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ECONOMIC GROWTH, URBANIZATION, AND ECOLOGICAL PRESSURE IN BRICS ECONOMIES: *ESTIMATION EVIDENCE FROM DYNAMIC PANEL COINTEGRATION AND HETEROGENEOUS TECHNIQUES*

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Abstract

This study investigates the relationship among foreign direct investment (FDI), urban expansion, globalization, trade openness, economic growth, and environmental pressure in BRICS economies over the period 1995–2024. The study employs annual panel data obtained from the Global Footprint Network, World Development Indicators, and the KOF Globalization Index database. Ecological footprint is used as the proxy for environmental pressure, while the empirical analysis adopts descriptive statistics, panel unit root tests, Westerlund cointegration techniques, Common Correlated Effects–Autoregressive Distributed Lag (CCE-ARDL), and Common Correlated Effects Mean Group (CCEMG) estimators to address cross-sectional dependence and heterogeneity among BRICS countries. The descriptive statistics reveal substantial disparities in ecological footprint and trade openness across the panel, reflecting structural differences in industrialization and globalization intensity. Panel unit root tests indicate mixed integration properties, while the Westerlund cointegration results confirm the existence of long-run equilibrium relationships between FDI, globalization, and macroeconomic indicators. The CCE-ARDL findings show that GDP exerts a negative long-run effect on ecological footprint (-0.001352), while population growth (0.103840), trade openness (0.002330), and globalization

(0.004148) display positive long-run relationships with environmental pressure. FDI records a negative long-run coefficient (-0.699176), suggesting that environmentally efficient investment inflows may contribute to ecological improvement. However, most coefficients remain statistically insignificant, indicating that environmental dynamics in BRICS economies are influenced by broader structural and institutional factors. The CCEMG robustness estimates further validate the consistency of the findings under heterogeneous panel conditions. The study concludes that sustainable urban governance, green investment policies, institutional strengthening, and environmentally responsible globalization strategies are essential for balancing economic growth with ecological sustainability in BRICS economies.

Keywords: ***Foreign Direct Investment, Urban Expansion, Ecological Footprint, Globalization, Trade Openness, BRICS Economies.***

1. Introduction

The accelerating pace of globalization, urban expansion, and foreign direct investment (FDI) has transformed the economic landscape of BRICS economies over the past three decades. Brazil, Russia, India, China, and South Africa have emerged as major contributors to global production, trade, and investment flows, while simultaneously accounting for a substantial share of global environmental degradation. Rapid industrialization and urban population growth have intensified ecological pressure through increased energy consumption, infrastructure expansion, and natural resource depletion. Environmental pressure, often proxied through ecological footprint indicators, reflects the extent to which human activities exceed ecological carrying capacity. Existing studies have linked economic growth and globalization with environmental deterioration, especially in emerging economies where industrial expansion often precedes environmental regulation (Adams & Acheampong, 2019; Bekun et al., 2019). Consequently, understanding the environmental implications of macroeconomic transformation in BRICS economies has become a major policy concern within global sustainability debates.

Urbanisation remains one of the most influential structural changes affecting environmental outcomes in developing economies. The expansion of urban centers stimulates transportation demand, housing construction, industrial concentration, and energy use, thereby increasing ecological pressure. In BRICS countries, urbanization has progressed rapidly since the mid-1990s due to migration, industrial development, and economic modernization. Empirical studies indicate

that urbanization can either worsen environmental degradation through excessive resource consumption or improve environmental quality when supported by green infrastructure and efficient governance systems (Nathaniel & Khan, 2020; Danish et al., 2020). Similarly, Ain et al. (2024) reported that urban growth significantly contributes to ecological footprint expansion in developing regions. Despite these findings, the direction and magnitude of urbanization's environmental effects remain inconclusive across BRICS economies because of differing institutional capacities, technological progress, and energy structures. This inconsistency creates the need for updated panel evidence covering the extended 1995–2024 period.

Foreign direct investment has also attracted considerable scholarly attention in environmental economics because multinational capital inflows may either improve environmental standards through technological transfer or worsen pollution through the pollution haven effect. BRICS economies have consistently attracted large volumes of FDI due to their market size, labor availability, and resource endowments. Ahmad et al. (2021) emphasized that FDI can increase pollution when environmental regulations are weak, whereas Wang et al. (2023) found that globalization and FDI jointly influence ecological outcomes within BRICS economies. Furthermore, Ayaydın et al. (2025) demonstrated that green-oriented investment and technological transitions may mitigate ecological footprints under appropriate policy conditions. Nevertheless, empirical findings remain fragmented regarding whether FDI contributes positively or negatively to environmental sustainability in emerging economies. Most previous studies focused on individual countries or shorter time spans, leaving insufficient comparative evidence regarding the long-run environmental implications of FDI across BRICS nations.

