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The impact of poverty on the ecological footprint in BRICS countries: A pane ARDL approach

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Abstract

This paper explores the relationship between poverty and ecological footprint in BRICS nations. Data for BRICS was gathered from the World Bank's World Development Indicators, Global Footprint Network, Worldwide Governance Indicators (WGI) and PovcalNet for the period 1996 to 2017. Panel autoregressive distributed lag (PARDL) analysis, along with corresponding preliminary cross-sectional dependence and second-generation specification tests were used to analyze the data. The estimates from the full sample support existing literature, revealing a strong long-run relationship between poverty and ecological footprint. Specifically, the results show that poverty decreases ecological footprint in the long-run, confirming a trade-off relationship between poverty and ecological footprints. However, when China is excluded from the full sample, the effect of poverty on ecological footprint becomes positive. Our results are consistent across various measures of ecological footprint and poverty, as well as alternative empirical specifications. With environmental degradation on the rise in some BRICS countries and persistent poverty in others, our study highlights the important role these developing nations play in global environmental outcomes. Policymakers are faced with significant challenges in aligning growth trajectories with sustainable environmental practices.

Keywords: BRICS; Poverty; Ecological Footprint; Environmental Economics; PARDL

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1. Introduction

The Sustainable Development Goals (SDGs) are 17 goals set by the United Nations to achieve specific economic, social, and environmental targets by 2030 (United Nations, 2015). These 17 SDGs are recognized as interconnected (van Soest et al., 2019) and achieving them can lead to trade-offs (Zhang et al., 2022). Among these interconnections are goals related to climate action and poverty alleviation. Both poverty allevation and climate action are at the forefront of policy objectives for developing countries and are considered to have strong interplays, especially in the context of BRICS nations (Brazil, Russia, India, China, and South Africa).

While some BRICS countries have made significant progress in poverty alleviation, with the number of working poor falling by more than 540 million between 2000 and 2019, there has also been a significant shift from an ecological surplus to an ecological deficit in BRICS countries, mainly due to rapid economic transformation (Nathaniel et al, 2021). The BRICS region now consumes more than 40% of the world's energy making it a major contributor to CO_2 emissions (Lin et al., 2021). Notably Nathaniel et al. (2021) empirically shows that economic growth and natural resource utilization increase the ecological footprint in these regions, highlighting a critical trade-off between poverty allevation and climate action. Moreover, BRICS nations heavy reliance on fossil fuels complicates efforts towards environmental sustainability (Caglar et al., 2022).

Although a substantial body of literature has explored these interconnections and trade-offs, there remains a need for more quantitative studies to assess the interconnections between different SDGs (Wei et al., 2023).While many studies have included BRICS members in their analysis (Finco, 2009; Koçak et al, 2019; Khan, 2021), these studies do not specifically focus on BRICS countries collectively, which would provide vital information on relationship between the ecological footprint and poverty in these nations. This paper aims to provide a focused assessment of the relationship between poverty and ecological footprint within the BRICS economic group.

The study aims to contribute to the existing literature on ecological footprints by making several key contributions. First, we aim to assess the poverty-environment nexus for BRICS countries, a task that has not been done for this specific group of countries. Since government regulations play a significant role in reducing poverty while considering environmental sustainability, the results should offer valuable insights for policymakers regarding the poverty-ecological footprint trade-off in BRICS countries. Additionally, the relationship between poverty and ecological footprints depends on factors like institutional quality (Rizk and Slimane, 2018; Koçak et al, 2019), which vary by country and complicate the relationship between ecological footprints and poverty. We also utilize second-generation unit root tests to account for cross section dependence and conduct several robustness checks to confirm the validity of the results for our full BRICS model and individual country level estimates. We employ various poverty and ecological footprint measures in our analysis, along with alternative empirical specifications to assess the relationship between poverty and ecological footprint in BRICS nations. Lastly, we conduct an analysis excluding China from the full sample to further assess the robustness of the results.

2. Literature review

In the past, a vast number of studies have focused on the impact of poverty on the ecological footprint in developed and developing countries. These studies show a causal relationship between poverty and the ecological footprint (Islam and Ghani, 2018; Khan, 2019; Koçak et al, 2019; Khan, 2021; Baloch et al, 2020). The theory behind this relationship can be derived from the popular Environmental Kuznets Curve (EKC). The EKC suggests an inverted U-shaped relationship between environmental degradation (led by higher ecological footprints) and income or economic development (Begum et al. 2015; Dogan and Seker 2016). According to the EKC, as a country's income initially increases, so does its environmental degradation. However, beyond a certain income threshold, further economic development leads to a decline in environmental degradation. In the context of poverty allevation, the EKC suggests that lifting people out of poverty, through economic development, could initially come at a cost of higher environmental degradation. But eventually the reduction in poverty will lead to lower environmental degradation, as those leaving poverty gain the means to invest in cleaner technologies, improve infrastructure, and pursue sustainable practices.

Empirical evidence supports both a negative and positive relationship between poverty and environmental degradation. For example, Khan (2021), observing developing Asian countries, find that there is a negative relationship between poverty and the ecological footprint in these countries. While Koçak et al (2019) show for Sub-Saharan African countries that there is a clear trade-off between poverty and CO2 emissions. The study argues that economic conditions that lead to lower poverty levels would also lead to environmental degradation. Similarly, Islam and Ghani (2018) find a negative relationship between poverty and energy consumption for the Association of Southeast Asian Nations (ASEAN) countries between 1995 and 2014. These studies argue that fossil fuel intensive industrialization and industrial policies aimed at eradicating poverty are driving environment degradation, while a reduction of poverty also leads to higher energy consumption that further strains the environment.

In contrast others have shown that there is a positive relationship between poverty and environmental degradation. Baloch et al (2020) assessed the relationship between poverty and CO2 emissions for 40 Sub-Saharan African countries and shows that the increase in poverty leads to higher levels of CO2 emissions. While Khan (2019) found, using ASEAN countries, that there is a positive relationship between poverty and the ecological footprint. Similarly, Masron and Subramaniam (2019) assessed the environmental-poverty nexus for 50 developing countries between 2001 and 2014, finding a positive and significant relationship between poverty and environmental degradation. These studies mainly flag the survival needs of the poor on natural resources as one of the main sources of environmental degradation and focus on measures to reduce poverty that will enhance environmental protection and reduce the ecological footprint. In sum, there are still contradicting views on the ecological footprint-poverty nexus and there still remains uncertainty on how government should approach these two worldwide issues. A detailed summary of past empirical studies assessing the poverty-environment nexus can be found in Table 1.

