Journal for Social Science Archives

Journal for Social Science Archives (JSSA)

Online ISSN: 3006-3310
Print ISSN: 3006-3302
Volume 2, Number 2, 2024, Pages 139 – 158
Journal Home Page
https://jssarchives.com/index.php/Journal/about

Exploring the Effects of Economic Policy Uncertainty, FDI, and Energy Use, on Environmental Quality in BRICS

Muhammad Asim Imam[1], Dr. Tabassum Riaz[2], Ume Salma Shafiq[3] & Muhammad Adeel Abbas[4]

[1]*Ph.D. Scholar, School of Business and Economics, Universiti Putra Malaysia. Email:* asimimam467@gmail.com
[2]*Assistant Professor, University of The Punjab Jhelum Campus, Email:* tabassumriaz.pujc@gmail.com
[3] *Ph.D, Scholar: School of Business and Economics, Universiti Putra Malaysia, Email:* umesalma571@gmail.com
[4] *Ph.D. Scholar, School of Business and Economics, Universiti Putra Malaysia, Email:* adeelabbas15690@gmail.com

ARTICLE INFO

Keywords:

EPU, EQ, FDI, EC, PMG-ARDL, BRICS

Corresponding Author:
Muhammad Adeel Abbas
Email:
adeelabbas15690@gmail.com

ABSTRACT

Using country-level data, this study examines the role of economic policy uncertainty (EPU) and the contribution of economic growth variables such as foreign direct investment (FDI), energy consumption (EC), and GDP on the environment quality in BRICS: Brazil, Russia, India, China, and South Africa between 2000 and the year 2023. Analyzing the relationships with a focus on short- and long-run dynamics by using a set of the most advanced econometric techniques including cross-sectional dependence tests, the panel PMG-ARDL model, and robustness checks with FMOLS, The findings show that EPU improves environmental quality in the long run by reducing pollution-intensive activities in uncertain times. On the contrary, FDI and EC appear to have a non-negligible negative impact, indicating their role in increasing environmental degradation, especially in fossil fuel-dependent economies with weak environmental regulations. GDP has a more complicated relationship: it is a powerful measure of growth (of how the wealth of nations increases), but also of sustainability. An additional consideration the study highlights is that knowledge based on the creation of green investment is still insufficient in BRICS-alluding to the importance for these nations to adopt stringent environmental regulations, support clean energy, and finance green investments that promote decoupling economic development from environmental damage. Policy implications of these results are discussed in the context of achieving sustainable development in the face of global environmental change. More research is needed to tease out the heterogeneous impacts of such policy uncertainty, as well as to take into account sectoral variation in FDI flows to improve targeted policy response to such environmental type's effects.

OPEN ACCESS

Introduction

Global carbon dioxide (CO_2) emissions hit an all-time high of 36.3 billion tons in 2021—up 6% over 2020. The increase can be largely explained by a swift economic recovery from COVID-19, which depended heavily on coal as an energy source (Pata, 2022). For example, burning fossil fuels is the single biggest source of carbon dioxide (CO_2) emissions – regarded as the most important factor behind climate change. The amount of CO_2 in the atmosphere has now reached historical highs for our species and is on a trajectory with no signs of stopping. For example, CO_2 emissions increased by 1.8% in 2021 and 1.1% in 2023 (IEA, 2023). While international attention on continuing the exploration of fossil energy is rising, the use of fossil energy is still significant, which offers great difficulty in the destruction of the ecological environment (Zhang & Zhou, 2023). Carbon emissions continue to rise due to the correlation between economic growth and energy consumption pressure in most countries where they use fossil energy, with numerous countries faced with a double allowance for economic growth and carbon emissions. In this context, economic policies and energy consumption are two of the most influential factors for the amount of CO_2 emissions released. BRICS countries are of great importance in global warming for being three of the fastest-growing economies in recent years and providing the largest proportion of global CO_2 emissions this work examines hypothesis regarding environmental degradation through economic policy uncertainty, energy consumption, and foreign direct investment (FDI) and CO_2 emissions with an extensive and real panel of 657 observations covering the period from 2002 to 2018.

The implications of rising CO2 emissions are especially pronounced in resource-abundant countries facing high economic and geopolitical volatility. Collectively, the BRICS nations—consisting of Brazil, Russia, India, China, and South Africa—contribute enormously to worldwide emissions totals as well as global economic output. Ranking among the top ten international emitters, these results partly from their skyrocketing development and growing reliance on fossil fuels to power said growth. Over time, emissions from these countries have swelled dramatically, fueled largely by swift industrialization and vast consumption of carbon-intensive energy sources. Alarmingly, in 2022 the five BRICS states alone generated over 44% of total worldwide CO2 releases, cementing their pivotal role in international climate conversations. Regarding financial production, together they accounted for approximately 23% of global GDP last year, with energy usage projected to surge significantly in the coming decades. Around one-third of total global energy was burned in these countries in 2019, estimates proposing this share may rise to 40% by 2040 amid sustained development. While emissions in more established economies have dipped some years, the opposite holds for BRICS nations—their outputs rocketing from 28% in 1990 to 44% in 2022 as fossil fuels remain their primary energy choice. Though policies like carbon taxes, incentives for renewables, and pledged emissions cuts have been implemented, the real-world impact on curbing energy demand has so far fallen short of goals, according to analyses.

While foreign direct investment has greatly contributed to economic growth within BRICS nations by channeling much-needed capital and advancing technologies to local markets, its environmental consequences remain complex. A notable increase in FDI shares for Brazil, Russia, India, China, and South Africa over the past two decades - from less than seven percent globally in 2000 to over twenty-two percent today - points to both deepening economic ties and potential environmental impacts across vast industrial sectors. The effects of investment on pollution are mixed; some studies show cleaner methods introduced, while others highlight strategic relocation to regions with more lenient oversight, potentially worsening emission levels over the long run without precautions. Where regulatory standards commonly fall short of developing standards, foreign money risks enabling higher discharges if proper checks are not in place to balance economic gains with ecological protection, as certain industries still favor locations permitting carbon-intensive operations in the pursuit of profitability. Careful management of inflows will thus prove important for BRICS members seeking sustainable growth alongside environmental safeguarding in the coming years.

The role of economic uncertainty in shaping environmental outcomes is also pivotal. Unpredictability regarding fiscal, monetary, and trade policies can influence investment, consumption, and green choices with profound implications. Several crises—including COVID-19, conflicts, and volatility—have exacerbated instability, intensifying consequences for both markets and the quality of air and water. High uncertainty tends to deter renewable projects and efficiency upgrades, leading to continued reliance on fossil fuels. Studies point to two key ways unpredictability impacts CO2: through consumption and investment. Consumption may fall with greater uncertainty, potentially reducing emissions in the short term. However, investment also dips when unpredictability climbs, discouraging greener solutions and prolonging dependence on carbon sources, driving emissions higher long-term. Considering these opposing forces, the influence of uncertainty on CO2 varies between short and long views, underlining the need for nuanced analyses over different periods.

This paper focuses on the BRICS states from 2000 to 2023; the goal of this work is to analyze the correlations between economic policy uncertainty (EPU), energy consumption, and FDI on CO_2 emissions in the BRICS nations that seem to have recently been overlooked within these examined dynamics. These findings highlight a complex yet strong relationship between economic policy uncertainty and carbon emissions in BRICS as a whole but also different among the countries and in the short and long run. The analysis further uncovers a positive contribution of both energy consumption and FDI to CO_2 emissions in these economies. The results have important consequences for the design of policies as BRICS countries will have to negotiate the trade-offs between economic growth, energy requirements, and environmental sustainability. These results indicate that a move to renewable energy with tamed FDI might be a feasible policy for cost-effective carbon emission control, but that the economic policy uncertainty channel is also consequential.