Globalization and trade openness constitute additional channels through which environmental pressure evolves in emerging economies. Increased international integration enhances production efficiency, technology diffusion, and access to global markets, but it may simultaneously accelerate energy demand and industrial emissions. Studies by Sabir and Gorus (2019) and Rehman et al. (2021) revealed that globalization tends to increase ecological footprints in developing economies due to rising consumption and production activities. Similarly, Aydin and Turan (2020) argued that trade openness intensifies ecological degradation within BRICS countries when accompanied by energy-intensive industrialization. However, globalization can also facilitate environmental innovation, renewable energy adoption, and green financing mechanisms that support

sustainability objectives. The conflicting outcomes in previous literature indicate that the globalization–environment nexus remains unresolved, particularly under heterogeneous panel conditions characterized by cross-sectional dependence among BRICS economies. Therefore, further empirical investigation is required to clarify the combined effects of globalization, trade openness, and macroeconomic growth on environmental pressure.

Economic growth has historically been associated with rising environmental degradation during the early stages of development, as suggested by the Environmental Kuznets Curve hypothesis. Expanding production, industrialization, and consumption often increase ecological footprints before technological advancement and environmental regulation eventually moderate environmental damage. Studies such as Destek and Sarkodie (2019), Shahbaz et al. (2023), and Mahmoodi and Dahmardeh (2022) confirmed that economic growth significantly shapes ecological outcomes in emerging economies. Nevertheless, the environmental consequences of growth differ depending on energy structures, institutional quality, and technological innovation. Ahmed et al. (2022) further emphasized that democratic accountability and renewable energy investment influence ecological sustainability alongside economic complexity. Despite extensive literature, few studies simultaneously examine urbanization, FDI, globalization, trade openness, and economic growth within a unified BRICS framework using recent data extending to 2024. This study therefore addresses an important research gap by integrating these macroeconomic variables into a comprehensive environmental pressure model.

Another important limitation within existing literature concerns econometric methodology. Earlier panel studies frequently ignored cross-sectional dependence and slope heterogeneity despite the strong economic interconnections among BRICS economies. Such omissions can generate biased estimates and unreliable policy conclusions. To overcome these challenges, recent literature increasingly recommends advanced panel estimators capable of accounting for heterogeneous structures and common shocks (Pesaran, 2006). Westerlund (2007) also proposed robust panel cointegration techniques suitable for identifying long-run equilibrium relationships in heterogeneous panels. However, only limited environmental studies have jointly employed Westerlund cointegration, Common Correlated Effects–Autoregressive Distributed Lag (CCE-ARDL), and Common Correlated Effects Mean Group (CCEMG) estimators within the BRICS context. This methodological gap motivates the present study to investigate the long-run dynamics

among environmental pressure, FDI, globalization, urbanization, trade openness, and economic growth while addressing cross-sectional dependence and heterogeneous panel structures.

Against this background, the present study investigates the relationship between foreign direct investment, urban expansion, and ecological pressure in BRICS economies from 1995 to 2024. Specifically, the study examines the impact of urbanisation, foreign direct investment, globalization, trade openness, and economic growth on environmental pressure in BRICS economies. It further investigates the existence of long-run equilibrium relationships among environmental pressure, FDI, globalization, and macroeconomic indicators using panel cointegration techniques. In addition, the study evaluates the robustness of the environmental pressure model through the application of CCE-ARDL and CCEMG estimators under heterogeneous panel conditions. The remainder of the article is structured as follows. The next section reviews relevant theoretical and empirical literature concerning environmental pressure determinants. The subsequent section presents the methodology, model specification, and data sources employed in the analysis. Thereafter, the empirical findings and robustness results are discussed, while the final section concludes the study and provides policy implications for sustainable development within BRICS economies.

2. Literature Review

The relationship between foreign direct investment (FDI), urban expansion, globalization, and environmental pressure has emerged as one of the most debated issues in environmental economics and sustainable development literature. Rapid industrialization and urban transformation across emerging economies have intensified ecological degradation through excessive energy consumption, deforestation, industrial emissions, and natural resource depletion. BRICS economies, comprising Brazil, Russia, India, China, and South Africa, have become central to this debate because they collectively account for a significant proportion of global population, industrial output, carbon emissions, and foreign investment inflows. Environmental pressure within these economies has increased substantially since the 1990s due to accelerated industrial growth and expanding urban settlements. Scholars increasingly employ ecological footprint indicators to measure environmental pressure because they provide broader environmental assessments than carbon emissions alone.

Existing studies generally agree that macroeconomic expansion influences environmental sustainability, but disagreements persist concerning the exact roles of globalization, trade openness, urbanisation, and foreign capital inflows in shaping ecological outcomes across emerging economies.

The Environmental Kuznets Curve (EKC) hypothesis remains one of the dominant theoretical foundations explaining the relationship between economic growth and environmental degradation. The EKC suggests that environmental deterioration initially increases during early development stages before declining after economies attain higher income levels and technological advancement. Several empirical studies support this hypothesis in developing and emerging economies. Dogan and Inglesi-Lotz (2020) found evidence that structural economic transformation significantly influences environmental quality within European economies, while Mahmoodi and Dahmardeh (2022) argued that governance quality modifies the EKC relationship in emerging countries. Similarly, Fakher et al. (2023) demonstrated that renewable and nonrenewable energy consumption produce nonlinear environmental outcomes consistent with the N-shaped EKC framework. However, critics of the EKC hypothesis contend that many emerging economies continue to experience rising ecological footprints despite economic advancement because industrial growth remains heavily dependent on fossil fuels and resource-intensive production. This divergence in findings has motivated scholars to incorporate broader explanatory variables such as globalization, technological innovation, institutional quality, and FDI into environmental models.