Table 1. Relevant literature on poverty and ecological footprints

Authors	Country	Time	Model	Main result
Khan et al. (2022)	Asian developing countries	2006 -2017	Driscoll-Kray standard error model	Their findings show a significant positive impact of poverty on the ecological footprint

Table 1. *Cont.*

Authors	Country	Time	Model	Main result
Khan (2021)	Asian developing countries	2010-2016	Driscoll-Kray regression	The key finding shows that there is a negative relationship between poverty and the ecological footprint.
Baloch et al. (2020)	Sub-Saharan African countries	2010-2016	Driscoll-Kray standard error model	Their findings shows that an increase in poverty has a detrimental effect on environmental pollution.
Khan (2019)	Southeast Asian countries	2007-2017	Generalized method of moments	The results show that poverty has a significant and positive relationship with greater environmental degradation.
Koçak et al. (2019)	Sub-Saharan African countries	2010-2016	Panel quintile regression model	Their findings indicate that there is trade-off between poverty and CO_2 emissions. Showing that access to electricity reduces poverty but has a negative impact on the environment. However, their results show that institutional improvement help reduce both poverty and CO_2 emissions.
Masron and Subramaniam (2019)		2001-2016	Generalized method of moments	Empirical results demonstrate that poverty is one of the main drivers for environmental depletion.
Rizk and Slimane (2018)	146 countries	1996-2014	Three-stage least squares (3SLS)	A non-linearity relationship between poverty and CO_2 emission is found. However, an increase in institutional quality reduces poverty and added protection to the environment.
Islam and Ghani (2018)	ASEAN countries	1995-2014	Linear regression model	There is a positive relationship between poverty and environmental pollution.
Zaman et al. (2010)	Pakistan	1980-2009	Granger causality	Their findings report that rural poverty has a significant long-run impact on environmental degradation. While also finding uni-directional causality between poverty and the environment.
Finco (2009)	Brazil		Non-linear probit model	Empirical results demonstrate that the relationship between rural poverty and environment degradation is weak.

Table 1. *Cont.*

Authors	Country	Time	Model	Main result
Swinton and Quiroz (2003)	Peru	1999	Random-effects regression model	Their findings shows that the link between poverty and environmental degradation is strongly linked to deforestation.
Barbier (2000)	Various African countries		Case study	Their findings show the impact economic policies could impact the economic incentives for rural households decisions to conserve or degrade owned land.

3. Methodology

As indicated earlier, the aim of this paper is to determine whether poverty affects the ecological footprint in the BRICS countries. To this end, we follow previous studies in this field (such as Khan 2021) and use GDP per capita, its square term, poverty, FDI, and rule of law to accurately explain ecological footprint. Owing to the fact that institutional variables (such as the rule of law) is obtainable for the period 1996 and 2017, our study is limited to these years (1996-2017). Most of the variables are converted into a logarithmic form. The association poverty and ecological print, can be expressed as follows:

$$lnEF = \delta 0 + \delta 1 lnPOV + \delta 2 lnINLF + \delta 3 lnAE + \delta 4 lnGDP_{pc} + \delta 5 lnGDP_{pc}SQ + \delta 6 lnRoL + \delta 7 lnFD + \mu \quad (1)$$

where $\delta 0$ denotes the constant term and $\delta 1$, $\delta 2$, $\delta 3$, $\delta 4$, $\delta 5$, $\delta 6$ and $\delta 7$ signify the coefficients of the explanatory variables, with μ representing the disturbance term. The Ecological Footprint (EF) is our dependent variable of interest, serving as a comprehensive measure of environmental degradation. It encompasses six dimensions: carbon footprint, built-up land, grazing land, ocean area, cropland, and forest area. A high EF value indicates a significant strain on natural resources and serves as a negative signal of environmental sustainability. POV is the poverty rate (Head Count Poverty %), $INLF$ is the inflation consumer prices (annual %), GDP_{pc} denotes the real GDP per capita (constant 2015 US$), $GDP_{pc}SQ$ is the square of real GDP per capita (constant 2015 US$), FDI represents foreign direct investment (BoP, current US$), and AE represents access to electricity (% of population). The data for inflation, GDP per capita, FDI and AE are obtained from the World Development Indicators. Data for the rule of law comes from the Worldwide Governance Indicators (WGI), data for ecological footprint per capita comes from the Global Footprint Network (GFN) and data for poverty comes from PovcalNet.

3.1. Panel autoregressive distributed lag

To set the scene and prepare for empirical investigation certain specification tests were performed to detect cross-sectional dependence and unit roots in the series. Cross-sectional dependence cannot be ruled out in the sample of countries under study due to the interdependence of these countries (owing to the buying and selling of goods between them and spatial spillover effects). Existing studies have shown that cross-sectional dependency can affect the estimated coefficients. Therefore, appropriate statistical tools (cross-sectional dependence tests) were used to detect the problem in the series prior to the implementation of unit root test. After detecting the presence of cross-sectional dependence in the series the next appropriate step was to apply second-generational unit root tests to assess the stationarity of the variable in the presence of cross-sectional correlations. To analyze the short-run and long-run relationship between poverty and ecological footprint in the BRICS countries, a PARDL model was specified. The choice of PARDL was based on three reasons: (i) it is suitable for addressing cointegration, (ii) it allows for variables that follow I(0) and I(1) processes and(iii) it is robust in the presence of endogeneity. The PARDL model is expressed as follows:

$$\begin{aligned}\Delta lnEF_{it} = \Phi_0 \quad &+ \sum_{i=1}^{n} \Phi_{1it}\, \Delta lnEF_{it-i} + \sum_{i=1}^{n} \Phi_{2it} \Delta lnPOV_{it-i} + \sum_{i=1}^{n} \Phi_{3i} \Delta lnINLF_{it-i} \\ &+ \sum_{i=1}^{n} \Phi_{4it} \Delta lnAE_{it-i} + \sum_{i=1}^{n} \Phi_{5i} \Delta lnGDP_{pc_{it-i}} \\ &+ \sum_{i=1}^{n} \Phi_{6it} \Delta lnGDP_{pc}SQ_{it-i} + \sum_{i=1}^{n} \Phi_{7it} \Delta lnRoL_{it-i} \\ &+ \sum_{i=1}^{n} \Phi_{8it} \Delta lnFDI_{it-i} \\ &+ \Omega_1 lnEF_{it-1} + \Omega_2 lnPOV_{it-1} + \Omega_3 lnINLF_{it-1} + \Omega_4 lnAE_{it-1} \\ &+ \Omega_5 lnGDP_{pc_{it-1}} + \Omega_6 lnGDP_{pc}SQ_{it-1} + \Omega_7 lnRoL_{it-1} + \Omega_7 lnFDI_{it-1} \\ &+ v_{it} \qquad (2)\end{aligned}$$

