2000 to 2020. The results showed that FDI promotes economic growth but may only sometimes align with environmental objectives. Using panel data approaches, Qamri et al. (2022) scored environmental degradation in 21 Asian countries from 1980 to 2018 and found mixed results. Looking at their study, they have pointed out that FDI always brings advanced technologies, which could also aggravate resource exploitation and emissions. Behera and Sethi (2022) developed the GMM model, Dumitrescu-Hurlin panel causal tests, and random effect to study green technology innovation in OECD countries. According to their findings, FDI stimulates green innovation, but they stress the need for targeted policy intervention. According to Demena and Afesorgbor (2020), FDI has an elasticity that can change with regions and industries when they did a meta-analysis on the effect of FDI on environmental emissions. In Uche et al. (2023), study look at the environmental performance in BRICS economies. The findings were mixed: FDI boosted ecological performance in some but created challenges in others.

Methodology

This study examines the long-run impact of human capital, foreign direct investment (FDI), renewable energy, and GDP on environmental sustainability in BRICS countries over the period 2000–2023. Given the possibility of cross-country economic interdependence, the analysis addresses three key econometric issues commonly found in panel data.

Table 1: Variable Description

Variable	Measurement	Symbol
Gross Domestic Product	GDP (constant 2015 US\$)	GDP
CO ₂	Carbon dioxide (CO ₂) emissions (total)	CO ₂
Human Capital	School enrollment, secondary (% gross)	HUC
Renewable energy consumption	Renewable energy consumption (% of total final energy consumption)	REN
Foreign direct investment	Foreign direct investment, net inflows (% of GDP)	FDI

Data source is World Development Indicator (WDI)

Model specification is as following:

$$CO_2 = f(HUC, FDI, REN, GDP) \quad (1)$$

$$CO_{2it} = \gamma_{it} + \beta_1 HUC_{it} + \beta_2 FDI_{it} + \beta_3 REN_{it} + \beta_4 GDP_{it} + \varepsilon_{it} \quad (2)$$

To begin, we assess cross-sectional dependence using the Pesaran (2004) CD test, which checks for contemporaneous correlation among panel units. The presence of significant CSD necessitates second-generation panel techniques. Additionally, to evaluate parameter homogeneity across

countries, we employ the slope homogeneity test proposed by Pesaran and Yamagata (2008). The rejection of slope homogeneity justifies the use of heterogeneous panel estimators, such as DCCE.

Since nonstationary data can yield spurious regressions, we apply the Cross-sectionally Augmented Im-Pesaran-Shin (CIPS) unit root test developed by Pesaran (2007). This second-generation test accounts for CSD by augmenting the standard ADF regression with cross-sectional averages of lagged levels and first differences. The results of the CIPS test inform the order of integration of each variable and are essential for proceeding with cointegration analysis.

To investigate the existence of a long-run equilibrium relationship among the variables, we use the Westerlund (2007) cointegration test, which is robust to both cross-sectional dependence and structural breaks. Unlike traditional residual-based tests, the Westerlund test does not rely on common factor restrictions and is well-suited for heterogeneous panels.

Given the presence of CSD, heterogeneity, and cointegration, the study applies the Dynamic Common Correlated Effects (DCCE) estimator developed by Chudik and Pesaran (2015). The DCCE model includes cross-sectional averages and their lags of both the dependent and independent variables to mitigate the impact of unobserved common factors and global shocks (Khan et al., 2025).

$$y_{it} = \gamma_{it} + \beta x_{it} + \sum_{l=0}^p \gamma_{il} \bar{z}_{t-l} + \varepsilon_{it} \quad (3)$$

where y_{it} is CO₂ emissions, x_{it} includes human capital, FDI, renewable energy, and GDP, and $\bar{z}_{t-1}$ represents cross-sectional averages of all variables and their lags.