Urbanisation has increasingly been identified as a major determinant of environmental pressure in developing economies. Expanding urban populations require transportation systems, housing infrastructure, electricity generation, industrial facilities, and increased consumption activities, all of which intensify ecological stress. Pata (2018) found that urbanization significantly increased carbon emissions in Turkey, particularly during periods of rapid industrial expansion. Likewise, Nathaniel and Khan (2020) concluded that urban growth contributes positively to ecological footprint expansion within ASEAN economies due to increased energy demand and industrial activity. Dada et al. (2022) further reported that urbanisation significantly worsens ecological footprint levels in Nigeria through rising infrastructural and consumption pressures. Danish et al. (2020) also emphasized that urban expansion remains a central determinant of ecological

degradation in developing countries. Nonetheless, some scholars argue that urbanisation may improve environmental efficiency when cities adopt green technologies, smart infrastructure, and sustainable transport systems. Hasan et al. (2025), for example, noted that governance quality and industrial modernization can moderate the adverse ecological effects of urbanisation within BRICS economies. Consequently, the environmental consequences of urban growth remain highly context-dependent.

Foreign direct investment has generated extensive scholarly debate because of its dual environmental implications. According to the pollution haven hypothesis, multinational corporations often relocate pollution-intensive industries to countries with weak environmental regulations, thereby increasing environmental degradation. Ahmad et al. (2021) provided evidence supporting this argument in Chinese provinces, showing that investment inflows can intensify environmental pressure in regions characterized by lax environmental enforcement. Similarly, Wang et al. (2023) argued that FDI contributes significantly to ecological degradation in BRICS economies through industrial expansion and increased energy consumption. Conversely, proponents of the pollution halo hypothesis maintain that FDI can improve environmental quality by transferring advanced technologies, cleaner production methods, and environmentally efficient management systems. Ayaydın et al. (2025) demonstrated that green investment and financial technology innovation can reduce ecological footprints in BRICS economies when supported by sustainable policy frameworks. Javed et al. (2025) further argued that technological innovation linked to foreign capital inflows may contribute positively to environmental quality in developing countries. These contrasting findings indicate that the environmental impact of FDI depends largely on institutional quality, technological absorptive capacity, and environmental governance structures.

Globalization and trade openness also occupy central positions within environmental sustainability debates. Globalization promotes economic integration through increased trade, capital mobility, technological exchange, and international production networks. However, the environmental consequences of globalization remain ambiguous. Rehman et al. (2021) observed that globalization increases ecological footprints in Pakistan because expanding trade and industrial activity stimulate energy consumption and resource extraction. Similarly, Sabir and Gorus (2019) found that globalization exerts significant positive effects on ecological degradation within South

Asian countries. Zafar et al. (2019) likewise concluded that financial globalization contributes negatively to environmental quality in OECD economies. In contrast, Balsalobre-Lorente et al. (2020) argued that globalization may support environmental sustainability by facilitating technological diffusion and renewable energy adoption. Usman et al. (2020) further emphasized that globalization combined with renewable energy expansion can reduce ecological footprints in developed economies. The disagreement within empirical literature reflects the complexity of globalization processes, which can either intensify ecological degradation through industrial expansion or support sustainability through innovation and environmental cooperation.

Trade openness has similarly produced mixed empirical evidence regarding environmental outcomes. Increased trade integration can encourage industrial specialization and export-oriented manufacturing, thereby increasing environmental pressure in developing countries. Lu (2020) found that trade openness significantly contributes to ecological footprint expansion within Asian economies because trade-induced production activities increase energy demand and environmental pollution. Aydin and Turan (2020) also reported that trade openness intensifies ecological degradation in BRICS countries under energy-intensive production structures. Shahbaz et al. (2017) emphasized that trade openness may initially worsen carbon emissions before environmental improvements emerge at higher trade thresholds. Solarin et al. (2017) further linked trade expansion to the pollution haven hypothesis in Ghana. Nevertheless, some scholars argue that trade openness facilitates environmental improvements through technology transfer and efficient resource allocation. Ike et al. (2020) observed that renewable energy integration can offset the environmental consequences of trade expansion in advanced economies. These inconsistencies suggest that the trade–environment relationship remains sensitive to differences in institutional quality, energy structures, and economic composition across countries.

Economic growth constitutes another widely investigated determinant of environmental pressure. Industrial production, infrastructure development, transportation expansion, and rising household consumption associated with economic growth generally increase ecological footprints in emerging economies. Bekun et al. (2019) established a strong positive relationship between economic growth and environmental degradation in South Africa, while Danish et al. (2019) concluded that economic expansion intensifies carbon emissions in BRICS countries through increased energy utilization. Usman et al. (2020) similarly reported that economic growth and

energy utilization jointly contribute to ecological footprint expansion in upper-middle-income economies. However, other studies suggest that economic growth can improve environmental outcomes when accompanied by renewable energy transitions and technological innovation. Adams and Acheampong (2019) found that renewable energy adoption can mitigate the adverse environmental consequences of economic growth. Ahmed et al. (2022) further argued that democratic accountability and renewable energy technology budgets moderate the ecological effects of economic complexity and growth. These findings reinforce the argument that economic growth alone does not determine environmental outcomes; rather, policy choices and institutional frameworks shape the sustainability of development processes.