where $\Phi_{1it}, \Phi_{2it}, \Phi_{3it}, \Phi_{4it}, \Phi_{4it}, \Phi_{5it}\ \Phi_{6it}, \Phi_{7it}$, represent the short-run estimated coefficients while Ω_1, δ_2, Ω_3, $\Omega_4, \Omega_{5,} \Omega_6, \Omega_7, \Omega_8$ signify the long-run estimated coefficients. The null hypothesis of no cointegration is H0: $\Omega_1 = \Omega_2 = \delta_3 = \Omega_4 = \Omega_5 = 0$. On the other hand, the alternative hypothesis of cointegration is expressed as follows: $\Omega_{1\neq}\ \Omega_2 \neq \Omega_3 \neq \Omega_4 \neq \Omega_5 \neq 0$. Similar to the standard ARDL the null hypothesis of no cointegration can be rejected if the critical values are exceeded by the F-statistics. On the other hand, if the F-statistics is less than critical values, then we fail to reject the null hypothesis of no cointegration, implying that the alternative hypothesis of cointegration can be accepted (Pesaran et al., 2001). The short-run dynamic parameters using panel error correction model (PECM) model with the long-run estimates specified as:

$$\begin{aligned}\Delta lnEF_{it} = \Phi_0 \quad &+ \sum_{i=1}^{n} \Phi_{1it}\, \Delta lnEF_{it-i} + \sum_{i=1}^{n} \Phi_{2it} \Delta lnPOV_{it-i} + \sum_{i=1}^{n} \Phi_{3i} \Delta lnINLF_{it-i} \\ &+ \sum_{i=1}^{n} \Phi_{4it} \Delta lnAE_{it-i} + \sum_{i=1}^{n} \Phi_{5i} \Delta lnGDP_{pc_{it-i}} \\ &+ \sum_{i=1}^{n} \Phi_{6it} \Delta lnGDP_{pc}SQ_{it-i} + \sum_{i=1}^{n} \Phi_{7it} \Delta lnRoL_{it-i} + \sum_{i=1}^{n} \Phi_{8it} \Delta lnFDI_{it-i} \\ &+ \delta_{it} ECM_{it-i} + v_{it} \qquad (3)\end{aligned}$$

where ECM is the error correction model or term. All other variables are as previously defined. As noted in Equation 2, Φ_{1it}, Φ_{2it}, Φ_{3it}, Φ_{4it}, Φ_{4it}, Φ_{5it} Φ_{6it}, Φ_{7it} represent the short-run estimated coefficients, while δ_{it} denote the speed of adjustment coefficient to equilibrium. If there is adjustment to equilibrium, the coefficient of the error correction model is expected to be negative and statistically significant.

4. Empirical results and analysis

Before delving into a discussion of the empirical regression results, it is helpful to first take a closer look at graphical representation of the series in order to understand the direction of the variables. Therefore, will begin the analysis by describing the trends of the ecological footprint for each member country within the BRICS community.

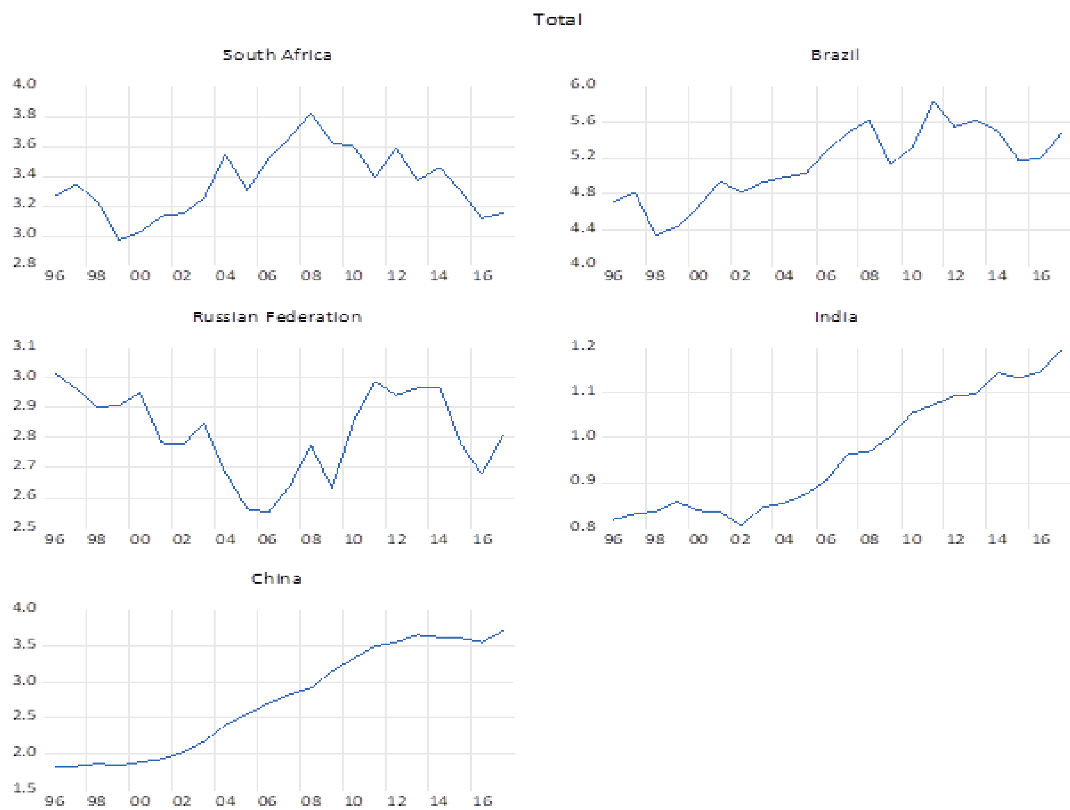

Figure 1. Trends in Ecological footprint for BRICS nations

In Figure 1, it is evident that the ecological footprint for China and India are trending upward. The reasons for the upward trends in China and India, the world's two most populous countries, can be attributed to population growth and increasing per capita ecological footprint (a measure of rising consumption). Similarly, Brazil has experienced a similar trend during the same period albeit with various fluctuations. The main contributing factor to these fluctuations is that Brazil is a unique case among the BRICS nations, as most of its emissions come from what's referred to as land-use change and forestry. However, South Africa and the

Russian Federation recorded a fair degree of fluctuation during the period under investigation. The reasons for this fluctuation may be due to environmental issues such as water and air pollution, land degradation and deforestation. Figure 2 sheds some light on the trends in poverty headcount for the BRICS nations as a whole. What emerges from this figure is a steady decline in poverty headcount in almost all BRICS countries. Additionally, there is a noticeable sharp decline in poverty head count for China. These results suggest that these countries have been effective in reducing the gap between the poor and non-poor. Therefore, the smaller gap, the easier it is for individuals to move out of poverty as they are closer to the poverty line than before. Moreover, most of these countries have prioritised the basic needs of vulnerable populations in their national development policies.

