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Exploring the Role of Natural Resources and Economic Policy Uncertainty on Environmental Quality: Fresh Evidence from BRICST Economies

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ABSTRACT

Environmental degradation is a global issue that has captured the attention of governments worldwide, as it can disrupt the Earth's carbon cycle and contribute to global warming. Climate change, primarily driven by greenhouse gas emissions such as CO_2 pollution, is one of the most pressing challenges facing humanity today. Researchers have studied various social, political, and environmental factors that affect CO_2 emissions. This study aims to explore how natural resources (NRR) and economic policy uncertainty (EPU) impact environmental degradation, considering the Environmental Kuznets Curve (EKC). We use an auto-regressive distributed lag (ARDL) regression model with annual data from 1990 to 2020. The findings suggest that increases in natural resource rent lead to higher CO_2 emissions. Likewise, EPU also has a positive effect on environmental degradation. The observed positive link between GDP and CO_2 emissions, along with the negative relationship between GDP2 and CO_2 emissions, supports the EKC hypothesis for BRICS-T countries. Based on the empirical results, this study provides a comprehensive policy framework for achieving the Sustainable Development Goals (SDGs), such as SDG 08 (economic growth), SDG 13 (climate action), and SDG 12 (resource efficiency).

Keywords: Environmental Kuznets Curve, Natural Resource Rents, CO_2 Emission, Sustainable Development Goals, BRICST Countries
JEL Classifications: C23, O13, O44, Q53, Q56

1. INTRODUCTION

Environmental degradation (EDE) is a serious threat that affects the world and has captured the attention of governments worldwide, as it can disrupt the global carbon cycle and contribute to global warming. One of the most pressing issues facing humanity today is climate change, driven primarily by greenhouse gas emissions (GHGs), including CO_2 pollution. These emissions pose unprecedented risks to human well-being, human rights, and survival (Dong et al., 2018; Suresh and Rajendran, 2022;

Kartal et al., 2025). The primary human activity contributing to pollution is the burning of fossil fuels, although certain production processes and changes in land use also release CO_2. The potential physiological, physical, and ecological implications of climate change and global warming are manifold. These effects include increased sea levels, disruptions to water systems, inhibited plant development, and severe weather events such as heatwaves, storms, and droughts (He et al., 2021; Yang et al., 2024). Owing to the enormous cost burden of cleaning up landfills and protecting endangered species, a nation may suffer from environmental deterioration with potentially disastrous economic repercussions. Thus, one of the contemporary global challenges that has been included in the political agendas of many countries is environmental protection and related rights. Considering that this study can offer insights into the macroeconomic variables of EDE, some research has been conducted to identify pollution drivers and comprehend the economic aspects of EDE (Alola and Kirikaleli, 2019; Adebayo et al., 2020; Bilgili et al., 2024).

Researchers (Ma et al., 2021; Sun et al., 2022) have investigated various social, political, and environmental factors that influence CO_2 emissions. Economic policy uncertainty (EPU) can be viewed as a risk associated with the legal and regulatory environment that impacts individuals and businesses. Due to its significant environmental impact, experts have noted that EPU is a major source of emissions. The government's sudden policy changes might lead to an EPU, which can have an influence on the economy and the environment. As such, the financial and public sectors deteriorate (Pirgaip and Dinçergok, 2020; Majeed and Luni, 2019). Economic actors (consumers and producers) adjust their investment and consumption choices in an unpredictable environment. Three distinct possibilities exist for their decisions to affect the environment. First, using traditional inexpensive energy sources for manufacturing to reduce risks and turnover has an indirect effect on the organization (Wang et al., 2020). Second, when environmental quality (EQ) improves and emissions decrease as a result of businesses reducing their output, the impact is likely to be positive. Third, according to Abbasi and Adedoyin (2021), the association may not be substantial. According to Wang et al. (2020), the "investment effect" and the "consumption effect" in the literature are linked to EPU and environmental deterioration. According to the investment impact, there will be a rise in carbon emissions (CE) as a result of EPU's inhibition of investments in clean technology and R&D. On the other hand, the consumption impact shows that EPU reduces the use of commodities that are high in pollution and energy. This led to a decline in CE.

Similarly, a major factor in establishing the degree of CE is natural resources (NR). It is widely accepted that countries endowed with important natural resources experience quicker growth than those lacking such advantages. Numerous investigations have been conducted in this area to determine the relationship between NR and EG (Clootens and Kirat, 2020; Hayat and Tahir, 2021). Some researchers, nonetheless, contend that NR is a curse in some cases because it has led to high levels of EPU, low institutional performance, and income inequality, all of which have a negative impact on a nation's environmental performance (Masi et al., 2020). It has also been discovered that there is very little agreement in the research currently in publication on the nature of the relationship, whether it be positive or negative, between NR and environmental performance. According to some scholars, NR hinders CE by advancing infrastructure, technology, and human capital (Badeeb et al., 2020). According to a study from a different line of investigation, NR revenue does not push economies to continuously improve their human capital and technological capabilities. Due to this, nations continue to employ outdated technology with low energy efficiency; as a result, CE is predicted to increase (Agboola et al., 2021; Shen et al., 2021). The NR-CE link has to be reexamined in light of the conflicting results.