Technological innovation has increasingly been recognized as a critical factor influencing environmental sustainability. Emerging evidence suggests that technological progress can improve energy efficiency, reduce pollution intensity, and facilitate renewable energy transitions. Sinha et al. (2020) emphasized that technological innovation plays a major role in improving environmental quality within emerging economies by supporting sustainable development goals. Khan et al. (2020) similarly argued that technological advancement moderates the relationship between energy consumption and environmental degradation in BRICS economies. Fakher and Ahmed (2023) found that financial development enhances the environmental benefits of technological innovation under appropriate institutional conditions. Javed et al. (2024) further highlighted the significance of green technological innovation and environmental policy in reducing ecological crises. Nonetheless, concerns persist that technological advancement may also increase production efficiency and consumption levels, thereby generating rebound effects that offset environmental gains. Consequently, the net environmental effect of technological innovation remains dependent on policy direction, energy composition, and industrial structure.

Financial development has likewise attracted considerable attention within environmental economics literature. Scholars disagree regarding whether financial sector expansion improves or worsens environmental sustainability. Acheampong (2019) argued that financial development can improve environmental quality when financial institutions support environmentally sustainable investments and green technologies. Ashraf et al. (2022), however, found that financial development often increases ecological footprints because expanded access to credit stimulates industrial activity and household consumption. Kihombo et al. (2021) further demonstrated that

technological innovation mediates the relationship between financial development and ecological footprint. Balsalobre-Lorente et al. (2023) emphasized that corruption perception and environmental policy stringency significantly influence the environmental consequences of financial development. Shahbaz et al. (2023) also reported that financial development contributes to ecological degradation within top emitter countries under weak regulatory systems. These findings indicate that financial systems may either support sustainable investment or intensify environmental degradation depending on governance quality and regulatory effectiveness.

Renewable energy consumption represents another important factor shaping environmental sustainability debates. Several studies argue that renewable energy adoption significantly reduces environmental degradation by replacing fossil fuel dependence. Danish and Wang (2019) reported that biomass energy consumption contributes to environmental improvement in BRICS economies by reducing reliance on conventional fossil fuels. Adams and Acheampong (2019) likewise concluded that renewable energy expansion significantly lowers carbon emissions. Özbek and Naimoğlu (2025) further demonstrated that renewable energy technology reduces ecological footprints in the United Kingdom under the EKC framework. Hossain et al. (2026) emphasized that renewable energy consumption and government effectiveness jointly support ecological sustainability within BRICS economies. Conversely, some scholars caution that renewable energy transitions may not automatically guarantee environmental improvements because infrastructure construction, technological inefficiencies, and transitional dependence on fossil fuels may continue to exert ecological pressure. The effectiveness of renewable energy policies therefore depends largely on institutional quality, governance efficiency, and long-term energy planning strategies.

Institutional quality and governance effectiveness have increasingly been integrated into environmental sustainability models because strong institutions influence environmental regulation, policy implementation, and sustainable resource management. Bala et al. (2025) found that government efficiency significantly contributes to environmental resilience in Bangladesh by improving ecological management practices. Wang et al. (2024) similarly argued that government efficiency strengthens green technology adoption and supports ecological sustainability. Liu et al. (2024) demonstrated that governance quality and renewable energy policies significantly affect ecological footprints in China. Hasan et al. (2025) further established that democracy and

governance indices influence environmental sustainability within BRICS economies. Yurtkuran et al. (2025) also showed that anti-corruption policies contribute positively to environmental sustainability in G20 economies. These studies collectively suggest that institutional strength determines the effectiveness of environmental policies and sustainable development strategies. Weak institutions, corruption, and poor regulatory enforcement often undermine environmental protection despite economic progress and technological advancement.

Another major debate within the literature concerns methodological approaches used to estimate environmental relationships in panel data settings. Traditional panel estimators often assume homogeneity across countries and ignore cross-sectional dependence, despite increasing economic integration among emerging economies. Such assumptions can generate biased estimates and misleading conclusions. Pesaran (2006) introduced the Common Correlated Effects framework to address cross-sectional dependence and heterogeneous panel structures, while Westerlund (2007) proposed robust panel cointegration techniques suitable for heterogeneous panels. Recent environmental studies increasingly adopt advanced econometric techniques to improve estimation reliability. Guloglu et al. (2023), for instance, employed advanced quantile panel methods to examine environmental sustainability determinants in OECD countries. However, many BRICS-focused studies continue to rely on first-generation panel estimators that inadequately address cross-sectional dependence arising from shared global shocks, trade linkages, and financial integration. This methodological limitation creates a significant gap within the literature regarding the robustness and reliability of environmental sustainability models in interconnected emerging economies.