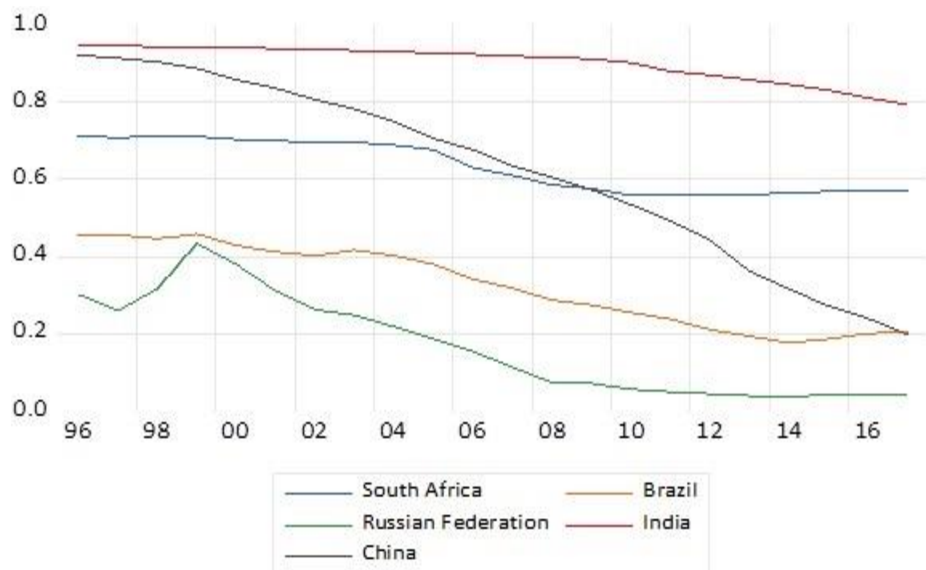

Figure 2. Trends in poverty headcount for BRICS nations

As noted earlier this study aims to investigate the relationship between ecological footprint and poverty in BRICS nations. Various statistical tools were employed to obtain meaningful and consistent estimates. We performed various test such as Breusch-Pagan LM (1980), Pesaran (2004) scaled LM and CD, and the Baltagi aet al. (2012) bias-corrected scaled LM tests. Table 2 presents the results of these tests, showing clear evidence of cross-sectional dependency in our panel dataset of BRICS nations. After identifying cross-sectional dependency, we proceeded to test for unit root. First generation unit root tests were not suitable as they assume cross-section units are cross-sectionally independent, potentially leading to inconsistent outcomes in the presence of cross-sectional dependency. Therefore, second-generation unit root tests (CIPS) proposed by Pesaran (2007) were conducted, with the results displayed in Table 3. According to Table 3, FDI, Inflation, and cropland are stationary at the level, while EF, POV, $lnGDP_{pc}$and $lnGDP_{pc}SQ$ are stationary at the first difference.

Table 9 in the appendix presents the descriptive statistics of the variables used in this study. EF ranged from 1.763062 to -0.215218, POV ranged from -0.556813 to -4.935157, GDP_{pc} ranged from 11731.38 to 652.5661, GDPpcSQ ranged from 18.74005to 12.96182, FDI ranged from 26.39634 to 20.12604, INLF varied from 47.75201 to -0.731971, AE from 4.605170 to 3.970358, and RULE OF LAW from 0.353991 to -1.097559.

Table 2. Test for cross-sectional dependence

Variables	BP LM	PSLM	BCSLM	PCD
lnEF	65.80623***	12.47865***	12.35961***	5.140933***
lnPOV	60.23591***	23.36646***	23.29503***	7.759172***
$lnGDP_{pc}$	61.45472***	23.86404***	23.79261***	7.837237***
$lnGDP_{pc}SQ$	61.50989***	23.88656***	23.81513***	7.840788***
lnFDI	19.59396***	6.774455***	6.703027***	4.399705***
$lnINLF$	1.163546	-0.749729	-0.82116	1.046555

**** and ** denote significance at the 1% and 5% significance*

Table 3. Second-generation panel CIPS unit root tests result

Variables	Level	First difference
lnEF	-1.56	-4.40***
lnPOV	-0.46	-2.28**
$lnGDP_{pc}$	-1.79	-3.04***
$lnGDP_{pc}SQ$	-1.79	-3.04***
lnFDI	-2.44**	-4.99***
$lnINLF$	-3.30***	-4.31***

**** and ** denote significance at the 1% and 5% significance levels*

4.1. Long and short-run estimates of PARDL approach

To confirm the impact of poverty on ecological footprint in the BRICS nations, the study utilized the PARDL estimation approach. Additionally, all variables in the PARDL model were transformed into logarithmic form, allowing the coefficients to be interpreted as elasticities, in line with the work of Khan et al. (2022). The empirical results of both the long-run and short-run estimates are presented in Table 4 below. However, the ARDL estimates in Table 4 will need to undergo diagnostic statistics to ensure the robustness of the results (refer to Table 5 and Table 6).

As shown in Table 4, poverty headcount reduces the ecological footprint in the long-run ARDL estimates. The results indicate that the ecological footprint decreases by -0.326 percent in response to a one percent increase in poverty headcount in the long-run. In the short-run, as poverty headcount increases by one percentage point, the ecological footprint increases by 0.189 percent, but the coefficient is insignificant. These results confirm a trade-off relationship between poverty and ecological footprints, suggesting that a decrease in poverty leads to an increase in environmental degradation in BRICS countries. This inverse relationship can be attributed to the industrialization process required to alleviate poverty, which results in significant CO2 emissions that harm the environment and contribute to environmental degradation (Jin et al., 2018). Our results align with previous studies on developing Asian countries by Khan (2021), developing countries by Dhrifi et al. (2020), and ASEAN economies by Islam and Ghani (2018), supporting the argument that poverty reduction through economic growth expansion leads to higher ecological footprints and environmental degradation. However, these findings contradict previous studies by Khan et al. (2019), Masron and Subramaniam (2019), Baloch et al. (2020), and Khan et al. (2022). In their recent study, Khan et al. (2022) applied the Driscoll-Kraay (D-K) regression approach to 18 developing Asian countries and found that a one-percentage increase in poverty headcount results in a 0.006 percentage increase in ecological footprint. The policy implications of these findings are significant and multifaceted, suggesting that policymakers in BRICS countries should focus on measures that address both poverty alleviation and environmental sustainability, such as investing in renewable energy sources, implementing green technologies, enforcing robust environmental regulations, and promoting incentives for clean energy consumption in urban and rural areas.