This study contributes to the literature by investigating economic policy uncertainty, energy consumption, FDI, and environmental quality nexus in the context of BRICS in the long run. To conduct the short- and long-run interactions, this study uses advanced econometric methodologies including cross-sectional dependence (CSD) tests, Fully Modified Ordinary Least Squares (FMOLS), and the Panel Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) model. These models have rarely been applied within the BRICS framework in the literature, thereby constraining knowledge about the long-run effects of EPU, energy use, and FDI on environmental quality. This study addresses this gap and offers a policy framework to accordingly pursue carbon neutrality by taking into account the socio-economic structures of the BRICS countries to better inform policy decisions.

The rest of this paper is structured as follows the second section (Review of Literature and Hypothesis Development) consists of a thorough review of the existing literature studies and related hypotheses. In the "Methodology and Data" section we present the methodological approach and data used in the analysis; The "Empirical Findings and Discussion" section offers results and a full valuation of results. Finally, the final section "Conclusion" highlights the most significant points and provides a policy recommendation in line with the current study.

Literature Review and Hypothesis Development

This section examines the relevant literature on the relationships among economic policy uncertainty, FDI, energy consumption, and environmental quality, with particular emphasis on the unique environmental context of BRICS countries.

Economic Policy Uncertainty and Environmental Quality

Economic policy uncertainty (EPU) is the economic disturbances caused by unclear or changing tax, fiscal, and regulatory policies (Ding et al stock index to ascertain its association with firm value. EPU index from Baker et al, as a measure of confidence of the economy In recent literature, (2016) has received substantial attention, with numerous studies demonstrating that EPU influences microeconomic and macroeconomic activities. As a result, high EPU can prevent corporate investment, disrupt output and lower employment rates (Huang et al., 2023). Businesses tend to avoid long-term investment commitments in high-risk environmental protection and green technologies given the increased risk and uncertainty during tough economic times (Wang & Liu, 2021).

EPU is likely to contribute, at the macro level, to an economic growth slowdown due to postponement on the part of the firms of investments in energy-efficient technologies, resulting in a greater dependence on traditional energy, i.e., energy that has a higher pollution intensiveness (Zhang & Yang, 2023). EPU as a fundamental force stimulating environmental damage has been well documented in the literature, in which instability in policy regimes dissuades companies from executing green initiatives. For example, research shows that both investment, output and employment decrease and research and development (R&D) spending drops during periods of policy uncertainty (Ahmed et al., 2022). Fossil fuel-based energy sources are preferred during uncertain times due to reduced innovation activity and this translates to worsening the anomaly of CO_2 emissions (Mushtaq et al., 2024). Consequently, EPU serves as an essential determinant of ecological sustainability (Pavlovic & Chen, 2023)

Noteworthy research investigated associative relationships between EPU and CO_2 emissions and produced results that are, on the one hand, consistent with rising, negative and no correlation results, on the other hand. For example, Jiang et al. Key sectors in which policy uncertainty impacts economic channels suggested a unidirectional relationship between EPU and CO_2 emissions (2021). The EPU-CO_2 association differs along countries and industries as reflected by the influence of sectoral dynamics.

Adedoyin et al. Huang et al. (2020) studied the UK context of last three decades and found that EPU has a significant effect on reducing CO_2 emissions globally the impact of which lasts in the short-run as the firms cut production and energy usage under high uncertainty. Nonetheless, this pattern reverses in long-run, where EPU stimulates emissions when firms will go back to cost-effective and polluting practices. On the same lines, Pirgaip and Dinçergök (2020) investigated the effect of economic policy uncertainty on G7 economies and found the relationship to be heterogeneous among member countries, where economic policy uncertainty impacted the G7 emissions only in a few countries such as the USA and Germany. This means that even in approaches with higher EPU, emissions from some economies decrease but increase from others because of the suboptimal regulatory and weaker mitigation response in green investments.

Syed and Bouri (2022) recently investigated both short and long-lasting effects of EPU on environmental quality, finding that in the short run, EPU promotes CO_2 emissions due to firms putting off green technology investments in favor of an increased dependence on inexpensive energy, which likely harms environmental Kant. But sustained EPU may indirectly promote emission reduction in the long run as firms respond to lower production or shift to energy-efficient processes to reduce economic risk. This short- and long-term contradictory impact indicated that more attention should be paid to the research of the mechanism channels (direct and indirect) for EPU production effects on the environment.

Such as Liu and Zhang(2022), they measured the effects of EPU in various energy sectors based on data between 2014 and 2019 in China. High EPU can discourage investing in conventional energy and decrease emissions this way in some instances, but it can conversely motivate investing in renewable energy sectors since firms try to seek alternatives in an aim to avoid regulation risks. Anser et al. also reported similar findings in their study. (2021) noticed that EPU caused a decrease in emissions in the short term but was responsible for an increase in the long run, especially in industries that rely on carbon-intensive production patterns. The opposite effect of EPU on environmental emissions indicates a complicated relationship between government policy pressures, firm strategy, and the environment.

Another research by Selmy and Elamer (2023) regarding the impact of EPU on green technology investment in emerging economies shows that EPU adversely affects green technology investment in weak regulatory environments of emerging economies. Policy uncertainty in a country such as Egypt acts as a disincentive for long gestation investments in energy innovations and renewables, resulting in high CO_2 emissions. The results lend further support to the argument that the impact of EPU on emissions could differ depending on the strength of the regulations within the economy. From the reviewed literature, we find that the relationship between EPU and CO_2 emissions can be both direct and indirect, as the nature of this relationship may change with country-specific conditions and how long the policy uncertainty lasts. Higher values of EPU, for example, generally are associated with higher first-moment emissions, as firms implement low-cost but polluting practices in the immediate term. Yet, in some circumstance, long-term EPU could improve emissions reductions if firms gradually adjust energy-efficient practices to steer through economic uncertainty. Inspired by this insight, we propose the next hypothesis:

H_1: Economic policy uncertainty significantly influences the environmental quality in BRICS countries.

Foreign Direct Investment (FDI) and environmental quality

In recent years, the discussion of the positive role of foreign direct investment (FDI) in economic development and environmental effects has received considerable attention (Shahbaz et al., 2018; Hossain & Saifullah, 2021; Abbasi et al., 2023). FDI has historically been characterized as an engine of economic growth, however, its environmental consequences are multifaceted with pros and cons as the inflow of FDI has the potential to influence environmental quality positively and negatively. Early theoretical models speculated that FDI might lead to negative environmental effects by promoting energy-intensive industrial development in host countries, which tended to make less stringent environmental regulations available (Grossman & Krueger, 1995). On the one hand, this is commonly believed, because foreign direct investment (FDI) attracts environmentally dirty (pollution-intensive) industries (Danish et al., 2021) such that it leads to higher levels of Kg CO 2 emissions (Chong et al., 2022). On the other hand, however, some scholars point out that FDI can stimulate the transfer of cleaner and more efficient production technology and thus make a positive contribution to environmental sustainability (Ali et al, 2022; Khan et al., 2023).

The relationship between FDI and CO_2 emissions is an empirical issue of controversial findings. However, a paradox emerges when studies analyze FDI in developing economies like those within BRICS groups where carbon emissions tend to rise with FDI inflows due to the pollution-heavy sectors FDI inflows are often directed to, and the lax environmental standards that prevail (Dogan & Altinoz 2020). For instance, Zaman et al. Using a sample of emerging economies, Wang et al. (2020) examined the effect of FDI on CO_2 emissions and determined that FDI inflow has a significantly positive impact on CO_2 emissions, particularly through the energy and manufacturing sectors. Similarly, Fang et al. IV insights for FDI environmental impactsA recent study conducted by (2023) on the implications of investment climate on environmental performance confirms that FDI inflows to BRICS economies have been driving the expansion of energy-intensive production processes, causing environmental degradation.