Results and Discussions

The descriptive statistics show high variability in CO₂ emissions and GDP, with both being positively skewed and non-normally distributed (Jarque-Bera $p < 0.01$). Human capital (HUC) is more symmetrically distributed and nearly normal. FDI also exhibits skewness and heavy tails, indicating occasional extreme values. Renewable energy (REN) is moderately skewed and non-normal. The correlation matrix reveals that CO₂ emissions are strongly correlated with GDP (0.97), weakly negatively correlated with HUC and REN, and almost uncorrelated with FDI. These results suggest economic output drives emissions, while human capital and renewable energy may help reduce them.

Table 2: Descriptive Statistics and Correlation Matrix

	CO ₂	GDP	HUC	FDI	REN
Mean	3057.625	3.10E+12	87.62180	2.181556	20.53767
Median	1750.144	1.48E+12	89.40417	2.002063	13.50000
Maximum	13259.64	1.76E+13	122.3883	9.660265	50.00000
Minimum	347.2973	2.22E+11	45.42105	-1.736810	3.200000
Std. Dev.	3665.770	4.13E+12	18.05609	1.487492	15.70265
Skewness	1.573354	2.091860	-0.333380	1.198631	0.526246
Kurtosis	4.044278	6.389928	2.337993	7.869758	1.714794
Jarque-Bera	47.17522	124.4374	3.788779	126.4386	11.84283
Probability	0.000000	0.000000	0.150410	0.000000	0.002681
CO ₂	1				
GDP	0.9661	1			

HUC	-0.2619	0.3712	1		
FDI	0.0453	0.0011	0.0208	1	
REN	-0.1861	0.0941	0.4158	0.1081	1

The results of the Pesaran CD test indicate significant cross-sectional dependence for all variables CO₂ emissions, HUC, FDI, REN, and GDP, since all test statistics are highly significant at the 1% level. The CIPS panel unit root test reveals that none of the variables are stationary at level (I(0)), as the test statistics are insignificant. Though, all variables converted stationary after first differencing (I(1)).

Table 3: Results of Cross – Sectional dependence test and panel unit root test

Pesaran CD Test Results					
Variable	CO₂	HUC	FDI	REN	GDP
	9.8026 (0.0000)*	9.5748 (0.0000)*	13.6375 (0.0000)*	4.9397 (0.0000)*	14.9278 (0.0000)*
CIPS Unit Root Test					
I(0)	0.8690	-0.4537	-0.1321	-0.6459	-0.4356
I(1)	3.6758*	-4.8675*	-4.6130*	-5.0342*	-2.7612*

Note:* & ** shows one & five percent significance level

The results (see table 4) of the slope homogeneity test indicating the presence of slope heterogeneity across panel units, meaning the associations between variables vary across countries. Additionally, the Westerlund cointegration test confirms a long-run equilibrium relationship among the variables.

Table 4: Slope homogeneity test & westerlund cointegration test

Slope Homogeneity Test		
	Delta	Adj. Delta
	9.6754 (0.0000)*	12.0579 (0.0000)*
Westerlund Cointegration Test	Statistic	p-value
	123.4756	(0.0000)*

Note:* & ** shows one & five percent significance level

The results of table of DCCE findings reveal significant insights into the association between human capital, FDI, renewable energy, GDP, and CO₂ emissions. In the long run, human capital (HUC) exhibits a strong negative effect on emissions in both models, indicating that improvements in education and skills contribute to environmental sustainability. Foreign direct investment (FDI) increases emissions in Model 1, suggesting that foreign investments may initially flow into pollution-intensive sectors. However, in Model 2, where the interaction term (FDI*HUC) is included, the positive impact of FDI diminishes significantly, while the interaction term shows a strong negative effect, implying that higher levels of human capital can mitigate the environmental harm associated with FDI. Renewable energy (REN) consistently demonstrates a substantial long-run negative effect on CO₂ emissions, particularly in Model 2, confirming its critical role in promoting a green economy. GDP shows an insignificant positive impact in Model 1 but becomes

negative and significant in Model 2, suggesting that economic growth aligned with human capital development and green policies can help reduce emissions.