The results in Table 4 also show a negative and statistically significant relationship between GDP per capita (a proxy for economic growth) and ecological footprint in the long-run ARDL estimates, while the coefficients are positive but insignificant in the short-run estimates. The estimated coefficient value of -0.00025 in the long-run implies that a one percent increase in GDP per capita would reduce the ecological footprint by 0.00025, whereas the short-run estimate value of 0.00043 indicates that a one percent increase in GDP per capita would increase the ecological footprint by 0.00043. These results contradict those of Islam et al. (2022), who found that GDP per capita contributes to the ecological footprint by 0.829 percent in the long-run. However, our findings support those of Mikayilov et al. (2019) for Azerbaijan, Nathaniel et al. (2019) for South Africa, Khan et al. (2019) for Pakistan, Zhang and Da (2015) for China, and Alshehry and Belloumi (2017) for Saudi Arabia.

Interestingly, the GDP per capita square, a measure of economic growth, has a positive and statistically significant effect on the ecological footprint in the long-run, while the coefficient is negative in the short-run. Specifically, the results indicate that a percentage increase in GDP per capita squared increases the ecological footprint by 0.8162 percent in the long-run, while a percentage change in GDP per capita squared in the short-run reduces the ecological footprint by -0.7298 percent. These findings challenge the Environmental Kuznets Curve (EKC) hypothesis, which suggests a positive relationship between economic growth and ecological footprint in the initial stages of development, followed by a negative relationship as environmental awareness and practices improve. Our results support the rejection of the EKC hypothesis, aligning with studies by Begum et al. (2015) for Malaysia, Shafiei and Salim (2014) for 25 OECD countries, Zoundi (2017) for 25 African countries, and Destek et al. (2018) for 15 EU countries. We find that the relationship between economic growth and ecological footprint starts negative and becomes positive over time, indicating a failure to reach a turning point in the economic growth-environment relationship. The extensive literature on the EKC hypothesis highlights the heterogeneous dynamics of each stage for different countries and the various techniques used to determine threshold limits (Tatoglu and Polat, 2021).

Similar to other developing countries, initial growth stages may not be environmentally friendly, supporting the Environmental Kuznets hypothesis (Khan et al., 2022). Access to education enters with a negative but insignificant coefficient in the long-run equation, while the coefficient is positive and insignificant in the short-run.

Table 4. Panel ARDL estimation

Variable	*Coefficient*	*Std. Error*	*t-Statistic*
Long-run Equation			
lnPOV	-0.326666	0.095117	-3.434371
$lnGDP_{pc}$	-0.000253	4.83E-05	-5.248753
$lnGDP_{pc}SQ$	0.816250	0.108772	7.504218
lnAE	-0.204700	0.125858	-1.626440
lnFDI	-0.005226	0.006493	-0.804902
lnINFL	0.008102	0.000941	8.611859
Short-run Equation			
ECT	-0.596195	0.104216	-5.720758
Δln(POV)	0.189717	0.651540	0.291183
Δln (GDP_{pc})	0.000431	0.000239	1.804023
Δln ($GDP_{pc}SQ$)	-0.729862	0.501393	-1.455669
Δln (AE)	3.740541	3.160427	1.183555
Δln (FDI)	-0.015300	0.005364	-2.852362
Δln (INFL)	-0.003698	0.001515	-2.440074
C	-6.178430	0.974939	-6.337249
@TREND	-0.009089	0.007165	-1.268504

Foreign direct investment has a negative but statistically insignificant effect on ecological footprint in the long-run estimates. In short-run estimates, the coefficient is negative and statistically significant at the 5% level of significance. These results are expected, as the inflow of foreign direct investment and the BRICS trade associations with other nations have been steadily growing over the years. However, Solarin et al. (2021) discovered the opposite for Nigeria. The authors revealed that foreign direct investment add 0.03 percent to environmental degradation in Nigeria by increasing the ecological footprint. In contrast to the results for foreign direct investment, inflation adds 0.0081 percent to environmental degradation in BRICS nations by increasing the ecological footprint. In the short-run, inflation has a reducing impact of -0.0036 percent. Lastly it is interesting to note that the Error Correction Term (ECT) -which specifies the speed of adjustment from the short-run towards long-run equilibrium has the anticipated sign. Thus, the ECM coefficient enters with a negative sign of -0.596195 in the short-run equation.

4.2. Robustness check

The robustness check was performed on the results presented in Table 5. To determine the robustness of the results, we first used an alternative measure of poverty - poverty gap instead of poverty head count. Overall, there are noticeable similarities between the estimates obtained when using poverty head count and those found when applying poverty gap. The similarities are in terms of the level of significance and direction of the impact of explanatory variables on ecological footprint.

Table 5. Panel ARDL estimation

Variable	Coefficient	Std. Error	t-Statistic
Long-run Equation			
lnPOV	-0.244391	0.067604	-3.615046
$lnGDP_{pc}$	-0.000218	4.68E-05	-4.648639
$lnGDP_{pc}SQ$	0.693047	0.103656	6.686004
lnAE	-0.131732	0.129671	-1.015891
lnFDI	0.010398	0.007129	1.458568
lnINFL	0.008041	0.001007	7.981179
Short-run Equation			
ECT	-0.607713	0.116873	-5.199753
Δln(POV)	0.001949	0.229968	0.008476
Δln (GDP_{pc})	0.000312	0.000289	1.077790
Δln ($GDP_{pc}SQ$)	-0.692291	0.695569	-0.995288
Δln (AE)	4.960447	4.350726	1.140142
Δln (FDI)	-0.025054	0.008461	-2.961188
Δln (INFL)	-0.004279	0.001802	-2.374499
C	-5.691659	1.012670	-5.620445
@TREND	-0.008210	0.006372	-1.288474

Consistent with the results presented in Table 4, poverty gap enters with the predicted negative sign significant at a 5% level of significance in the long-run. In line with the results of the short-run equation presented earlier, poverty gap enters with a positive but insignificant coefficient, reinforcing the estimates of the model when using poverty head count. Other variables included in this estimation technique still follow the same pattern in terms of the direction of the impact and the level of significance as those reported earlier. These variables include among others GDP per capita (proxy for economic growth), GDP per capita square (square of economic growth). Although foreign direct investment has changed the direction of the impact in the long-run estimates presented in Table 5, the coefficient is still insignificant. In the short-run, foreign direct investment has maintained its negative and statistically significant impact on ecological footprint in the BRICS nations. The ECM coefficient, which indicates how variables are readjusted back to equilibrium, still enters with the expected negative sign. The coefficient of access to education follows the same trend and direction of the impact as revealed in Table 4. We can conclude that our results are not sensitive to the model used.