On the other side of the coin, some studies are more contextually specific and suggest that FDI can benefit the environment, especially when FDI targets greener sectors or when.FDI is coupled with regulatory incentives for green business investment. In their study of the high-tech sector development on CO_2 emissions in East Asian economies, Zhang and Liu (2021) find that high-tech related FDI tends to decrease CO_2 emissions since it usually involves clean technologies and energy-efficient technologies while the opposite effect is true for CO_2 emissions when FDI is directed towards the service sector. Recent work by Alam et al. is another example of this. (2023) indicates that when foreign direct investment (FDI) are attracted to countries with strict environmental policies, they can lead to better environmental performances by directing investments to environmental-friendly sectors.

Two main hypotheses are often referenced in the literature regarding the effect of FDI on environmental quality, known as the “pollution haven hypothesis” and the “pollution halo hypothesis. According to the pollution haven hypothesis, FDI flows to countries with weak environmental standards so that multinational companies locate polluting activities in foreign countries with less rigid standards than in their home countries. Such an explanation has been verified by previous studies documenting that under the weak regulatory environment of developing countries, foreign direct investment (FDI) inflows tend to raise emissions (Muhammad et al, 2022; Yasmin & Rehman, 2023). On the other hand, when host governments are strict, the pollution halo hypothesis argues that FDI could improve environmental quality in host countries by transferring clean technologies and management practices. The favorable impact of FDI inflow through advanced technology transfers and compliance with environmental standards is presented as evidence against the pollution halo hypothesis (Sharma & Kautish, 2022).

A recent study by Shen et al. Fahimnia et al. (2022) offer more specific evidence through sector-based channels pertaining to FDI and CO_2 emissions. The study by examining data from multiple emerging economies has found that FDI environmental impact is sector-specific. The dualism of FDI — positive in terms of environmental effects when it comes to renewable energy and in service sectors, but negative when it comes to manufacturing and resource-extraction sectors — was confirmed by FDI channels. Caglar and Bayar (2024) that found together with particularly supportive governmental factors, FDI during cross-border flows into eco-friendly sectors can help reduce carbon footprints as well.

Similarly, country characteristics, regulatory and environmental policies, also affect the relationship between FDI and CO_2 emissions. For instance, Dutta et al. In a recent paper, Li et al. (2023) examined FDI inflows in developing countries and documented that nations with higher levels of environmental regulations draw in “green FDI” that reduces emissions. In contrast, poor regulation typically raises emissions as firms invest in pollution-intensive industries. This situation emphasizes the necessary role of host countries in developing stringent environmental policies to channel FDI into sustainable paths.

From the literature, the environmental effects of FDI depend on a range of factors, including the investment sector, the regulatory environment of the host country, and the technological level of foreign investors (Deriviere et al., 2014; Inoue et al., 2018). FDI can contribute positively or negatively to the environment, with a different temporal and possibly complex relationship involving the two phenomena of environmental degradation and its restoration—namely, that while FDI may increase CO_2 emissions in the short run, most importantly in countries with weak regulation, it can and should increasingly focus on sustainable sectors, thus providing a long-term environmental upside. Therefore, we hypothesize:

H_2: FDI has a significant impact on environmental quality.

Energy Consumption and Environmental Quality

Energy consumption/economic growth/environmental quality nexus is the central theme in creating sustainable development and mitigating climate change. Many empirical studies have tried to investigate this relationship focused on the impact of energy consumption on environmental quality under growing global carbon emission and environmental degradation. Exposure to energy usage, mainly fossil fuel energies, as it is well-documented in literature, is an important factor for occurrence of environmental outcomes at different levels affecting air pollution, ecosystem functions, and human health (Zhao et al., 2021; Lee & Lee, 2022).

Literature has emerged that studies the long-lasting association between the use of energy, and environmental degradation between various countries and their economic standing or shape. As an example, Shafiei and Salim (2014) investigated the data of OECD countries and discovered that the result of non-renewable energy consumption is environmental degradation and the use of renewable energy enhances environmental quality. Similarly, Li et al. (2017) found that energy consumption is directly influence the environmental quality in emerging economies since it supports activities that generate emissions and deplete resources. These results emphasize that there is bidirectional relationship between energy consumption and environmental quality where economic growth usually increase energy usage and later on impact environmental health.

Panel cointegration studies have provided additional evidence for the existence of an estimated dynamic stable long-run relationship between energy consumption and environment indicators. For instance, Chen et al. (2016) using a large number of countries to disclose that there is a negative relationship between energy use and environmental quality, indicating that many economies will get stuck in a vicious cycle of higher energy demand and environmental degradation. However, this link varies by income group and high-income countries appear to implement better policies to reduce energy-related environmental degradation than a lower-income country (Wang et al., 2019).

Regional diversity in the energy-environment nexus has been pointed out in several studies, demonstrating how the energy-environment nexus adapts according to geographic and economic backgrounds. To illustrate, Wang and Fang (2018) undertook a comprehensive empirical research based on panel data of 170 economies, to arrive at the conclusion that the impact of energy consumption on environmental quality also depends on domestic conditions, and the connection between energy consumption and environmental degradation is more prominent in low- and middle-income economies. Adebayo and Akinsola (2021) used vector error-correction models (VECM) in Thailand and also discovered an increase in energy consumption with a worsening environmental quality. The authors found this is true both short- and long-term, meaning energy policies in such regions cannot accept that energy consumption no longer affects ecological outcomes after a period of time.

As well as by Musah et al., (2022) in North Africa show that fossil fuels causes more energy consumption which resulting in the deterioration of environmental quality significantly. Equally, in the neighbouring Vietnamese context, the increasing energy demand due to economic growth is similarly causing environmental damages through a variety of pollutants. The impacts can be seen in the short run and also in the long run (Raihan, 2023). Those findings indicate that developing countries need to diversify their energy supplies and move to more sustainable sources of energy in order to protect the environment.

There is also new evidence that the energy consumption-environment quality nexus is heterogeneous by energy source. Environmental degradation is one of them and renewable energy has been considered to mitigate it because it tends to emit lesser greenhouse gases (GHGs). On the other hand, coal and oil and the rest of the non-renewable energy sources usually reduce the environmental quality efficiently (Chen et al., 2021) Khan and Khan (2024) indicates that switching from fossil fuels to renewable energy sources could lead to a better environmental outcome in Saudi Arabia by decreasing energy-associated pollutants. This, in turn, is consistent with Pradhan et al. (2024), (SA and G7 comparison on energy impact) found that the reduction to cleaner technologies can efficiently reduce the energy consumption environmental footprint on South Asia and G7.

Even with the above insights, the relationship between energy consumption and environmental quality remains complex. Background: The presence of certain structural, energy-efficient, and technological factors will be decisive in creating a correlation between energy consumption on the one hand, and environmental degradation on the other or environmental improvement (Praveen & Sharma, 2023). We, among others, find that energy-intensive industries with high energy efficiency and state-of-the-art green technologies are more likely to detach the energy use-growth nexus from energy detrimental impact, indicating substantial role for policy measures to prevent the negative environmental consequences of energy use (Zhao and Wu, 2023).

The existing literature indicates a substantive link between energy consumption and environmental quality, particularly emphasizing the detrimental impact of non-renewable energy use. Given that increased energy consumption often corresponds with economic growth and rising emissions, we hypothesize that:

H_3: Energy consumption significantly influences environmental quality.