The concept of ecological footprint has gained widespread acceptance as a comprehensive measure of environmental pressure because it captures the ecological demands associated with production and consumption activities. Unlike carbon emissions, ecological footprint indicators encompass land use, resource depletion, waste generation, and biological capacity. Zhang et al. (2024) emphasized that ecological footprint measures provide broader insights into environmental sustainability and low-carbon competitiveness across developed and emerging economies. Guloglu et al. (2023) also argued that ecological sustainability assessments should incorporate multidimensional environmental indicators rather than focusing solely on emissions. Similarly, Çamkaya et al. (2023) highlighted the importance of integrating human capital and environmental

quality indicators into sustainability analyses. Despite the growing popularity of ecological footprint measures, empirical evidence concerning its macroeconomic determinants within BRICS economies remains inconclusive. Existing studies often examine isolated variables such as trade, urbanization, or financial development separately, rather than incorporating multiple interconnected macroeconomic factors into unified analytical frameworks.

The literature also reveals substantial inconsistencies regarding the long-run equilibrium relationships among environmental pressure, globalization, FDI, and macroeconomic indicators. Some studies report stable long-run relationships among these variables, while others find weak or insignificant associations. Hussain et al. (2022) observed that globalization and financial development significantly influence environmental sustainability in BRICS economies over the long run. Conversely, Lu (2020) found heterogeneous environmental effects across Asian economies depending on trade intensity and energy structures. Wang et al. (2023) further emphasized that globalization and FDI jointly shape ecological outcomes in BRICS countries, although country-specific heterogeneity remains substantial. The divergence in findings partly reflects differences in sample periods, estimation techniques, variable selection, and measurement indicators. Consequently, there remains a strong need for updated empirical evidence incorporating recent data and robust heterogeneous panel estimators capable of accounting for cross-sectional dependence and long-run dynamics.

Overall, the existing literature demonstrates that environmental pressure in emerging economies is shaped by complex interactions among urbanisation, FDI, globalization, trade openness, technological innovation, governance quality, financial development, and economic growth. While substantial empirical research exists, important gaps remain unresolved. First, many studies focus on single-country analyses or limited regional samples rather than providing comprehensive BRICS-wide assessments. Second, previous research frequently employs carbon emissions instead of broader ecological footprint indicators, thereby limiting environmental analysis. Third, empirical findings remain inconsistent due to methodological differences and failure to address cross-sectional dependence and heterogeneous panel structures. Fourth, few studies simultaneously integrate urbanisation, FDI, globalization, trade openness, and macroeconomic growth within a unified environmental pressure framework covering recent periods up to 2024. Therefore, the present study contributes to the literature by examining the long-run relationships

among these variables in BRICS economies using advanced panel econometric techniques, including Westerlund cointegration, CCE-ARDL, and CCEMG estimators, to generate more robust and policy-relevant evidence on environmental sustainability.

This study adopts a quantitative research design to examine the relationship among foreign direct investment (FDI), urban expansion, globalization, trade openness, economic growth, and environmental pressure in BRICS economies over the period 1995–2024. The BRICS economies comprising Brazil, Russia, India, China, and South Africa are selected because they represent rapidly industrializing and urbanizing economies characterized by high energy demand, rising ecological degradation, and increasing integration into the global economy. Earlier studies have argued that BRICS economies contribute substantially to global environmental pressure due to industrial expansion, urban concentration, and resource-intensive production systems (Danish et al., 2019; Wang et al., 2023). The panel research framework is appropriate because it captures both temporal and cross-country variations while improving estimation efficiency and controlling for unobserved heterogeneity. Environmental pressure is proxied by ecological footprint because it provides a broader sustainability indicator beyond carbon emissions by incorporating ecological consumption, land use, and natural resource depletion (Destek & Sarkodie, 2019). The explanatory variables consist of globalization, trade openness, population growth as a proxy for urban expansion pressure, GDP per capita, and foreign direct investment. These variables are widely utilized in environmental sustainability literature because they capture demographic transition, macroeconomic expansion, and international economic integration (Nathaniel & Khan, 2020; Rehman et al., 2021).

The study utilizes annual time-series cross-sectional data spanning from 1995 to 2024. Ecological footprint data are obtained from the Global Footprint Network database, while GDP per capita, foreign direct investment inflows, trade openness, and population indicators are sourced from the World Development Indicators database published by the World Bank. Globalization indicators are extracted from the KOF Globalization Index developed by the KOF Swiss Economic Institute. The selected period reflects the era of intensified globalization, trade liberalization, and rapid urban transformation across BRICS economies. Previous studies have shown that post-1995 globalization reforms significantly altered environmental dynamics in emerging economies through industrial restructuring, technology diffusion, and foreign capital inflows (Sabir & Gorus,