Economists have disagreed much over how EDE and EG are related. According to the EKC theory, at a certain point in economic growth, EDE decreases with GDP. However, in the initial phases of EG, it grows with income (Andreoni and Levinson, 2001). The traditional EKC theory is valid when pollution is produced at an early stage of development, resulting from increased output and resource exploitation. The term "scale effect of production on the environment" describes this. For the simple reason that nations with greater GDP create and utilize more products and services, there is a scale impact. As production processes and output mix remain unchanged, an increase in size always results in a corresponding increase in pollution. When production shifts from primary to industrial production, the scale effect produces the upward trend of the EKC. Economic development at this stage provides opportunities for investments in information-based services and industries, as well as in enhancing manufacturing methods and implementing more sustainable technologies. These are referred to as composition and technique effects (Shafik and Bandyopadhyay, 1992). The overall pollution trend should decrease as production increases if the impacts of composition and technique effects are significant enough, leading to a decreasing trend in EKC. Stated differently, the scale impact can be mitigated by the effects of composition and technique (Dinda, 2004). This suggests that since technology can predict the duration required to reach the EKC turning point, it is a significant force shaping the EKC's shape (Du and Xie, 2020). Technology makes it possible to use cleaner technologies, which lower CO_2 emissions and hasten the change in environmental conditions, or to use less input per unit of output.

However, due to their low level of technology, resource-based nations face significant challenges (Papyrakis and Gerlagh, 2004). With human and physical capital moving from the manufacturing sector to the construction sector, most resource-based nations experience the Dutch disease phenomenon. This might lead to resource-based economies experiencing more unsustainable growth patterns (Ross, 1999; Badeeb et al., 2017). According to Shao and Yang (2014), the manufacturing sector has high technology, whereas the construction sector has low technology. This indicates that in resource-based nations, low-tech industries have displaced high-tech businesses. Therefore, access to advanced greener technology will be restricted in resource-based nations. Consequently, the technique and composition effect will be hindered, and the scale effect cannot be addressed. Additionally, the scale effect may be increased since the initial phase of EG is dependent on highly polluting industries, such as oil and gas production.

BRICS-T economies have experienced significant economic development in recent decades, with an average annual GDP growth of approximately 7%. This paper has selected these nations for pragmatic investigation. In addition, the BRICST areas account for 42% of the world's population, hold foreign reserves exceeding USD 5 trillion, and contribute 25% of the world's GDP. The use of fossil energy resources has increased the externalities associated with climate change, despite rising modernization (Siddiqui et al., 2023). For instance, BRICST countries account for 40% of the world's fossil fuel consumption, which poses significant environmental risks to the global community. To achieve sustainable development, BRICST economies have demonstrated a stronger readiness to engage in environmental initiatives aimed at lowering GHGs, diversifying their energy sources, and utilizing cutting-edge environmental technology (Gyamfi et al., 2022).

The BRICST nations' agricultural position has steadily improved internationally in recent years. Over half of the global total gross agricultural production in 2018 came from the BRICST nations (Zhang, 2018). Despite this, these nations have changed from being mostly agrarian to being manufacturing-based. NR continues to be crucial for economic growth, raising questions about whether the BRICST countries are cursed by their abundant resources (Bekhet and Othman, 2018). Premature negative deindustrialization has been plaguing these nations since 2000, as seen by a decline in manufacturing production and value-added (Rasiah et al., 2011). As evidence suggests that they have not been able to effectively transition to higher-value-added manufacturing industries, the economies of the BRICST nations have heightened concerns that they are stuck in a middle-income trap (Suehiro, 2019). The industrial sector is contracting, which might lead to broad environmental concerns and hinder the rate of environmental development. These factors can have a negative influence on economic prospects (Du and Xie, 2020). By 2020, the BRICST countries want to become high-income countries. To promote development and change, more energy is needed to reach this goal (Shafie et al., 2011). The present study investigated this relationship. For this purpose, we are employing an autoregressive distributed lag regression model with yearly data from 1990 to 2020. The structure of the remaining paper is as follows: The relevant literature on the topic is reviewed in Part 2. The theoretical framework and related theories are discussed in Part 3. The data and method are presented in Part 4. The results and discussion are presented in Part 5, and the conclusion and policy implications are presented in the last section.

2. LITERATURE REVIEW

Developing economies continue to face several challenges in their pursuit of sustainable development. One of the primary challenges these nations face is environmental degradation, which must be addressed by reducing global carbon dioxide emissions. Otherwise, the rising trend of CO_2 emissions might be more problematic (IPCC, 2018). The discussion of environmental deterioration, climate change, and global warming has therefore increased in recent years. The degradation of the ecosystem is one consequence of energy production (Mukhtarov, 2022). The use of fossil fuels accelerates EDE due to increased demand and a limited energy supply (Ojekemi et al., 2023). As a result, the largest rate of GHG emissions is CO_2. According to Olivier et al. (2012), industrialized countries are a significant contributor to global environmental degradation. However, this situation is shifting as developing nations such as the BRICS-T economies start to make greater contributions to environmental deterioration.