Data and Methodology

Data

The selected period goes from 2000 to 2023 and BRICS countries given the fact that the study uses annual data for BRICS countries (Brazil, Russia, India, China, and South Africa). This period was chosen as, through the present study variables, the information is available only for the years from 1985 to 2014. Table 1 displays some information about data sources for all variables used.

Data on economic policy uncertainty is extracted from the World Uncertainty Index (WUI), which reflects the uncertainty over economic policy and political stability of each BRICS country (source: www. worlduncertaintyindex. com). The proxy of carbon dioxide; —the measure of environmental quality is obtained from the World Energy Statistical Review. WDI-based information on foreign direct investment (FDI) which is reported as a percentage of GDP demonstrates the extent to which a country is attracting external investment. Data on primary energy consumption, which denotes a country's annual energy usage, is also obtained from the

World Energy Statistical Review. GDP per capita (current US$) values are from the World Development Indicators (WDI) database of the World Bank.

Model Specification

The current study explores the influence of economic policy uncertainty (EPU) along with other facets namely foreign direct investment (FDI), primary energy consumption (EC), economic size (GDP), and environmental quality of BRICS nations (Brazil, Russia, India, China, and South Africa). We employ heterogeneous causality testing between these variables to explore the short-run dynamics. The Panel data model is specified as follows:

$$EQ_{it} = \beta_0 + \beta_1 EPU_{it} + \beta_2 FDI_{it} + \beta_3 EC_{it} + \beta_4 GDP_{it} + \varepsilon_{it} \quad (1)$$

Where: EQ_{it} represents environmental quality for country *i* at time *t*. β_0 is the intercept, accounting for fixed effects across countries; $\beta_1, \beta_2, \beta_3$, *and* β_4 represent the elasticities of economic policy uncertainty, FDI, energy consumption, and GDP, respectively, and εit denotes the error term. We apply a logarithmic transformation for each variable (denoted by L) to ensure better distributional properties and to reduce heteroscedasticity issues, as suggested by Selmey and Elamer (2023). The model thus takes the following logarithmic form:

$$LEQ_{it} = \beta_0 + \beta_1 LEPU_{it} + \beta_2 FDI_{it} + \beta_3 LEC_{it} + \beta_4 LGDP_{it} + \varepsilon_{it} \quad (2)$$

In this model, If $\beta_1>0$, then increased EPU is associated with reduced environmental quality; otherwise, if $\beta_1<0$, EPU improves environmental quality. If $\beta_2>0$, higher energy consumption corresponds with environmental degradation; if $\beta_2<0$, FDI improves environmental quality. Similarly, EC (β_3) and GDP (β_4) parameters are assessed for their positive or negative effects on environmental quality.

Econometric techniques

Abstract Testing for cross-sectional dependence is a key prerequisite for reliable panel data analysis. Cross-sectional dependence means that the observations of a country can be affected by the observations of another country, and therefore, some adjustments should be made in the estimation (Alataş, 2022). To test cross-sectional dependence in this study, we perform three tests: the Breusch and Pagan (1980) LM test, Pesaran (2004) scaled LM test, and Pesaran (2004) CD test. The following forms the basis for calculating these tests:

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \quad (3)$$

$$CD_{LM2}\sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{\rho}_{ij}^2 - 1) \quad (4)$$

$$CD = \sqrt{\frac{2T}{N(N-1)}\sum_{i=j}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2} \quad (5)$$

Here, ρ_{ij} represents the correlation coefficients derived from the residuals of each cross-section. Rejecting the null hypothesis implies cross-sectional dependence.

To ensure the variables are stationary, we apply the Cross-sectional Augmented Dickey-Fuller (CADF) and Cross-sectional Im, Pesaran, and Shin (CIPS) tests (Pesaran, 2007; Alataş, 2022).

These second-generation unit root tests account for cross-sectional dependence, enhancing reliability in stationarity testing across the panel. Stationary data prevent spurious regression results in panel data analysis, crucial for valid inference.

$$\Delta y_{it} + \omega_o + \omega_1 y_{i,t-1} + \omega_2 \bar{y}_{t-1} + \sum_{j-1}^{m} \beta_{1ij} \Delta \bar{y}_{i,t-j} + \sum_{k=0}^{n} \beta_{2ij} \Delta y_{t-j} + \mu_{it} \quad (6)$$

For identifying the potential long-run relationships between variables, we employ the panel bootstrap cointegration test that accommodates for non-stationary series to be cointegrated. Using a Lagrange multiplier framework introduced by McKoskey and Kao (1998), this test is valid under small sample sizes and allows for cross-sectional dependence across countries (Westerlund & Edgerton, 2007).

To estimate short-run and long-run relationships, we use the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) method by Dumitrescu and Hurlin (2012). More importantly, this method enables both I(0) and I(1) series to be integrated within the same panel, hence allowing more general mixed integration orders within a single panel (Asghar et al., 2024; Ameer et al., 2024). Moreover, PMG-ARDL gives good cointegration results in small samples. The PMG-ARDL model can be expressed in general form as;

$$\begin{aligned} LCO2_{it} = &\alpha_0 \\ &+ \varphi_i \sum_{j=1}^{p} \Delta LWQ_{it-j} \\ &+ \theta_i \sum_{j=1}^{q} \Delta EPU_{it-j} + \omega_i \sum_{j=1}^{q} \Delta LFDI_{it-j} + \beta_i \sum_{j=1}^{q} \Delta LEN_{it-j} + \delta_i \sum_{j=1}^{q} \Delta LGDP_{it-1} \\ &+ \pi_i + \lambda_1 LEQ_{it-1} + \lambda_2 EPU_{it-1} + \lambda_3 LFDI_{it-1} + \lambda_4 EC_{it-1} + \lambda_5 LGDP_{it-1} + \varepsilon_{it} \end{aligned} \quad (7)$$

$$\Delta Ly_{it} = \phi_i ECT_{it} \sum_{j=0}^{q-1} \Delta Lx_{it-j} \beta_{ij} \sum_{j=1}^{p-1} \psi_{ij} \Delta Lx_{it-j} + \varepsilon_{it} \quad (8)$$

$$ECT_{it} = y_{it-1} - X_{it} \quad (9)$$

Where ECT_{it} is the error correction term indicating adjustment towards equilibrium. ϕ_i, θ_{ij}, ω_{ij}, β_{ij}, and δ_{ij} are short-run coefficients, while λ represents the long-run coefficients for each explanatory variable. *p* and *q* show the maximum lags, Δ denotes first differences, and subscripts *i* and *t* indicate country and time, respectively. The PMG-ARDL model is applied to estimate both short- and long-term effects, ensuring robust insights into how EPU, FDI, ENC, and GDP impact environmental quality over time.

Empirical Results and Discussion

So this section provides details of the exploratory statistical tests along with the main empirical results. We start our analysis with cross-sectional dependence check in BRICS countries. Results are presented in Table 2 and show that the null hypothesis of independence between the countries cannot be rejected, that is, we can confirm the cross-sectional dependence. The 1% and 5% significance levels observed in the Pesaran scaled LM, Pesaran CD and Breusch-Pagan LM test results, as illustrated in Table 6, indicate the high probability of economic or environmental shocks co-existing in at least one of the other BRICS countries. This result underlines the high level of interdependence established between BRICS economies and verifies the findings that argue for the use of cross-sectionally dependent unit root and cointegration tests (Alataş, 2022).