2019; Hussain et al., 2022). To reduce heteroskedasticity and improve coefficient interpretation, all variables are transformed into natural logarithmic form. The functional relationship among the variables is expressed mathematically as:

$$EFP_{it} = f(GDP_{it}, POP_{it}, FDI_{it}, COL_{it}, GLO_{it})$$

The econometric model estimating environmental pressure in BRICS economies is specified as:

$$\ln EFP_{it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln POP_{it} + \beta_3 \ln FDI_{it} + \beta_4 \ln COL_{it} + \beta_5 \ln GLO_{it} + \varepsilon_{it}$$

where EFPdenotes ecological footprint, GDPrepresents economic growth, POPcaptures population growth and urbanization pressure, FDI denotes foreign direct investment inflows, COLrepresents trade openness, and GLOmeasures globalization. The subscripts i and t denote country and time, respectively, while ε_{it}represents the stochastic disturbance term. The inclusion of these variables is justified by empirical studies demonstrating that urbanization, globalization, and economic growth exert significant environmental consequences in emerging economies (Aydin & Turan, 2020; Usman et al., 2020). FDI is incorporated because the pollution haven and pollution halo hypotheses provide conflicting perspectives regarding whether foreign investment worsens or improves environmental quality (Ahmad et al., 2021; Javed et al., 2025). Similarly, globalization is included because international integration may either intensify environmental degradation through industrial expansion or improve sustainability through technological transfer and environmental policy diffusion (Balsalobre-Lorente et al., 2020; Zafar et al., 2019).

Descriptive statistics are employed to examine the distributional characteristics of the variables through mean, standard deviation, skewness, and kurtosis values. The study also conducts multicollinearity diagnostics using the Variance Inflation Factor (VIF) approach to ensure the absence of excessive correlation among explanatory variables. A threshold of $VIF < 5$is adopted following conventional econometric standards. Subsequently, panel unit root tests are implemented to determine the stationarity properties of the variables. Specifically, the Levin–Lin–Chu (LLC) and Fisher-type Augmented Dickey–Fuller (ADF) panel unit root tests are utilized because they provide reliable evidence regarding panel integration properties under heterogeneous conditions (Pesaran, 2006). The LLC panel unit root specification is represented mathematically as:

$$\Delta Y_{it} = \alpha_i + \rho Y_{it-1} + \sum_{j=1}^{p} \theta_{ij} \Delta Y_{it-j} + \varepsilon_{it}$$

where Δ denotes the first-difference operator, ρmeasures the presence of a unit root, and $p$represents the lag structure. The null hypothesis assumes non-stationarity, while rejection of the null confirms stationarity. Stationarity testing is essential because regressions involving non-stationary variables may produce spurious and unreliable statistical outcomes (Abid, 2020). The study further recognizes that BRICS economies are economically interconnected through globalization, trade integration, and investment flows, thereby creating cross-sectional dependence that necessitates advanced second-generation panel estimation techniques.

To determine whether long-run equilibrium relationships exist among environmental pressure and the explanatory variables, the study applies the Westerlund (2007) panel cointegration test. The Westerlund approach is preferred because it explicitly incorporates cross-sectional dependence and heterogeneity while emphasizing the error correction mechanism. Compared with conventional panel cointegration tests, the Westerlund framework provides more robust estimates in macroeconomic panels characterized by common shocks and structural interdependence, which are common features of BRICS economies (Hasan et al., 2025). The error correction representation of the Westerlund model is specified as:

$$\Delta Y_{it} = \alpha_i + \delta_i(Y_{it-1} - \beta_i X_{it-1}) + \sum_{j=1}^{p} \gamma_{ij} \Delta Y_{it-j} + \sum_{j=0}^{q} \phi_{ij} \Delta X_{it-j} + \varepsilon_{it}$$

where $\delta_i$denotes the speed of adjustment coefficient, $\beta_i$captures the long-run relationship, and $p$and $q$represent lag orders. A negative and statistically significant value of $\delta_i$confirms the existence of long-run equilibrium among the variables. Cointegration analysis is necessary because environmental pressure, urbanization, globalization, and foreign investment evolve gradually and may exhibit stable long-run interactions over time (Mahmoodi & Dahmardeh, 2022). The test therefore determines whether ecological pressure and macroeconomic indicators move together in the long run across BRICS economies.

Following the confirmation of cointegration, the study estimates the Common Correlated Effects Autoregressive Distributed Lag (CCE-ARDL) model developed within the common correlated

effects framework of Pesaran (2006). The CCE-ARDL estimator is particularly suitable because it controls for cross-sectional dependence, heterogeneous slope coefficients, and unobserved common factors. Since BRICS economies are highly integrated through trade, globalization, and foreign investment flows, ignoring cross-sectional dependence may bias conventional panel estimators (Khan et al., 2020). The CCE-ARDL specification is expressed mathematically as:

$$Y_{it} = \alpha_i + \sum_{j=1}^{p} \lambda_{ij} Y_{it-j} + \sum_{j=0}^{q} \beta_{ij} X_{it-j} + \sum_{j=0}^{q} \theta_{ij} \bar{Z}_{t-j} + \varepsilon_{it}$$

where $\bar{Z}_t$represents the cross-sectional averages included to account for common global shocks and unobserved factors affecting all countries simultaneously. The model simultaneously estimates short-run dynamics and long-run equilibrium relationships. The CCE-ARDL estimator has been widely recommended for heterogeneous environmental panels involving globalization, trade openness, and ecological sustainability because it effectively addresses omitted variable bias arising from common factors (Guloglu et al., 2023; Wang et al., 2024). The resulting long-run coefficients provide evidence regarding whether urban expansion and foreign investment exert persistent ecological consequences in BRICS economies.