Economic policy uncertainty (Su et al., 2022; Adebayo et al., 2022), natural resources (Wen et al., 2022; Kirikkaleli and Umar, 2024), and EG are some of the factors that are discussed in the literature as contributing to environmental degradation. EPU can be linked to several circumstances that lead to unclear economic policy, including the COVID-19 epidemic, the financial crisis, China-US trade war, and Brexit. EPU contributes to both poor EG and EDE. This is because EPU increases environmental damage by lowering economic development and energy consumption. EPU can also impede technological innovation, research and development, and the creation of renewable energy sources, all of which contribute to environmental deterioration (Anser et al., 2021). Sekrafi and Sghaier (2018) have emphasised that corruption in the government may also compromise effective guidance and control, thereby hindering the achievement of EQ. On the other hand, political stability can help mitigate environmental deterioration by enacting effective regulations that reduce pollution and waste, thereby protecting the environment (Helland and Whitford, 2003). Strong institutions promote environmental quality by reducing corruption and enabling the effective implementation of strict ecological legislation (Ahmad et al., 2021). However, countries with weak institutions have corruption, ineffective bureaucracy, and inadequate environmental regulations (Danish and Ulucak, 2020). To suggest measures to combat environmental degradation, it is necessary to establish the association between EPU and EDE, a matter of ongoing discussion (Vu and Huang, 2020; Farooq et al., 2023). A comprehensive explanation is provided, grounded in theoretical and empirical investigations of the relationship between emissions caused by the increase in energy. Since it is impossible to fully describe the association between GDP growth and CO_2 in isolation, the research that follows Nassani et al. (2017)'s literature analysis includes several other factors and examines how they impact CO_2. As the subsample, research on Asian nations is examined, yielding differing conclusions (Apergis and Ozturk, 2015; Li et al., 2022). Nevertheless, every other study—aside from Niu et al. (2011)—has treated different nations as a single entity.

2.1. Economic Policy Uncertainty and CO_2 Emission

Several variables, beyond economic expansion, contribute to environmental degradation. This study references multiple studies on the independent variables influencing EDE. This study cites several studies on the independent variables influencing EDE. Notably, the economic risk associated with uncertain or unknown future legislative acts and regulatory changes is referred to as "policy uncertainty." It can arise from various factors, including legal changes, shifts in the global economy, and advancements in technology. It can also obscure the resources sector. Businesses may struggle to take risks or make informed decisions without clear laws and regulations in place. Therefore, rules and regulations are crucial in addressing EPU because they provide clarity, stability, and predictability to individuals and companies (Bai et al., 2023). The existing literature has yet to explore the link between EPU and EDE. There are limited studies analyzing how EPU influences EDE. For example, Jiang et al. (2019) investigate the causal connection between EPU and EDE, finding a one-way relationship between EDE uncertainty in sectors like transportation, power generation, and industry, and EPU. Adedoyin and Zakari (2020) examine the relationship between EPU and EDE in the UK, concluding that EPU has both short- and long-term heterogeneous effects on CO_2. Additionally, Pirgaip and Dinçergök (2020) study the connection between EPU and CO_2 in G7 countries, noting that the CO_2 emissions of only a few G7 nations are impacted by EPU. EPU plays a role in linking energy consumption to emissions by slowing the rise of CO_2 emissions. Over time, the effect of EPU varies and reacts to increasing CO_2 emissions. There are unidirectional causal links between energy use and CO_2, CO_2 and EPU, as well as energy use and EPU. Moreover, a direct relationship exists between EPU and CO_2; however, sustained reliance on this relationship over time leads to environmental degradation. Consequently, the government should consider developing a long-term policy to manage EPU (Hoque et al., 2023). For instance, Anser et al. (2021) suggest that the short-term impact of EPU on EDE is positive, while its long-term impact is negative. Conversely, Syed and Bouri (2022) found that EPU has a long-term direct effect on EDE, despite having a negative short-term impact.

2.2. Economic Growth and CO_2 Emission

Numerous studies have examined the relationship between EG and CO_2 (Kasman and Duman, 2015; Dogan and Turkekul, 2016; Magazzino et al., 2023). According to the EKC, most of these studies explore the connection between environmental quality and EG. The EKC describes a relationship between GDP and EDE. EDE increases in the early stages of EG, but this pattern reverses once GDP reaches a certain point. This suggests that the relationship between EDE and GDP has an inverted U-shape (Stern, 2018). Based on the EKC theory, sectoral shifts tend to favour less-polluting sectors as economic growth and wealth expand, with industry share declining as the service sector expands (Jänicke et al., 1997; Muğaloğlu et al., 2023). The literature review notes that research, such as Suki et al. (2020) and Raza et al. (2020), supports the EKC theory. However, studies like those by Erdogan et al. (2020) did not yield the results predicted by the EKC hypothesis. Gormus and Aydin (2020) and Murshed et al. (2022) found that while the EKC holds for some economies, it does not for others. Ansari (2022) also concluded that the EKC theory is invalid for GHGs but valid for EDE. Conversely, several studies have shown the EKC theory to be invalid for ecological footprints (Dogan et al., 2020; Bilgili et al., 2024; Saleem et al., 2025).