Then, we test the stationarity of each variable, using unit root tests with cross-sectional dependence. In particular, the order of integration of the time series data is tested using the Cross-sectional Im, Pesaran, and Shin (CIPS) test and the Cross-sectional Augmented Dickey-Fuller (CADF) test. As shown in Tables 3 and 4, we observe that, CIPS, and CADF results uphold these, indicating that all of the variables (environmental quality, proxied by pollution indicators; economic policy uncertainty (EPU); primary energy consumption; GDP per capita; and fdi) are I(0) at their first differences. These tests show that we can reject the null of a unit root for each variable at the 1% and 5% level, which is a necessary condition for the order of integration of the variables for the analysis below.

Table 2: Cross-sectional dependence test findings

Test	Prob.	Statistic
Breusch-Pagan LM	0.0142**	21.4536
Pesaran scaled LM	0.0045*	2.7563
Pesaran CD	0.0012*	3.2475

The CIPS and CADF test results in Tables 3 and 4 reveal that all variables are stationary at their first difference. The tests all reject the null hypothesis of a unit root at 1% and 5% levels for all variables thus confirming that the time series are integrated at their first differences.

Table 3: CIPS Test Findings

Variable	CIPS Δ (Prob.)	Level (Prob.)
Environmental Quality	0.0395**	0.3789
EPU	0.0000*	0.1128
FDI	0.0017*	0.7390
Energy Consumption	0.0003*	0.4876
GDP	0.0029*	0.6102

Table 4: CADF Test Findings

Variable	CADF Δ (Prob.)	Level (Prob.)
Environmental Quality	0.0369**	0.1478
EPU	0.0000*	0.1263
FDI	0.0032*	0.5297
Energy Consumption	0.0004*	0.3275
GDP	0.0083*	0.7856

After examining stationarity, we employ the panel bootstrap cointegration test to test for possible long-run associations between these series. The Westerlund (2005) cointegration test is a test for the existence of cointegration between non-stationary variables that is based on the Lagrange Multiplier principle (McKoskey and Kao, 1998). The Augmented Dickey-Fuller (ADF) statistic as presented in table 5 is significant at 1% level (p = 0.0002) thereby reject null hypothesis of no cointegration which indicates the long-term equilibrium relationship between the variables.

Table 5: Cointegration Test Results

Test	Prob.	t-statistic
Augmented Dickey–Fuller (ADF)	0.0002*	-3.4531

After establishing stationarity, cointegration, and cross-sectional dependence, we will use the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) model to estimate the short and long-term effects. According to the Akaike Information Criterion (AIC), the appropriate lag structure is PMG-ARDL (4, 1, 1, 1, 1), which is illustrated in Table 6. Then, I estimate this specification, which permits an investigation of both short- and long-run dynamics, and a more robust analysis of the effect-contingent months.

Table 6: Akaike Information Criterion Test Findings

Specification	AIC Score	Model
PMG-ARDL (4, 1, 1, 1, 1)	-6.4346*	4
PMG-ARDL (3, 1, 1, 1, 1)	-6.4054	3
PMG-ARDL (2, 1, 1, 1, 1)	-6.3648	2
PMG-ARDL (1, 1, 1, 1, 1)	-6.3686	1

Long-term Findings and Interpretation

Table 7 shows the PMG-ARDL estimation results, which indicate that economic policy uncertainty has a robust, negatively signed long-run relationship with economic quality of − 0.0293, suggesting that an increase (decrease) in economic policy uncertainty boosts (deteriorates) environmental quality. The underlying reason is that during uncertainty, consumption and investment in pollution-intensive activities decline, which is consistent with previous studies highlighting the mitigating impact of EPU on energy consumption and emissions (Liu and Zhang, 2022; Wen et al., 2022). FDI has a significantly favorable effect on environmental quality in the long run, with a coefficient of 0.0721. This reinforces the pollution haven hypothesis that states FDI in high-emission sectors tends to flow to BRICS countries with loose environmental regulations. On a more positive note, it also underlines prospects of sustainable development measured through green investment policies, given well-regulated FDI (Zafar et al., 2022; Li and Haneklaus, 2022).

Longitudinally, a 1% increase in EC contributes to a 1.12% deterioration in environmental quality, meaning that EC inhibits environmental quality. Such finding illustrates the BRICS countries reliance on traditional energy which is a major source of environmental degradation. Moreover, previous research also indicates that fossil fuel consumption has a negative effect on environmental quality (Acheampong et al., 2019; Musah et al., 2022). In the long run, GDP per capita has a statistically significant and positive relationship with environmental quality degradation (0.0194). This is a result of the fact that BRICS economies are characterized by pollution-led models of economic growth where increasing incomes stimulate consumption of energy-intensive goods and expansion of industrial activities. Such finding aligns with the Environmental Kuznets Curve conjecture, and previous researches that linked economic growth with environmental degradation in developing economy (Dauda et al., 2021; Shah et al., 2022).

The findings also show EPU has an insidious relationship with environmental quality in the short run, but its impact really begins in the long run. This is also true for FDI and GDP per capita because they do not impact in the short term, which also shows the lagging effect of these variables which expand in economic activities and investments. On the other hand, EC has a swift and lasting detrimental effect on environmental quality, with a 0.69 in the short-run coefficient. Such results underscore the need for policy measures that curb dependency on fossil fuels, including a transition to renewable energy sources. The error correction term (ECT), which represents the rate of convergence to the long-run equilibrium is negative and equal to 0.3947, and is significant at the 1% level. Put differently, 39.5% of the deviations from the equilibrium level are corrected each year, and it thus takes slightly more than two and a half years for these deviations to completely stabilize. The ECT results are stable and significant, therefore these long-run results stand, and they confirm the long-run relationships between EPU, FDI, EC, GDP, and environmental quality are stable.

These findings reflect the inherent interaction effect of economic drivers and environmental quality for the BRICS countries. Although economic policy uncertainty dampens the degree of environmental degradation, the continued dependence on fossil fuels and the adverse environmental impacts of FDI inflows highlight the need for focused policies. The transition from fossil fuels to generators of energy, the creation and enforcement of environmental standards, and the provision of incentives for green investment are all also key to sustainable development in BRICS economies.

Table 7: Long-Run and Short-Run Estimation Results

Variable	Coefficient	t-statistic	P-value
EPU	-0.0293	-2.49	0.018**
EC	1.1203	19.31	0.000*
GDP	0.0194	2.97	0.004*
FDI	0.0721	4.57	0.000*
Short-Run			
EPU	0.0023	0.097	0.918
FDI	-0.0059	-0.168	0.867
EC	0.6941	6.42	0.000*
GDP	0.0081	0.502	0.616
ECT (-1)	-0.3947	-5.49	0.000*

For examining the causal associations between the variables selected in EPU, FDI, EC, and GDP per capita and environmental quality in Dumitrescu& Hurlin (2012) panel causality through panel Dumitrescu and Hurlin (2012). Panel data and the allowance for country specific heterogeneity makes this method appropriate for joint estimation of causation. The results, shown in Table 8, highlight powerful directional and bidirectional causal relationships between the variables.

These results emphasize the one-way causal effect from environmental quality to economic policy uncertainty, suggesting that worsening environmental quality will cause more policy instability (Wen et al., 2022). This indicates that governments are typically reacting to environmental issues, adopting idiosyncratic or inconsistent policies to tackle ecological hazards. The lack of reverse causality implies that EPU does not affect environmental quality, at least in the short run, highlighting the importance of long-term predictable policy designs to reach environmental targets.

Foreign direct investment shows bidirectional causal links with environmental quality, both a driver and result of environmental degradation (Zafar et al., 2022). FDI can lead to environmental deterioration especially when channeled to pollution intensive industries, thus supporting the pollution haven hypothesis. On the other hand, investments with respect to green technologies can improve environmental quality. Likewise, environmental conditions play a role in FDI inflow, where countries with stricter environmental regulations can prove more appealing to invest in sectors focused on sustainable practices. These results highlight the need for regulatory regimes that adapt FDI so as to be consistent with national sustainability objectives.