Table 6. Panel ARDL estimation

Variable	Coefficient	Std. Error	t-Statistic
Long-run Equation			
lnPOV	-0.556783	0.002531	-220.0280
$lnGDP_{pc}$	-7.26E-07	4.17E-07	-1.740539
$lnGDP_{pc}SQ$	0.054450	0.000361	150.6393
lnAE	-0.359348	0.008230	-43.66339
lnFDI	-0.011669	0.000490	-23.81170
lnINFL	0.023037	0.000214	107.6398
RULE OF LAW	0.746991	0.010458	71.43098
Short-run Equation			
ECT	-0.269737	0.136887	-1.970504
Δln(POV)	-0.270851	0.160382	-1.688785
Δln (GDP_{pc})	4.79E-05	0.000936	0.051129
Δln ($GDP_{pc}SQ$)	1.257057	2.258039	0.556703
Δln (AE)	4.203595	5.000276	0.840673
Δln (FDI)	-0.010345	0.018598	-0.556248
Δln (INFL)	-0.005210	0.002655	-1.962658
Δ (RULE_OF_LAW)	-0.160540	0.072489	-2.214684
C	0.141289	0.115735	1.220791

It is interesting to observe that controlling for institution does not qualitatively change the results. Even when using the rule of law as proxy for institutions, the results are largely similar as shown in Table 6 below. Some of the variables still mimic the same pattern and structure as before, though the impact of some control variables differs in terms of magnitude and significance level. For example, variables such as poverty gap, GDP per capita (as a proxy for economic growth), GDP per capita square (the square of economic growth), access to education and inflation still show present non-significant results in the long-run equation. The conclusions drawn earlier also apply to the results presented in this section. Some of the results in the short-run equation align with previous estimates. As evident from Table 6 below, the ECM coefficient enters with the expected negative sign of -0.269737 for the short-run equation Our results are consistent with those obtained by Uzar (2021) who found that institutions reduce the ecological footprint in China, India, Indonesia, and Russia. The rule of law, as a proxy for institution, enters with a positive and statistically significant coefficient in the long-run equation. In contrast, the rule of law enters with a negative and statistically significant coefficient, indicating that institutional quality decreases the ecological footprint for all BRICS countries.

Table 7. Panel ARDL estimation

Variable	Coefficient	Std. Error	t-Statistic
Long-run Equation			
lnPOV	-0.119022	0.019640	-6.060070
$lnGDP_{pc}$	-9.23E-05	1.73E-05	-5.348250
$lnGDP_{pc}SQ$	0.097894	0.059570	1.643346
lnAE	0.193827	0.077075	2.514802
lnFDI	-0.017959	0.003907	-4.596967
lnINFL	0.003324	0.000615	5.405378
Short-run Equation			
ECT	-0.565634	0.312268	-1.811374
Δln(POV)	-0.047674	0.026166	-1.821991
Δln (GDP_{pc})	0.000267	0.000145	1.838370
Δln ($GDP_{pc}SQ$)	-0.812742	0.396166	-2.051520
Δln (AE)	0.489455	0.393877	1.242659
Δln (FDI)	0.004488	0.004536	0.989412
Δln (INFL)	0.000117	0.000538	0.217912
C	-0.830506	0.482958	-1.719624
@TREND	-0.002956	0.002491	-1.186752

The results in Table 7 which use another measure as a component of ecological footprint (grazing land), indicate that the majority of variables included in this estimation technique still mimic the same pattern in terms of the direction of the impact and the level of significance as those reported earlier. Specifically, the results show that the coefficient of our variable of interest (poverty gap) has maintained its negative sign in both the long-run and short-run models. Therefore, a percentage change in the poverty gap leads to approximately a -0.119022 reduction in ecological footprint, which is statistically significant at the 1% level. These results are consistent with those presented earlier. The coefficient of ECM remains negative as expected and is statistically significant in the short-run model. The impact of various variables continues to align with those presented earlier.

Table 8. Panel ARDL estimation

Variable	Coefficient	Std. Error	t-Statistic
Long-run Equation			
lnPOV	0.214083	0.087756	2.439523
$lnGDP_{pc}$	-0.000272	8.22E-05	-3.314287
$lnGDP_{pc}SQ$	1.650579	0.318041	5.189824
lnFDI	0.012194	0.007841	1.555211
lnINFL	0.004069	0.001863	2.184307
lnAE	-0.188057	0.241352	-0.779180
Short-run Equation			
ECT	-0.673595	0.302499	-2.226770
Δln(POV)	0.097949	0.199119	0.491913
Δln (GDP_{pc})	4.66E-05	0.000444	0.104901
Δln ($GDP_{pc}SQ$)	-0.339837	1.211718	-0.280459
Δln (AE)	-0.026546	0.009489	-2.797535
Δln (FDI)	-0.004185	0.002746	-1.523991
	1.129162	0.912213	1.237828
C	-16.31008	7.611649	-2.142779
@TREND	-0.014699	0.010712	-1.372265

However, if we exclude China from the analysis, there are noticeable differences in the estimated coefficients can be observed, as shown in Table 8. These differences are evident in terms of both the direction of the impact and the level of significance. For instance, the poverty gap variable enters the model with a positive and statistically significant coefficient. Consistent with the findings of Khan et al. (2022), our results indicate that a one-percentage increase in the poverty gap leads to a 0.214083 percentage increase in ecological footprint. Other variables that have changed their signs include access to education and foreign direct investment. It is interesting to note that even when China is removed from the analysis, there is still a considerable degree of consistency with respect to other estimates, such as inflation, GDP per capita and GDP per capita squared. The results for most variables show that the signs of the long-run coefficients remain the same as those reported in the full sample of the ARDL model. The short-run results reveal that the ECM remains negative and statistically significant.