Nonetheless, due to the complexity of the link between EG and EDE, several scholars have proposed adding one or more variables to the EKC model explanation (Paramati et al., 2018; Magazzino et al., 2023). Research more frequently includes financial development and energy use when discussing the relationship between EDE and EG (Shahbaz et al., 2013; Hashmi et al., 2025). Researchers are also paying particular attention to industrialization, trade openness, and urbanization (Sbia et al., 2014; Rafiq et al., 2020). Additional characteristics that may affect environmental quality include democracy, literacy, and wealth inequality, according to existing empirical research (Grossman and Krueger, 1995). Inconclusive results may stem from factors such as the length of the study period, the estimation methods used, and the inclusion of different control variables. We believe that incorporating NRD as a potential factor influencing the form of the EKC could expand current research. In this study, we aim to examine the connections between CO_2 emissions, EG, and NRD. This will enhance our understanding of the interconnection between economic growth and environmental protection.

2.3. Natural Resources and CO_2 Emission

The economy's expansion and the improvement of people's quality of life have heavily relied on energy, natural resources, and technological progress. For example, Khan et al. (2023) highlighted that technological innovation played a vital role in helping Asian economies address climate change. They also observed that the primary contributors to climate change in these nations are the exhaustion of resources and the excessive consumption of nonrenewable energy. Nevertheless, advancements in the economic and technological sectors of the region may serve as important strategies for mitigating climate change. The main objective of the energy system is to ensure an adequate energy supply at the lowest feasible cost. In recent years, the global community has been exploring methods to decarbonize the Earth through the effective and sensible use of technological innovation (Cai et al., 2022). Although the economic advantages of utilizing fossil fuels are clear, it is important to recognize that their detrimental external effects, including pollution and depletion of natural resources, can result in significant and lasting consequences (Shang et al., 2023). As stated by Onifade and Alola (2022), investment in research and development is vital for fostering technological progress, innovation, and economic expansion. Consequently, this will encourage the responsible use of natural resources and promote the generation of environmentally friendly energy. In middle-income countries, insufficient investment in the energy sector results in elevated carbon emissions, with a substantial portion of funding directed towards fossil fuels (Tariq et al., 2025). Therefore, emissions of greenhouse gases and carbon emissions in South and Southeast Asian economies can be attributed to the combustion of fossil fuels.

As stated by Ahmed et al. (2022), advancements in technology propel sustained growth across various industries. The relationship between technological advancement and productivity has also been a subject of exploration within endogenous growth theories. Samour et al. (2022) indicate that technological differences can provide both the business sector and the energy industry with a competitive edge. Since the mid-1990s, there has been a decline in support for the energy sector, and the industrial sector's dependence on outdated technologies has heightened pressure on the energy sector, resulting in inefficient use of natural resources. Research by Adebayo et al. (2022) further highlighted the importance of technological progress in safeguarding the natural capital of BRICS nations. They determined that technological progress is essential for safeguarding natural resources and ensuring their efficient use in the countries studied. The public sector plays a vital role in making certain that individuals reap the benefits of technological advancements. Insufficient industrial investment in various technology sectors generally heightens environmental challenges, particularly in developing or low-income countries (Ameer et al., 2025).

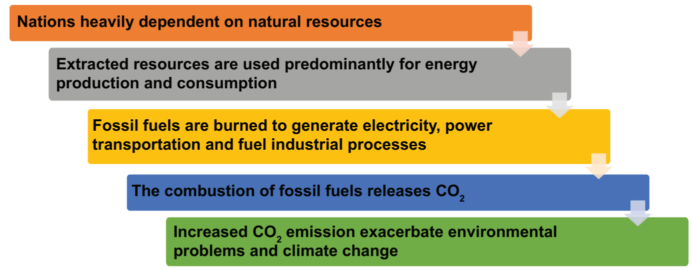
2.4. Evaluation of the Literature

A growing number of countries, politicians, societies, and the general public are interested in the current literature on environmental progress. Numerous explanatory variables that may be useful in preventing environmental deterioration are considered in the current literature, along with a range of indicators (such as CO_2 and environmental footprint). Many nations and country groups have been examined in recent research using a variety of different analysis techniques. Many studies have examined the impact of natural resources, GDP, economic policy uncertainty, and other factors on environmental quality in a number of nations (such as China, Bangladesh, France, India, and the G7). However, no research has looked at the impact of natural resources and EPU on environmental degradation for BRICST nations in the presence of environmental degradation. Hence, a gap exists in the literature. This study fills this gap in the literature by examining the effect of NRR and EPU on environmental degradation in BRICST economies.