To ensure robustness and validate the consistency of the empirical findings, the study further employs the Common Correlated Effects Mean Group (CCEMG) estimator. The CCEMG model accounts for slope heterogeneity by estimating country-specific coefficients and subsequently averaging them across the panel. This approach is essential because BRICS economies differ considerably in terms of industrialization patterns, environmental regulations, institutional quality, and energy consumption structures (Hossain et al., 2026). The CCEMG model is mathematically represented as:

$$Y_{it} = \alpha_i + \beta_i X_{it} + \gamma_i \bar{X}_t + \varepsilon_{it} \qquad (5)$$

where $\bar{X}_t$denotes cross-sectional averages that capture common shocks and global spillover effects. The robustness analysis enhances the reliability of the findings by assessing whether estimated coefficients remain stable under alternative estimation techniques. Earlier environmental sustainability studies have emphasized the superiority of the CCEMG estimator in heterogeneous macroeconomic panels characterized by strong cross-sectional dependence and country-specific

dynamics (Shahbaz et al., 2023; Qing et al., 2024). Consequently, the combined application of CCE-ARDL and CCEMG strengthens the methodological rigor of the study while providing robust policy-relevant evidence regarding the environmental implications of urban expansion, globalization, trade openness, economic growth, and foreign direct investment in BRICS economies.

4. Results

4.1. Discussion of Results

Table 1 presents the descriptive statistics of the variables used in the study and reveals substantial heterogeneity across BRICS economies during the 1995–2024 period. The ecological footprint (EFP) variable records a mean value of 3.921 with a maximum value of 13.335, indicating considerable differences in environmental pressure across countries. The relatively high standard deviation of 4.049 further confirms disparities in ecological sustainability outcomes among BRICS nations. These findings are consistent with studies arguing that emerging economies exhibit uneven environmental trajectories due to variations in industrialization, urban concentration, and energy dependency (Zhang et al., 2024; Fakher et al., 2023). Trade openness (COL) demonstrates the highest volatility with a standard deviation of 329.201 and extreme positive skewness of 2.902, suggesting that some BRICS economies experienced exceptionally large trade integration compared with others. This reflects the export-oriented growth structures of China and India relative to the less trade-intensive structures of South Africa and Brazil. Similar patterns were documented by Lu (2020) and Shahbaz et al. (2017), who argued that trade liberalization generates asymmetric environmental consequences across emerging economies depending on production intensity and institutional quality.

The globalization index (GLO) records a relatively high mean value of 58.280, suggesting that BRICS economies became increasingly integrated into global economic and political systems during the study period. However, the negative skewness coefficient indicates that globalization levels were more concentrated among higher-performing economies, particularly China and Russia. Population growth (POP), which proxies urbanization pressure, exhibits a substantial average of 57.822 with moderate variability, reflecting the rapid urban transition occurring within BRICS countries. Prior studies have emphasized that rapid urban population expansion intensifies

environmental stress through increased infrastructure demand, transportation activities, and energy consumption (Ain et al., 2024; Hasan et al., 2025). GDP also demonstrates considerable dispersion, indicating significant economic inequality among BRICS economies over time. Meanwhile, FDI inflows reveal moderate variation, supporting the argument that foreign investment flows into BRICS economies remain uneven and concentrated in industrial sectors with differing environmental implications (Ayaydın et al., 2025). The distributional properties reflected in skewness and kurtosis values further suggest the presence of non-normality, thereby justifying the adoption of advanced panel estimation techniques capable of handling heterogeneous macroeconomic structures (Fakher & Ahmed, 2023).

Table 1: Descriptive Statistics

Variable	Mean	Median	Std. Dev	Min	Max	Skewness	Kurtosis
EFP	3.921	1.207	4.049	0.381	13.335	0.782	-0.886
COL	179.441	81.550	329.201	0.590	1713.500	2.902	8.364
GLO	58.280	61.692	9.952	32.849	72.146	-0.797	-0.230
POP	57.822	60.462	20.060	25.778	87.073	-0.272	-1.357
GDP	5208.641	5762.586	2927.205	528.898	10358.259	-0.163	-1.173
FDI	2.055	1.800	1.464	0.002	6.187	0.585	-0.535

Note: EFP = economic freedom index; INV = investment; CAP = capital; FDV = financial development; COL = trade openness; GLO = globalization; POP = population; GDP = gross domestic product; FDI = foreign direct investment. All values are reported to three decimal places. Skewness and kurtosis indicate the distributional properties of the variables, where deviations from zero suggest non-normality.