The demonstration of strong bidirectional causality between energy consumption and environmental quality highlights the potential necessity of a shift toward renewable energy. The findings indicate that fossil fuel consumption continues to compromise environmental quality, aligning with previous studies (Acheampong et al., 2019; Musah et al., 2022). On the other hand, worsening environmental conditions may spur changes in energy policies that promote cleaner energy technologies. To break this vicious circle and lower fuel-based energy consumption, BTU, developing countries in BRICS must put investments in renewable energy infrastructure at the top of their political agenda.

In fact, GDP per capita exhibits bi-directional causal relationship with environmental quality which reflects the relationship between economic development as well as environmental sustainability (Qiao et al., 2019; Li and Haneklaus, 2022; Asghar et al. 2024). Economic growth fuels the industries and depletes the resources that destroy the environment. On the other hand, deteriorating environmental conditions may restrain sustainable development as they place burdens on resources and enhance exposure to macroeconomic risk from climate change. These findings underscore the critical need to decouple economic growth from environmental degradation via technological innovations and sustainable industrial practices.

This highlights the bidirectional impact of GDP and FDI where both growth and foreign investment reinforce each other. FDI, through inflows of capital and technology transfer, contributes to GDP growth; on the other hand, higher GDP enhances the attractiveness of a country to foreign investors (Adams et al., 2020). But this relationship illustrates the risks of shortcuts and the environmental costs of losing time, which is why more sustainable investment strategies are needed to help offset investment in traditional extractive industries during rapid industrialization.

These results stress the urgent need for integrated policies in BRICS that take into account the environmental consequences of energy consumption and foreign investments. [3] Governments need to promote FDI that supports sustainable development and clean energy practices as well as fostering economic growth through environment-first policy orientation. Thus, BRICS member countries can realize balanced development through the dissemination of this knowledge, leading toward sustainable development in the context of protecting the environment while obtaining economic growth. These findings also create the foundation for evidence-based policymaking and open up new areas of research related to how these relationships develop and under what socio-economic conditions.

Table 8: Dumitrescu and Hurlin Causality Test Findings

Causality Flow	**Null Hypothesis**	**W-Stat**	**P-value**
EQ → EPU	EPU does not cause ENQ	2.784	0.560
	ENQ does not cause EPU	5.432	0.002*
FDI → EQ	EQ does not cause FDI	2.814	0.049**
	FDI does not cause ENQ	5.632	0.001*
EC ↔ EQ	PEC does not cause ENQ	6.287	0.0003*
	ENQ does not cause EC	8.042	0.0001*
GDP ↔ EQ	GDP does not cause EQ	7.216	0.0004*
	EQ does not cause GDP	6.741	0.0006*
GDP↔ FDI	GDP does not cause FDI	6.932	0.0005*
	FDI does not cause GDP	7.108	0.0003*

Robustness Check

The study employed the Panel-Fully Modified Least Squares (FMOLS) estimation--calibrated in Table 9--for the robustness check, considering heterogenous issues to derive robust results throughout the panel. The FMOLS estimation process corrects potential serial correlation and endogeneity issues, yielding valid estimates of coefficients in the presence of cross-sectional dependencies (Pedroni, 2004; Zakari et al., 2021). The FMOLS findings suggest that EPU has a negative and statistically significant effect on environmental quality in BRICS countries. The negative coefficient indicates that increased economic policy uncertainty leads to a decrease in the environmental quality (improved environmental quality), which can be attributed to the hindrance of pollution-oriented economic activities (Liu & Zhang, 2022). This result is consistent with the long-run PMG-ARDL findings which support the understanding whereby EPU may mitigate some economic activities that would harm environmental health.

Positive coefficients of FDI and GDP indicate their long-run detrimental effects on the quality of the environment. The overall findings indicate that whilst being important for economic development, FDI may also lead to environmental degradation where regulatory standards are not high (Li & Haneklaus, 2022; Zafar et al., 2022). These findings serve to validate the PMG-ARDL results that recommend tighter environmental regulations to address the negative externalities caused by foreign investments.

In contrast, we see that EC has a positive and highly significant effect on the decline of environmental quality (the coefficient is greater than unity). This finding is consistent with previous findings such as Iram et al. (2024), Acheampong et al. (2019), Weimin et al. (2022) and Musah et al. (2022), demonstrating that energy consumption still provides a great deal of pollution in BRICS, and the dependence of the region on fossil fuels in energy adds great risk to the environment. FMOLS outcome validates the PMG-ARDL results, noting that the policies must simultaneously address economic growth and environmental sustainability in BRICS nations. The substantial negative influence of energy consumption and FDI on environmental quality degradation shows the need for balanced policy measures to translate to a decade of cleaner energy consumption and sustainable investment practices.

Table 9: Panel-FMOLS Estimation Findings

Variable	Coefficient	t-Statistic	P-value
EPU	-0.1894	-1.78	0.0774**
Energy Consumption	1.0965	24.11	0.0000*
GDP	-0.1996	-3.58	0.0005*
FDI	0.1013	1.77	0.0785**

Conclusion

Over the years, this study investigates the effects of EPU, FDI, EC, and GDP on environmental quality in BRICS nation (Brazil, Russia, India, China & South Africa) for the period spanning from 1995 to 2023. The PMG-ARDL technique allowed the study to capture the long-run and short-run relationships between these variables, revealing noteworthy findings regarding the interaction between the level of economic activity, variations in environmental policy, and environmental quality outcomes. The results show a strong and positive impact of economic policy uncertainty on long-run environmental quality. The elevated economic uncertainty, however, can restrain pollution-intensive economic activities, and decrease energy use, which can indirectly improve the environment, as in times of uncertainty, various actors invested in the commitment might scale back on investment and consumption. This result corroborates previous studies indicating that EPU creates short-term economic downturns that lead to environmental benefits (Iqbal et al., 2023; Wen et al., 2022). This can yield temporary environmental benefits when lower economic activities generate lower emissions in times of high policy uncertainty.

Findings also reveal that FDI positively contributes to environmental quality indicating that although FDI serves as a driver of economic expansion, it can also drive environmental degradation, especially when funding high-pollutant industries. Consistent with the pollution haven hypothesis, FDI inflow(s) to countries with weaker environmental regulations may spread pollution, making environmental sustainability even more difficult. Nevertheless, FDI can also play a role in the promotion of sustainability under the condition that it is framed by legally binding systems that enable environmental investment.

Conversely, the result reveals that primary energy consumption has a significant negative effect on environmental quality in the short- and long-term. This only highlights how dependent BRICS countries continue to be on fossil fuels even though they adversely affect the quality of the environment. Consequently, the growing reliance on primary energy sources, particularly fossil fuel combustion, by the rapidly industrializing and economically growing BRICS countries, has led to significant levels of pollution and bus out sweetening with the findings from the studies attesting to energy consumption acting as the core detrimental factor in the degradation of environmental quality. Hence, these findings highlight the importance of BRICS governments investing in renewable energy projects like wind, solar, and hydropower for environmental sustainability by reducing the adverse effects of traditional energy consumption. So, BRICS policymakers might best serve the common good by promoting green investments that drive sustainable development without endangering environmental health.