2.4.1. Theoretical framework

The heightened risk of blackouts due to depletion of resources is a result of this excessive dependency. To grow the economy while protecting the environment, policymakers need to advocate for alternative energy developments. This is the reason developed countries invest in and use renewable energy options such as solar, biomass, geothermal, tidal, hydropower, and wind energy. The growing demand for natural resources that accompanies a booming economy significantly contributes to environmental harm (Ramzan et al., 2022). Industrialization, driven by a country's expanding economy, increases the demand for and consumption of natural resources. The overuse of natural resources affects both a country's biocapacity and its ecological deficit. Besides accelerating the depletion of natural resources, these economic methods also heighten the volume and toxicity of waste generated, which in turn raises carbon emissions in the environment. Nonetheless, some experts have argued that resource extraction should be viewed from a production standpoint, while emissions are considered from a consumption angle. Thus, the extensive extraction of natural resources for export and profit inadvertently contributes to carbon emissions in the BRICS economies. Consequently, it is essential to treat carbon emissions as a dependent variable rather than focusing on production-related emissions. However, since this study centres on the EKC model, utilizing production-based emissions would not be suitable for the current research. According to the EKC theory, up to a threshold, EDE in the early phases of development is often caused by EG. The economy then advances to the next stage of growth. At this point, more EG will reduce EDE as new rules are developed, new technologies are developed, and material demands are reduced (Canel et al., 2010). Stated differently, there will be a negative correlation between EG and EDE. Any rise in EG resource-based economies is attributed to increased levels of natural resource extraction, which will exacerbate environmental damage (Figure 1).

Figure 1: The effect of natural resources dependence on environmental degradation



3. MODEL SPECIFICATION

In our study, environmental degradation is used as a dependent variable. Natural resource rent, economic policy uncertainty, and economic growth are used as independent variables. All variables are analyzed in natural logarithmic form.

The main econometrics function analyzed in this study is reported in Equation 1.

$$CO2_{it} = f(GDPpc_{it}, GDPpc2_{it}, NRR_{it}, EPU_{it}) \quad (1)$$

$$\ln(CO2_{it}) = \beta_0 + \beta_1 \ln(GDPpc_{it}) + \beta_2 \ln(GDPpc2_{it}) + \beta_3 \ln(NRR_{it}) + \beta_4 \ln(EPU_{it}) + \mu_{it} \quad (2)$$

3.1. Econometric Technique

The research employed various econometric techniques to confirm the connections between EDE and selected explanatory factors (Figure 2).

3.1.1. Unit root test

To examine the long-run relationship between the determinants, we initially conducted panel unit root tests to establish the stationarity of the data. Utilizing panel unit root tests is preferable to specific unit root tests, as it enhances the characteristics of the data series through cross-sections. Considering the limited power of standard stationarity tests, we have applied panel stationarity tests that account for the features of panel data, both in terms of time and cross-sectional dimensions. We employed the Im et al., 2003, and the ADF-Fisher panel test to assess stationarity. The Im, Pesaran, and Shin (IPS) test builds on the Levin et al. (2002) test by allowing for a heterogeneous coefficient. In the IPS unit root test, the possibility of varying coefficients across all i is incorporated using the model outlined here:

$$\Delta y_{it} = \sigma_i + \varphi_i y_{it-1} + \sum_{j=1}^{k} \alpha_j \Delta y_{it-j} + \theta_i t + \vartheta_t + \epsilon_{it} \quad (3)$$

Equation 3 illustrates the IPS test based on the average ADF statistics across multiple entities. The null hypothesis is stated as H_o: $\varphi_i = 0$ for all i, in contrast to the alternative hypothesis H_1: $\varphi_i < 0$ for at least one i. The purpose of the H_0 is to confirm the existence of a unit root issue. In contrast, the alternative hypothesis aims to identify the stationarity present in the panel data series.

Figure 2: Econometric analysis

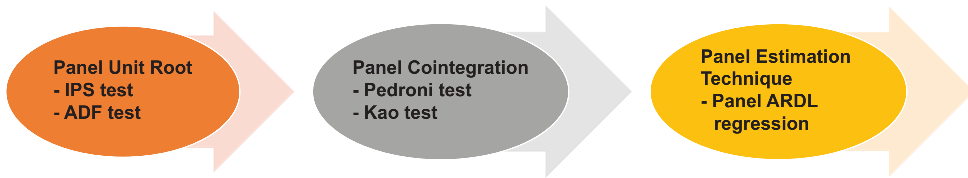


Table 1: Description of the variables and data source

Variables	Definition	Abbreviation	Source
Carbon dioxide emission	Carbon dioxide emissions (metric tons per capita)	CO_2	World Bank (2023)
Natural Resource	Total natural resource rents (percentage of GDP)	NR	World Bank (2023)
Economic Policy Uncertainty	World Uncertainty Index	EPU	EPU (2023)
Gross Domestic Product	GDP per capita (constant 2015 US$)	GDP	World Bank (2023)
Square of Gross Domestic Product	Squared term of GDP per capita	GDP^2	World Bank (2023)

All variables used after taking natural logarithm.