5. Conclusion

This paper investigates the relationship between ecological footprint and poverty while considering of GDP per capita, its square term, FDI, access to education and the rule of law within the BRICS countries (Brazil, Russia, India, China, and South Africa). The study used panel data covering the period 1990–2017 for the BRICS nations. The data for this study was extracted from various sources, such as the Worldwide Governance Indicators (WGI), the Global Footprint Network (GFN) and the PovcalNet. To estimate the short-run and long-run relationship between poverty and ecological footprint within the BRICS countries, a PARDL model was specified. The reason for choosing PARDL was threefold: (i) it is appropriate for addressing cointegration, (ii) it permits variables that follow I(0) and I(1) processes, and (iii) it is robust in the presence of endogeneity.

The results of the PARDL model showed an inverse relationship between ecological footprint and poverty head count in the long-run. The results suggested that ecological footprint diminishes by 0.326 percent in response to a one percent increase in poverty head count in the long-run. In the short-run, as poverty head count increases by one percentage point, ecological footprint escalates by 0.189 percent, but the coefficient was insignificant. This confirms the existing trade-off between poverty alleviation and environmental protection, two vital sustainable development goals. On the other hand, the study established a negative and statically significant relationship between GDP per capita (proxy for economic growth) and ecological footprint in the long-run model, while the coefficients were positive but insignificant in the short0run estimates. For the access to education variable, results surprisingly showed a negative relationship with ecological footprint in the long-run equation, while the coefficient was positive and insignificant in the short-run. Foreign direct investment had a negative but insignificant effect on ecological footprint in the long-run estimates, whereas in the short-run equation, the coefficient was negative and statistically significant at the 5% level of significance. An inverse relationship between ECT and ecological footprint within the BRICS nations was also found. Surprisingly, there were noticeable similarities between the estimates obtained when using poverty head count and those found when applying poverty gap, in terms of the level of significance and direction of the impact of many explanatory variables on ecological footprint.

Upon conducting a comprehensive analysis that involved decomposing the full sample and removing China from the regression, a noteworthy observation surfaced: the established negative correlation between the environment and poverty transformed into a positive association. These results are also robust when various other measures of ecological footprint, poverty and alternative empirical specifications are used. Moreover, the environmental-poverty nexus leads to a possible conflict of policies aimed at expanding economic activity, targeting poverty alleviation, and protecting the environment.

There are some limitations to our study that warrant careful consideration. Firstly, our dataset only extends until 2017, thereby excluding any analysis post the Covid019 pandemic, which could have altered ecological footprint and poverty in BRICS nations. Moreover, we make use of aggregated country-level data, which obscures important regional or local variations that could influence the ecological footprint and poverty relationship. Recognizing these limitations is crucial not only for interpreting the results of the study but also presents opportunities for future research to account for these gaps.

Given that the BRICS nations still suffer from high poverty, our findings show the complex policy design needed to simultaneously reduce both poverty and the ecological footprint. More precisely, our results determine some vital policy recommendations that require the involvement of various stakeholders like researchers, government, institutions, non-profit organizations and residents for the effective implementation of environment-friendly policies. However, the current upward trend of environmental degradation for some BRICS countries and the high poverty in others leaves the environment-poverty nexus still in balance. Given the growth trajectory of the BRICS nations, the future of the planet could very well be in the hands of these developing nations.

References

Alshehry, A.S. and Belloumi, M. (2017), “Study of the environmental Kuznets curve for transport carbon dioxide emissions in Saudi Arabia”, *Renewable and Sustainable EnergyReviews*, Vol 75, pp. 1339-1347.

Baloch, M.A., Danish, Khan SU-D, Ulucak Z.Ş. and Ahmad A. (2020), “Analysing the relationship between poverty, income inequality, and CO2 emission in sub-Saharan African countries”, *Sci Total Environ*, Vol. 740, p. 139867.

Baltagi, B., Feng, Q. and Kao, C. (2012),” A Lagrange Multiplier Test for Cross-Sectional Dependence in a Fixed Effects Panel Data Model”, Center for Policy Research. 193.

Barbier, E.B. (2000), “The economic linkages between rural poverty and land degradation: Some evidence from Africa”, *Agriculture, Ecosystems & Environment*, Vol. 82, pp. 355-370.

Begum R.A., Sohag, K., Abdullah, S.M.S. and Jaafar M. (2015), “CO2 emissions, energy consumption, economic and population growth in Malaysia”, *Renew Sust Energy Rev*, Vol. 41, pp. 594-601.

Bennich, T., Weitz, N. and Carlsen, H. (2020), “Deciphering the scientific literature on SDG interactions: A review and reading guide”, *Science of the Total Environment*, Vol. 728, p. 138405.

Caglar, A.E., Zafar, M.W., Bekun, F.V. and Mert. (2022), “Determinants of CO2 emissions in the BRICS economies: The role of partnerships investment in energy and economic complexity Sustainable Energy”, *Technologies and Assessments*, Vol. 51, p. 101907.

Destek, M.A., Ulucak, R. and Dogan, E. (2018) “Analyzing the environmental Kuznets curve for the EU countries: the role of ecological footprint”, *Environ Sci Pollut Res*, Vol. 25, pp. 29387-29396.

Dhrifi, A., Jaziri, R. and Alnahdi, S. (2020), “Does foreign direct investment and environmental degradation matter for poverty? Evidence from developing countries”, *Structural Change and Economic Dynamics*, Vol. 52, pp. 13-21.

Dogan, E. and Seker, F. (2016), “Determinants of CO2 emissions in the european union: The role of renewable and non-renewable energy”, *Renewable Energy*, Vol. 94, pp. 429-439.

Finco, M.V.A. (2009), “Poverty-environment trap: A non linear probit model applied to rural areas in the North of Brazil”, *American-Eurasian Journal of Agricultural and Environmental Science*, Vol. 5, pp. 533-539.

Islam, R. and Ghani, A.B. (2018), “Link among energy consumption, carbon dioxide emission, economic growth, population, poverty, and forest area”, *International Journal of Social Economics*, Vol. 45, pp. 275-285.

Jin, G., Fu, R., Li, Z., Wu, F. and Zhang, F. (2018), “CO2 emissions and poverty alleviation in China: an empirical study based on municipal panel data”, *J Clean Prod*, Vol. 202, pp. 883-891.