Overall, this study shows that a more balanced policy is warranted in the future, as contested evidence on economic growth is reduced by incorporating also the factors that surround the economy and sustainability. Promoting cleaner energy sources, adopting strict and accountable regulatory measures with FDI, and assessing the influence of economic uncertainty on environmental policies are essential for BRICS economies and promoting sustainable development. Investing in research and development (R&D) for cleaner energy technologies also continues to be significant. These innovations could help BRICS countries to uncouple economic growth from environmental degradation, hence preparing them for more efficient and sustainable energy systems (Adams et al., 2020).

Such relevant future research could involve separating the effects of types of uncertainty – e.g., risk, and ambiguity – on environmental phenomena. A more nuanced understanding of how different types of policy uncertainty impact environmental quality will enable researchers and policymakers to devise climate policies that are both evidence-led and robust. Additionally, exploring how FDI could be utilized to facilitate green development would also enhance sustainable policymaking.

References

1. Abdella, Y., & Ying, L. (2023). FDI, environmental regulation, and carbon emissions: Evidence from developing economies. *Environmental Economics and Policy Studies, 25*(2), 203–220.
2. Acheampong, A. O., Erdurmazlı, E., & Mouhtarim, A. (2019). Energy consumption, carbon emissions, and economic growth: Evidence from the sub-Saharan region. *Renewable and Sustainable Energy Reviews, 112*, 234–247.

3. Adams, J., & Nsiah, C. (2019). Economic growth, governance, and carbon dioxide emissions in developing countries. *Applied Energy, 236*, 128–138.
4. Adams, S., Klobodu, E. K. M., & Apio, A. (2020). Renewable and non-renewable energy, regime type, and economic growth. *Renewable Energy, 150*, 668–678.
5. Adedoyin, F. F., & Akinsola, G. D. (2021). Energy consumption and environmental quality in Thailand: Evidence from VECM analysis. *Renewable and Sustainable Energy Reviews, 150*, 111423.
6. Adedoyin, F. F., Ozturk, I., Agboola, M. O., Agboola, O. P., & Bekun, F. V. (2020). Environmental pollution in the United Kingdom: The role of renewable energy consumption, FDI, and economic growth. *Science of the Total Environment, 732*, 139293.
7. Ahmed, M. A., Rehman, S., & Ahmed, A. (2022). Policy instability and ecological sustainability: The role of innovation activities. *Environmental Research Letters, 17*(3), 035006.
8. Alam, M. J., Raza, S. A., & Shahbaz, M. (2023). Green FDI, stringent environmental policies, and CO_2 emissions: Insights from emerging economies. *Environmental Science and Pollution Research, 30*(4), 5203–5216.
9. Alataş, S. (2022). A cross-sectional dependence perspective on the relationship between environmental quality and economic growth. *Environmental Science and Pollution Research, 29*(23), 34489–34502.
10. Alataş, S. (2022). Cross-sectional dependence and second-generation unit root tests in panel data. *Journal of Economic Research*, 34(4), 345–359.
11. Ali, S., Zaman, K., & Abdullah, A. (2022). Does FDI improve environmental sustainability? Evidence from South Asian economies. *Journal of Cleaner Production, 332*, 129910.
12. Ameer, N., Bhutta, M. A., Nawaz, D., Asghar, M. M., & Jawad, F. (2024). Navigating the Role of Remittances in Attaining Sustainable Development Goals in Developing Countries: New Insights from Panel ARDL Model. *The Critical Review of Social Sciences Studies*, *2*(2), 384-396.
13. Anser, M. K., Zhang, Z., & Usman, M. (2021). Impact of economic policy uncertainty on energy demand in China: Evidence from wavelet coherence analysis. *Energy Policy, 148*, 111956.
14. Asghar, M. M., Arshad, Z., Yousaf, S., e Ali, M. S., & Tariq, M. (2024). Environmental Degradation in BRI Countries: Navigating the Role of Natural Resources, Green Energy and Green Finance. *Pakistan Journal of Humanities and Social Sciences*, *12*(3), 2705-2716.
15. Asghar, M. M., Safdar, R., Zubair, M., & Hanif, M. (2024). Exploring the Influence of Financial Development, Institutional Quality and Trade Openness on Inclusive Growth in SAARC Countries. *Pakistan Journal of Humanities and Social Sciences*, *12*(2), 1450-1461.
16. Baker, S. R., Bloom, N., & Davis, S. J. (2016). Measuring economic policy uncertainty. *The Quarterly Journal of Economics, 131*(4), 1593–1636.
17. Bouri, E., Jain, A., & Roubaud, D. (2023). Geopolitical risk and environmental sustainability: Evidence from green energy markets. *Energy Economics, 108*, 105719.
18. Caglar, A., & Bayar, Y. (2024). Environmentally friendly investments and carbon footprint reduction: A sectoral analysis. *Journal of Environmental Economics and Management, 115*, 102223.
19. Chen, Y., Huang, J., & Wang, Y. (2016). Energy consumption, economic growth, and environmental degradation: Evidence from dynamic panel models. *Energy Policy, 99*, 132–142.
20. Chen, Y., Liu, C., & Zheng, M. (2021). Renewable energy and environmental quality: Evidence from Saudi Arabia. *Energy Economics, 101*, 105462.

21. Dauda, R. O. S., Long, X., Mensah, C. N., & Salman, M. (2021). The effects of economic growth and innovation on CO2 emissions in different regions. *Environmental Science and Pollution Research, 28*(11), 13612–13630.
22. Ding, S., Wang, C., & Liu, Z. (2022). Economic policy uncertainty and corporate investment in green technologies. *Journal of Environmental Economics and Policy, 12*(2), 240–256.
23. Dogan, E., & Alkan, C. (2022). Economic policy uncertainty and CO_2 emissions: Evidence from emerging markets. *Journal of Environmental Management, 302*, 113964.
24. Dogan, E., & Altinoz, B. (2020). The nexus between economic growth, energy consumption, and environmental quality in BRICS economies. *Energy, 190*, 116218.
25. Dogan, E., Tzeremes, P. G., & Tzeremes, N. G. (2023). Energy efficiency, renewable energy, and environmental degradation in BRICS countries. *Renewable Energy, 198*, 386–395.
26. Dumitrescu, E.-I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling, 29*(4), 1450–1460.
27. Dutta, A., Das, S., & Ghosh, S. (2023). Green FDI and environmental sustainability in developing economies: Regulatory frameworks and impact. *Journal of Cleaner Production, 381*, 135342.
28. Fang, Z., Xu, Y., & Zhang, L. (2023). The impact of FDI and energy consumption on CO_2 emissions: Evidence from BRICS countries. *Energy Policy, 165*, 112961.
29. Fang, Z., Yuan, W., & Li, Q. (2023). FDI inflows and carbon emissions: A study on BRICS countries. *Journal of Environmental Management, 339*, 117876.
30. Gao, X., Hu, Z., & Li, Y. (2023). CO_2 emissions, trade openness, and energy consumption in BRICS countries. *Sustainable Development, 31*(3), 555–566.
31. Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics, 110*(2), 353–377.
32. Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics, 110*(2), 353–377.
33. Hossain, M. S., & Saifullah, M. (2021). Foreign direct investment and environmental degradation: Empirical evidence from developing countries. *Journal of Economic Development, 46*(3), 85–102.
34. Huang, X., Li, J., & Wang, Y. (2023). Economic policy uncertainty and its effects on environmental investments in China. *Journal of Cleaner Production, 398*, 136658.
35. Huang, Y., Zhang, J., & Zhang, W. (2023). The economic consequences of policy uncertainty: Evidence from global markets. *Economic Modelling, 118*, 105739.
36. International Energy Agency (IEA). (2023). Global CO_2 emissions in 2021: Analysis and data insights. Retrieved from https://www.iea.org
37. Iqbal, N., Yousaf, U., & Rauf, A. (2023). Economic policy uncertainty and environmental sustainability: Evidence from panel data. *Journal of Cleaner Production, 385*, 135767.
38. Iram, M., Zameer, S., & Asghar, M. M. (2024). Financial Development, ICT Use, Renewable Energy Consumption and Foreign Direct Investment Impacts on Environmental Degradation in OIC Countries. *Pakistan Journal of Humanities and Social Sciences, 12*(2), 1303-1315.
39. Jiang, P., Chen, S., & Wang, F. (2021). Economic policy uncertainty and carbon emissions in transportation: A sectoral analysis. *Transportation Research Part D: Transport and Environment, 96*, 102821.
40. Khan, M. T., & Khan, M. M. (2024). Renewable energy consumption and environmental quality: Evidence from Saudi Arabia. *Energy Reports, 10*, 302–312.
41. Li, J., & Haneklaus, N. (2022). FDI, economic development, and environmental quality: A cross-country analysis. *Environmental Economics and Policy Studies, 24*(1), 119–135.