The ADF test was proposed by Maddala and Wu (1999) as follows:

$$\tau = -2\sum_{i=0}^{n} ln\rho_i \quad (4)$$

In this context, P-values show the results of separate ADF tests for individual cross-section i, based on the chi-square distribution with 2n degrees of freedom.

3.1.2. Panel cointegration test

The long-term relationship among the determinants has been established using Pedroni and Kao cointegration tests. Pedroni (1999) introduces multiple tests that account for heterogeneity between cointegrated vectors. Kao's cointegration test has also been applied because it can address the heterogeneity among cointegrating vectors. However, it overlooks the issue of endogeneity of explanatory factors due to its asymptotic uniformity. The equation of the cointegration regression, as outlined by Pedroni (2004), is presented as:

$$y_{it} = \sigma_i + \partial_{it} + \alpha_{1i}x_{1it} + \alpha_{2i}x_{2it} + \ldots + \alpha_{mi}x_{mit} + \varepsilon_{it} \quad (5)$$

In equation 5, the parameter σ_i represents constant influences, while the deterministic trend is represented by ∂_{it}.

3.1.3. Panel estimation technique

We utilized the ARDL model to investigate our time series data to identify any long- and short-term equilibrium. The ARDL model effectively addresses two prevalent issues in panel data analysis: endogeneity and serial correlation. Endogeneity occurs when the independent variables are correlated with the error term, whereas serial correlation involves the correlation of error terms over time. To address these concerns, the ARDL model incorporates lagged dependent variables and error correction terms, which substantially mitigate the issues associated with endogeneity and serial correlation. In this research, we adopted the ARDL model in conjunction with the Pedroni cointegration test to assess the long- and short-run relationships among our variables of interest. The Pedroni cointegration test is a widely used approach for panel data analysis that helps us ascertain whether a stable long-run equilibrium is present.

To establish the suitable lag length for the ARDL model, we employed the Akaike Information Criterion (AIC). This criterion helped us select the optimal number of lags that accurately represent the dynamics of the variables without leading to overfitting. The panel ARDL analysis considers both the cross-sectional and time-series aspects of the data, enabling the simultaneous estimation of both long- and short-term coefficients while accounting for heterogeneity across the panel units. Estimation is generally performed using panel data estimation methods, such as Pooled OLS, Fixed Effects, or Random Effects models. By applying the ARDL model in conjunction with the Pedroni cointegration test and panel data techniques, we can thoroughly analyze the relationships among our variables. This method addresses the dynamic characteristics of the data, considers potential long-run equilibrium, and accommodates variations among the panel units.

Table 2: Descriptive statistics

Estimation	CO_2	GDP	NRR	EPU
Mean	1.360	8.392	1.015	−1.827
Median	1.391	8.699	1.178	−1.717
Maximum	2.835	9.408	3.068	0.295
Minimum	−0.403	6.276	−1.938	−4.370
Std. Dev.	0.828	0.832	1.124	0.864
Skewness	−0.265	−1.149	−0.6001	−0.259
Kurtosis	1.959	3.113	2.928	2.987
Jarque-Bera	10.559	41.047	11.234	2.089
Probability	0.005	0.000	0.004	0.352

3.2. Data Source

This study examines the impact of NRR and EPU on CO_2 emissions in the presence of the EKC for BRICST economies. The data sources and variable definitions utilized in our research for the BRICST countries from 1990 to 2020 are listed in Table 1. Before analysis, all of the data is converted to natural log form.

4. RESULTS AND DISCUSSIONS

The descriptive statistics are displayed in Table 2. The variable with the lowest average is the EPU, with an estimated value of −1.827, while the GDP has the greatest average, with a typical value of 8.392. NRR has the highest standard deviation (1.124), while CO_2 has the lowest (0.828). The results of the Jarque-Bera test P-values indicates that the data is not normally distributed.

The unit root is tested using the IPS (Im et al., 2003) and ADF tests in the next step. The test outcomes are revealed in Table 3. For each variable, the null hypothesis cannot be refuted at I(0). This suggests that the data is not stationary at level I(0). However, for each variable, the null hypothesis may be rejected at the I(0) level, suggesting that the data are stationary in first differences, I(1).

After that, we examine the cointegration using the Pedroni and Kao cointegration test. The test outcomes are shown in Table 4. The results of the Pedroni cointegration tests reveal that there is a cointegration relationship among the variables, with four of the seven statistics indicating P-values under 0.05. This long-term connection among the determinants is additionally corroborated by the Kao cointegration test, which also shows an ADF P-value below 0.05. Furthermore, the study has applied a long-run estimation approach.