In the short run, similar patterns are observed. Human capital reduces emissions significantly in both models, with a stronger effect in Model 2. FDI has a positive and significant impact in Model 1, but becomes insignificant when interacting with human capital, indicating that knowledge-based FDI is less harmful to the environment. Interestingly, renewable energy shows a positive short-run effect in Model 2, which may be attributed to the initial environmental costs of renewable energy infrastructure development. GDP increases emissions in the short term, highlighting growth-driven environmental pressure. Notably, the interaction term (FDI*HUC) has a strong negative effect, suggesting that when FDI is accompanied by skilled human capital, it can effectively contribute to reducing emissions. Overall, the findings underscore the importance of investing in human capital and renewable energy while channeling FDI into knowledge-intensive sectors to achieve sustainable development goals.

Table 5: Results of DCCE

Long Run	Model 1	Model 2
HUC	-0.406* [0.081]	-0.973* [0.306]
FDI	2.669* [0.245]	0.525* [0.218]
REN	-0.489* [0.055]	-2.698* [0.686]
GDP	0.050 [0.111]	-0.838* [0.309]
(FDI*HUC)	---	-0.318* [0.039]
Short Run		
D(HUC)	-0.298* [0.102]	-0.655* [0.044]
D(FDI)	0.584* [0.218]	0.1173 [0.244]
D(REN)	-0.087** [0.035]	1.312** [0.542]
D(GDP)	0.360* [0.098]	0.526* [0.241]
D(FDI*HUC)	---	-1.990* [0.124]

Note: * & ** denotes significance level at 1 & 5%. [] values shows standard errors.

Concluding Remarks

The study examines the impact of human capital (HUC), foreign direct investment (FDI), renewable energy (REN), GDP, and their interaction on CO₂ emissions in BRICS, using DCCE methodology over 2000-2023. The findings reveal that human capital significantly mitigates emissions in both time horizons, underscoring the importance of education and skill development in fostering environmental sustainability. FDI, while initially contributing to higher emissions,

becomes environmentally neutral when combined with strong human capital, as indicated by the negative and significant effect of the interaction term (FDI*HUC). This suggests that the environmental impact of FDI depends on the absorptive capacity of the host economy. Renewable energy consistently exhibits a substantial long-run negative effect on emissions, confirming its pivotal role in green transition, though short-run implementation costs may temporarily increase emissions. GDP shows an optimistic impression on emissions, highlighting growth-induced environmental pressures, but turns negative in the long run under sustainable growth frameworks. Overall, the results emphasize the synergistic role of human capital, renewable energy, and sustainable investment strategies in achieving low-carbon development pathways for BRICS countries.

BRICS economies should prioritize funds in education, technical training, and skill development programs to augment the quality of human capital. A well-educated workforce improves environmental cognizance and facilitates the implementation of cleaner technologies, reducing the carbon intensity of production. Policymakers should design targeted incentives for attracting FDI in green sectors such as renewable energy, clean technology, and energy-efficient industries. Environmental standards and green certification mechanisms should be integrated into FDI policies to ensure that foreign investments bring into line with sustainability goals. Governments should accelerate investments in renewable energy projects by providing subsidies, tax incentives, and low-interest financing for solar, wind, and hydropower projects. Regional cooperation among BRICS nations in renewable technology transfer and joint ventures can further scale up green energy adoption. BRICS policymakers should adopt a holistic approach that links human capital development with FDI strategies. Encouraging knowledge-intensive FDI and fostering research and development (R&D) collaborations between multinational corporations and local institutions can help reduce the environmental footprint of industrial growth. While economic growth remains a priority, BRICS economies should implement strict environmental regulations and carbon pricing mechanisms to decouple GDP growth from emissions. Incentivizing cleaner production processes and penalizing polluting industries will be essential for sustainable growth. Given that renewable energy deployment may cause temporary emissions during infrastructure development, governments should complement these projects with carbon offset mechanisms and stringent monitoring to minimize transitional environmental costs.

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