Khan, S.A.R. (2019), ‘The nexus between carbon emissions, poverty, economic growth, and logistics operations-empirical evidence from southeast Asian countries”, *Environmental Science and Pollution Research International*, Vol. 26, pp. 13210-13220.

Khan, SU-D. (2021), “Environmental sustainability: a clean energy aspect versus poverty”, *Environ Sci Pollut Res*, Vol. 28, pp. 13097-13104.

Khan, S., Yahong, W. and Zeeshan, A. (2022), “Impact of poverty and income inequality on the ecological footprint in asian developing economies: Assessment of sustainable development goals”, *Energy Reports*, Vol. 8, pp. 670-679.

Koçak, E., Ulucak, R., Dedeoğlu, M. and Ulucak, Z.Ş. (2019), “Is there a trade-off between sustainable society targets in Sub-Saharan Africa?”, *Sustain Cities Soc*, Vol. 51, p. 101705.

Lin, J., Shen, Y., Li, X., and Hasnaoui, A., (2021), “BRICS Carbon Neutrality Target: Measuring the Impact of Electricity Production from Renewable Energy Sources and Globalization”, *J. Environ. Manage*, Vol. 298, p. 113460.

Masron, T.A. and Subramaniam, Y. (2019), “Does poverty cause environmental degradation? Evidence from developing countries”, *Journal of Poverty*, Vol. 23, pp. 44-64.

Mikayilov, J.I., Mukhtarov, S., Mammadov, J. and Azizov, M. (2019), “Re-evaluating the environmental impacts of tourism: does EKC exist?”, *Environ Sci Pollut Res*, Vol. 26, pp. 19389-19402.

Nathaniel, S., Nwodo, O., Adediran, A., Sharma, G., Shah, M. and Adeleye, N. (2019), “Ecological footprint, urbanization, and energy consumption in South Africa: including the excluded”, *Environ Sci Pollut Res*, Vol. 26, pp. 27168-27179.

Nathaniel, S.P., Yalçiner, K. and Bekun, F.V. (2021), “Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS”, *Resources Policy*, Vol. 70, p. 101924.

Pesaran, M.H., Shin, Y. and Smith, R.J. (2001), "Bounds testing approaches to the analysis of level relationships." *Journal of Applied Econometrics*, Vol. 16No. 3, pp. 289-326.

Pesaran, M.H. (2004), “General diagnostic tests for cross section dependence in panels”, University of Cambridge, Faculty of Economics, Cambridge Working Papers in Economics No. 0435.

Pesaran, M.H. (2007), “A simple panel unit root test in the presence of cross-section dependence”, *Journal of Applied Econometrics*, Vol. 22, No. 2, pp. 265-312.

Rizk, R. and Slimane, M.B. (2018), “Modelling the relationship between poverty, environment, and institutions: A panel data study”, *Environmental Science and Pollution Research International*, Vol. 25, pp. 31459-31473.

Shafiei, S. and Salim, R.A. (2014), “Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: A comparative analysis”, *Energy Policy*, Vol. 66, pp. 547-556.

Solarin, S.A., Nathaniel, S.P., Bekun, F.V., Okunola, A.M. and Alhassan, A. (2021), “Towards achieving environmental sustainability: environmental quality versus economic growth in a developing economy on ecological footprint via dynamic simulations of ARDL”, *Environ Sci Pollut Res*, Vol. 28, pp. 17942-17959.

Swinton, S.M. and Quiroz, R. (2003), “Is poverty to blame for soil, pasture and forest degradation in Peru’s altiplano?”, *World Development*, Vol. 31, pp. 1903-1919.

Tatoğlu, F.Y. and Polat, B. (2021), “Occurrence of turning points on environmental Kuznets curve: Sharp breaks or smooth shifts?”, *Journal of Cleaner Production*, Vol. 317, p. 128333.

United Nations (2015), “Transforming our world: The 2030 agenda for sustainable development”, General Assembly 70 session.

UNFCCC (2017), “UN climate change ANNUAL REPORT 2017”, United nations framework convention on climate change. Bonn, Germany.

Uzar, U. (2021), “The relationship between institutional quality and ecological footprint: Is there a connection?”, *Natural Resources Forum*, Vol. 5 No. 4, pp. 380-396.

Van Soest, H.L., van Vuuren, D.P., Hilaire, J., Minx, J.C., Harmsen, M.J.H.M., Krey, V., Popp, A., Riahi, K. and Luderer, G. (2019), “Analysing interactions among Sustainable Development Goals with integrated assessment models”, *Global Transitions*, Vol. 1, pp. 210-225.

Wei, Y., Zhong, F., Song, X. and Huang, C. (2023), “Exploring the impact of poverty on the sustainable development goals: Inhibiting synergies and magnifying trade-offs”, *Sustainable Cities and Society*, Vol. 89, p. 104367.

Zaman, K., Ikram, W., and Ali Shah, I. (2010), “Bivariate cointegration between poverty and environment: a case study of Pakistan (1980–2009)”, *Journal of Environmental Planning and Management*, Vol. 53, pp. 977-989.

Zhang, J., Wang, S., Pradhan, P., Zhao, W. and Fu, B. (2022), “Untangling the interactions among the Sustainable Development Goals in China”, *Science Bulletin*, Vol. 67, pp. 977-984.

Zoundi, Z. (2017), “CO2 emissions, renewable energy and the environmental Kuznets curve, a panel cointegration approach”, *Renewable and Sustainable Energy Reviews*, Vol. 72, pp. 1067-1075.

Appendix

Table 9. Descriptive stats

	EF	POV-GAP	GDPpc	GDpcSQ	FDI	INFL	AE	Rule of law
Mean	0.987455	-1.858255	5877.340	16.87008	23.69986	7.176749	4.481869	-0.261325
Median	1.107304	-1.365319	5714.626	17.30157	24.07518	6.136020	4.575675	-0.193651
Maximum	1.763062	-0.556813	11731.38	18.74005	26.39634	47.75201	4.605170	0.353991
Minimum	-0.215218	-4.935157	652.5661	12.96182	20.12604	-0.731971	3.970358	-1.097559
Std. Dev.	0.573950	1.214843	3241.355	1.626325	1.617871	6.239859	0.163286	0.383371
Skewness	-0.856368	-1.184400	-0.034482	-1.023364	-0.391684	3.490691	-1.334404	-0.402534
Kurtosis	2.641853	3.536295	2.051340	2.805564	2.300852	21.55170	3.844543	1.956343
Jarque-Bera	11.86422	22.85796	3.505758	16.37923	4.272088	1522.508	30.36367	6.732248
Obs	93	93	93	93	93	93	93	93