Table 5 presents the panel ARDL long-run and short-run results after confirmation of co-integration. The findings demonstrate convincing evidence of the EKC. GDP has both a positive and a negative coefficient in the quadratic form, and both coefficients are statistically significant. This result indicates an inverse U-shaped EKC for BRICST and is consistent with the findings of Li et al. (2024), which validate the presence of EKC in BRICST. Additionally, we found a direct link between NRR and CO_2. In other words, higher CO_2 emissions will result from an increase in NRR. The difference between the value of producing a natural resource at market prices and its entire production costs is known as natural resource rent. This indicates that the proxy is extremely susceptible to changes in the price of natural resources, such as gas and oil. The NRR will rise in response to any increase in these prices. Thus, the findings of our analysis indicate that a direct correlation between NRR and CO_2 is in line with the widely recognized positive correlation between NRR and CO_2. These results suggest a link between resource extraction and heightened greenhouse gas emissions. The overuse of natural resources, which undermines their ability to regenerate, can contribute to the positive correlation between income generated from these resources and carbon emissions in BRICS countries. Natural resource extraction is a major factor contributing to environmental degradation and ecological deficits (Mngumi et al., 2022). The BRICS nations are the most recently industrialized economies, and since 2000, the share of industrial GDP allocated to material extraction has been increasing steadily. As the economies of the BRICS nations continue to grow during this period of intense industrialization their unsustainable usage of natural resources has resulted in a greater dependency on foreign fossil fuel imports (Li et al., 2022). Research on carbon emission accounting (Hailiang et al., 2023) investigates that the trade of natural resources is linked to approximately 20-30% of total carbon dioxide (CO_2) emissions, which represent the majority of greenhouse gas (GHG) emissions. Although international trade has increased by 60% since 2005, carbon emissions adjusted for trade in the BRICS countries rose by 10% between 2005 and 2015 (Du et al., 2023).

EPU has a direct and significant impact on EDE, whereas in short-term models, it has an insignificant effect. The positive correlation between EPU and CO_2 emissions might stem from different reasons in both developed and developing countries. For instance, in developed nations, EPU could result in increased GHG emissions due to the delayed and gradual implementation of mitigation strategies. EPU can generate uncertainty regarding economic policies, as it may lead to unpredictable future results. In such situations, policy makers might postpone the adoption of mitigation strategies, leading to prolonged higher emissions over time. Additionally, increased EPU might hinder or decelerate the shift from conventional fossil fuels to renewable energy sources. Further delays in climate initiatives negatively impact economic growth and have consequences for the move toward a more sustainable future (Carton and Natal, 2022). The longer a country postpones its transition, the greater the costs incurred will be. This delay will obstruct the shift towards a low-carbon economy. Additionally, it gives compelling reasons for governments and policymakers to create strategies aimed at reducing EPU to accelerate and encourage an environmentally

Table 3: Results of unit root test

Indicator	IPS test		ADF test	
	I[0]	I[1]	I[0]	I[1]
CO_2	−1.253	−4.248***	−0.896	−4.127***
GDP	0.352	−2.097**	0.384	−2.129**
NRR	−0.747	−2.998***	−0.756	−3.074***
EPU	−0.470	−3.814***	−0.269	−3.819***

Source: Author's Estimation. "*** and **indicate significant levels at 1% and 5% respectively"

Table 4: Results of the cointegration test

A. Pedroni Cointegration Test		
Alternative hypothesis: Individual AR coefficient (within dimensions)		
Estimates	**Stats.**	**Prob.**
Panel ADF Stat.	−1.679	0.047
Panel PP Stat.	−1.404	0.081
Panel v Stat.	−0.435	0.668
Panel rho Stat.	0.461	0.855
Alternative hypothesis: individual AR coefficient (Between Dimensions)		
Group ADF Stat.	−1.945	0.034
queGroup PP Stat.	−1.827	0.041
Group rho Stat.	1.665	0.953
B. Kao cointegration test		
	t-statistic	**Prob.**
ADF test	−2.918***	0.002

Source: Author's Estimation. "*** and ** indicate significant levels at 1% and 5% respectively"

Table 5: Panel ARDL long-run results

Long-run results			
Variable	**β**	**S.E. (β)**	**P-value**
GDP	0.213***	0.023	0.000
GDP^2	−2.974***	0.729	0.000
NRR	0.292***	0.075	0.000
EPU	0.241**	0.109	0.029
Short-run results			
GDP	1.836***	0.673	0.007
GDP^2	0.004	0.004	0.302
NRR	0.005	0.008	0.486
EPU	−0.003	0.002	0.919
ECM-1	−0.130***	0.021	0.002