42. Liu, G., & Zhang, Y. (2022). Economic policy uncertainty and CO2 emissions: Evidence from China's provincial data. *Ecological Economics*, *194*, 107331.
43. Liu, J., & Zhang, Y. (2022). Economic policy uncertainty and environmental outcomes: Evidence from Chinese energy sectors. *Energy Policy, 168*, 113163.
44. Luo, L., & Lu, Z. (2022). FDI, institutional quality, and carbon emissions in emerging economies. *Journal of Environmental Economics and Management, 111*, 102608.
45. McKoskey, C., & Kao, C. (1998). A residual-based test of the null of cointegration in panel data. *Econometric Reviews, 17*(1), 57–84.
46. Muhammad, M., Hassan, R., & Tariq, Z. (2022). Foreign direct investment and pollution haven hypothesis: Evidence from South Asia. *Journal of Cleaner Production, 371*, 132947.
47. Musah, M., Agyapong, E. K., & Obeng, E. (2022). Energy consumption and environmental degradation in North Africa: A VECM approach. *Energy Policy*, *162*, 112787.
48. Mushtaq, M., Iqbal, J., & Rehman, A. (2024). Exploring the effects of economic policy uncertainty on CO_2 emissions: Evidence from emerging markets. *Environmental Research, 220*, 115172.
49. Nguyen, T. T., & Bui, M. T. (2023). Economic complexity and environmental degradation in BRICS countries: An empirical analysis. *Environmental Science and Policy, 141*, 141–152.
50. Pavlova, E., & Li, Z. (2023). Assessing the impact of renewable energy policies on carbon emissions in BRICS countries. *Energy Research & Social Science, 99*, 103118.
51. Pavlovic, I., & Chen, L. (2023). Green innovation in uncertain times: A global perspective on ecological sustainability. *Journal of Innovation and Sustainability, 28*(1), 65–82.
52. Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, *20*(3), 597–625.
53. Pesaran, M. H. (2004). General diagnostic tests for cross-section dependence in panels. *Cambridge Working Papers in Economics,* 435.
54. Pesaran, M. H. (2004). General diagnostic tests for cross-sectional dependence in panels. *CESifo Working Paper Series No. 1229.*
55. Pirgaip, B., & Dinçergök, Y. (2020). Environmental effects of economic policy uncertainty: Evidence from G7 countries. *Environmental Science and Pollution Research, 27*(8), 9431–9443.
56. Pradhan, P., Bahadur, K. C. R., & Fischer, G. (2024). Renewable energy transitions and environmental quality in G7 and South Asian countries. *Global Environmental Change, 88*, 102682.
57. Qiao, J., Yuan, C., & Zhou, X. (2019). Examining the dynamic impact of GDP on CO2 emissions in emerging markets. *Sustainability, 11*(5), 1372.
58. Selmy, A., & Elamer, A. (2023). Economic policy uncertainty and green investment: Lessons from emerging economies. *Energy Research & Social Science, 96*, 103015.
59. Shah, A., & Kautish, P. (2022). Pollution haven or pollution halo? Evidence from FDI inflows in developing economies. *Environmental Research*, *211*, 113032.
60. Sharma, R., & Kautish, P. (2022). Pollution halo hypothesis and green FDI in developing economies. *International Journal of Energy Economics and Policy, 12*(3), 302–310.
61. Shen, B., Zhang, R., & Liu, Q. (2022). Sectoral impacts of foreign direct investment on environmental quality: A comparative analysis. *Ecological Indicators, 134*, 108567.
62. Syed, M. A., & Bouri, E. (2022). Economic policy uncertainty and its environmental implications: A global perspective. *Journal of Environmental Management, 305*, 113784.
63. Tang, X., Wang, Y., & Liu, J. (2023). The role of economic policy uncertainty in shaping sustainable development. *Sustainability, 15*(4), 1893–1910.

64. Wang, Q., & Fang, Z. (2018). Renewable energy consumption and carbon emissions in G20 countries. *Journal of Environmental Economics and Policy, 27*(3), 409–423.
65. Wang, S., & Liu, X. (2021). Macroeconomic instability and its impact on green investments. *Environmental Policy Studies, 19*(4), 245–259.
66. Wang, Y., & Fang, S. (2018). Energy consumption and environmental quality: Evidence from a global analysis. *Renewable and Sustainable Energy Reviews, 92*, 301–310.
67. Wang, Y., Zhou, L., & Liu, W. (2023). FDI, trade, and carbon emissions: A study of BRICS economies. *Environmental Research and Policy, 14*(2), 167–182.
68. Weimin, Z., Sibt-e-Ali, M., Tariq, M., Dagar, V., & Khan, M. K. (2022). Globalization toward environmental sustainability and electricity consumption to environmental degradation: does EKC inverted U-shaped hypothesis exist between squared economic growth and CO 2 emissions in top globalized economies. *Environmental Science & Pollution Research*, *29*(40).
69. Wen, H., Sun, Y., & Gao, Z. (2022). The nonlinear effects of economic policy uncertainty on environmental quality: A panel threshold analysis. *Journal of Environmental Management, 306*, 114418.
70. Wen, X., Liu, H., & Zhang, Y. (2022). How economic policy uncertainty influences CO_2 emissions: Evidence from multi-country analysis. *Energy Economics, 107*, 105873.
71. Westerlund, J., & Edgerton, D. L. (2007). A panel bootstrap cointegration test. *Economics Letters, 97*(3), 185–190.
72. Westerlund, J., & Edgerton, D. L. (2007). A panel bootstrap cointegration test. *Economics Letters, 97*(3), 185–190.
73. World Bank. (2022). World Development Indicators. Washington, DC: World Bank Group. Retrieved from https://data.worldbank.org
74. Yasmin, S., & Rehman, Z. (2023). Foreign direct investment and carbon emissions: A cross-country analysis of pollution havens. *Journal of Environmental Economics, 56*(2), 185–199.
75. Zafar, M. W., Saud, S., & Ullah, S. (2022). Foreign direct investment, energy consumption, and CO2 emissions: Assessing the role of environmental regulations. *Journal of Environmental Management, 316*, 114803.
76. Zakari, A., & Ying, S. (2021). Economic policy uncertainty and environmental sustainability: Fresh evidence from the Belt and Road Initiative countries. *Sustainable Development, 29*(3), 453–467.
77. Zhao, X., & Wu, Y. (2023). Energy efficiency and environmental quality: A case study of emerging markets. *Environmental Economics and Policy Studies, 25*(4), 761–778.
78. Zhou, X., Zhang, R., & Zhao, H. (2023). BRICS energy transition and its impact on carbon neutrality. *Energy Reports, 9*, 45–58.