P<0.1 is point out by *, P<0.05 by ** and P<0.01 by ***, respectively friendly transformation. A reduction in EPU would aid in the structural shift of the economy from reliance on fossil fuels to the use of renewable and clean energy in both production and consumption. The study's findings align with those from Wang et al. (2020), which indicate that EPU influences environmental quality through consumption and investment pathways. EPU positively affects environmental quality by leading to a decrease in the consumption of energy-intensive goods. The quality of the environment declines through investment pathways as it obstructs technological innovation and development, resulting in reduced research and development (R&D) efforts (Wang et al., 2020). Three key mechanisms connect EPU to environmental quality: Energy intensity, reliance on fossil fuels, and innovation. According to Yu et al. (2021), EPU drives up energy consumption, which negatively impacts environmental quality. Furthermore, EPU increases dependence on non-renewable energy sources, causing an uptick in CO_2 emissions. Additionally, EPU hinders technological innovation and development, discourages investments in energy-efficient technologies, and adversely affects environmental quality. Moreover, EPU diminishes R&D funding, slows down technological advancements, and contributes to higher CO_2 emissions (Yu et al., 2021; Udeagha and Muchapondwa, 2022).

5. CONCLUSION AND RECOMMENDATION

This study examines the impact of NRR and EPU on environmental degradation in the presence of EKC. For this purpose, we employ panel ARDL regression analysis to explore the dynamic relationships among the variables. The results of ARDL show that the effect of NRR and environmental degradation is positive. Similarly, the effect of EPU and environmental degradation is positive. The results validate the presence of EKC. Our outcomes give a clear and significant message to decision-makers. The outcome suggests that the relationship between EG and CO_2 is mostly dependent on the economic diversification activities and the economic structures of the nations. To mitigate EDE in these economies, authorities must develop growth-oriented policies and plans. It is necessary to reconstruct fiscal and monetary policies while considering the environmental impact of growth. Environmental-friendly green production technologies and renewable energy adaptation should support the structural changes in the economy that are expected to occur as a result of rising production and income. This change should also be supported by laws, incentives, joint ventures, certain tax rebates, and subsidies. It is essential to offer tax exemptions, discounts, or incentives to businesses and individuals that invest in products or services related to renewable energy. Legislators and governments should promote both technology-push and market-pull strategies to foster innovation. Numerous technological pushes and market pull policies have been shown to be quite effective overall, indicating that successful policies could encourage managers of private equity funds to engage in new renewable energy technologies. The best technological push policies were identified as incentives, joint ventures, tax exemptions, and government subsidies. The fact that fossil fuels are the primary source of pollution means that energy policy will significantly impact both the structural advancement of the economy and environmental degradation. To lower NRD, it is recommended that the government enhance its diversification activities within the economic structure. This can accelerate the EKC direction toward its second stage and mitigate the adverse moderating effect of NRD on CO_2 that has been noticed in both phases of development. However, since the EKC is hosted by nations, measures should be taken to encourage the diversification of economic activity. These industries should be given tax incentives and lower interest rates. Composition and technique effects will accelerate as we transition to a knowledge-based economy, contributing to a reduction in overall pollution. Furthermore, fines for violations should be implemented to preserve the forest.

The current study discovers that in the second stage, the moderating role is positive. This suggests that, unlike in the case of nations not dependent on resources, CO_2 emissions appear to be rising at this time. According to this, long-term environmental strategy planning should be the government's top priority. To save energy and increase the use of renewable energy, such planning should prioritize energy efficiency initiatives. By doing this, the amount of CO_2 produced when energy from non-renewable natural resources is consumed will be reduced. It is anticipated that the use of natural resources will increase to support economic growth. These activities can only be conducted securely and with the least amount of negative environmental impact by developing more effective extraction methods. Companies that extract natural resources must be innovative in developing environmentally friendly and sustainable methods for their operations. Resource extraction firms may reduce unnecessary emissions and spills of resources by optimizing modern equipment and using new technology. Furthermore, it is recommended that the existing mining rules and regulations be evaluated. To promote environmentally friendly mining practices, the mining industry should be provided with tax incentives, tax exemptions, easy credit, and accessible opportunities. The mining sector should be financed using a variety of alternative instruments, like green bonds.

Policymakers must consider the important role of the EPU as well as the effects that rises in the EPU will have on the environment. Two distinct policies might be created to address the connection between environmental deterioration and EPU. The first of these initiatives is designed specifically to lower the EPU. Some strategies to lower the EPU include strengthening financial institutions, promoting transparency in economic decisions, increasing economic predictability, and ensuring that the economy operates in accordance with the law. The alternative option is to reduce the connections between environmental degradation and the EPU. As a result, either the rise in EPU would not cause environmental deterioration, or its impact would be minimal. Traditional manufacturing practices, excessive use of natural resources, and investment withdrawals from environmentally friendly technology and renewable energy sources are all consequences of high EPU. The inverse relationship between EPU and environmental degradation will be weakened if incentives and tax relief are provided to these regions. The panel data of the BRICST nations served as the basis for this study; however, future research might use the dataset of each nation independently to examine each nation in greater detail. The dataset of additional groups of nations with comparable attributes, such as the E-7, G-7, and G-20, may potentially be used in future research.

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