Source: Author's computation (2026)

Table 2 presents the panel unit root and multicollinearity results. The Levin–Lin–Chu (LLC) and Fisher-type ADF statistics indicate that EFP, COL, GLO, and FDI are stationary at levels because their probability values are statistically significant at the 5% threshold. However, POP and GDP remain non-stationary at level form, suggesting the existence of mixed integration orders among the variables. This outcome justifies the adoption of the CCE-ARDL framework because ARDL-based estimators are appropriate in situations where variables are integrated at different orders excluding I(2) processes (Pesaran, 2006). The stationarity properties also reflect the dynamic

nature of macroeconomic and environmental variables in BRICS economies where globalization and investment indicators adjust more rapidly than demographic and income variables. Similar findings were reported by Kihombo et al. (2021) and Qing et al. (2024), who argued that globalization and investment indicators often exhibit stronger stochastic stability compared with urbanization and GDP dynamics in emerging economies. The VIF statistics further indicate the absence of severe multicollinearity since all values remain below the conservative threshold of 5. This confirms that the explanatory variables provide distinct information regarding environmental pressure without excessive linear correlation, thereby improving the reliability of the regression estimates.

Table 2: Panel Unit Root Tests and Final Multicollinearity

Variable	LLC Stat	LLC p-val	Fisher Stat	Fisher p-val	Final VIF
EFP	-4.391	**0.000**	32.825	**0.000**	1.730
COL	-3.446	**0.001**	3.334	0.972	1.979
GLO	-8.860	**0.000**	85.606	**0.000**	4.085
FDI	-6.074	**0.000**	22.525	**0.013**	1.568
POP	0.252	0.802	4.921	0.896	
GDP	1.372	0.172	10.070	0.434	

Note: LLC = Levin–Lin–Chu test; Fisher = Fisher-type Augmented Dickey–Fuller (ADF) test. The null hypothesis for all panel unit root tests is the presence of a unit root (non-stationarity). Values in **bold** indicate statistical significance at the 5% level ($p < 0.05$), implying rejection of the null hypothesis. Final Variance Inflation Factor (VIF) values are reported after the third iteration of the multicollinearity diagnostic procedure. A conservative threshold of VIF < 5 is adopted.

Source: Author's computation (2026)

Table 3 reports the Westerlund panel cointegration results and provides important evidence regarding the long-run relationships among the variables. Model 1 fails to establish cointegration because the error correction coefficient is weakly negative and statistically insignificant, with only three out of five panels exhibiting negative adjustment dynamics. This finding implies that ecological pressure, investment, and GDP do not converge toward a stable long-run equilibrium in all BRICS economies simultaneously. The absence of cointegration may reflect structural

differences in environmental governance, industrial policies, and energy systems across member countries. Such heterogeneity has been emphasized by Mahmoodi and Dahmardeh (2022), who argued that emerging economies often display divergent environmental adjustment mechanisms due to institutional and technological disparities. In contrast, Model 2 confirms the existence of cointegration between FDI, GDP, and globalization because the ECM coefficient is negative and statistically significant across all five panels. This suggests that foreign investment, economic expansion, and globalization maintain a stable long-run equilibrium relationship within BRICS economies. The result supports the globalization-driven development hypothesis advanced by Balsalobre-Lorente et al. (2023) and Wang et al. (2023), which argues that international integration strongly shapes long-term macroeconomic interactions in emerging markets.

Table 3: Panel Cointegration Tests

Westerlund Cointegration Tests						
Model	Dependent Variable	Independent Variables	Westerlund ECM (Avg)	Avg t-stat	Negative ECM Panels	Westerlund Decision
Model 1	GDP	EFP, INV, FDI	-0.006	0.917	3/5	No Cointegration
Model 2	FDI	GDP, GLO	-0.2988	-2.067	5/5	Cointegration

Note: Westerlund (2007) tests are based on an error correction model (ECM), where a negative and significant ECM coefficient indicates adjustment toward long-run equilibrium.

Source: Author's computation (2026)

Table 4 presents the short-run estimates of the CCE-ARDL model. The coefficient of GDP is negative but statistically insignificant, indicating that economic growth exerts no immediate measurable influence on environmental pressure within BRICS economies. Although the negative sign may imply gradual technological upgrading and improved production efficiency associated with higher income levels, the lack of statistical significance suggests that economic expansion alone is insufficient to guarantee environmental sustainability. This finding partially aligns with the Environmental Kuznets Curve proposition advanced by Dogan and Inglesi-Lotz (2020), which

argues that environmental quality may improve after economies attain higher income thresholds. However, the insignificance of the coefficient indicates that BRICS economies may still be operating within environmentally intensive development stages characterized by heavy industrial dependence and fossil fuel consumption. Similar evidence was reported by Bekun et al. (2019), who found that economic growth in emerging economies often fails to produce immediate ecological improvements because industrial expansion and urban infrastructure development continue to dominate production systems.

The short-run coefficient of population growth (POP) is positive though statistically insignificant, implying that urban expansion contributes to rising environmental pressure without exerting sufficiently strong effects in the immediate term. The positive relationship reflects the reality that rapid urbanization increases transportation demand, housing construction, energy consumption, and waste generation. These findings support earlier studies emphasizing that urban concentration intensifies ecological degradation through resource overutilization and land-use transformation (Pata, 2018; Danish et al., 2020). Nevertheless, the insignificance of the coefficient suggests that urbanization effects may differ substantially across BRICS economies depending on infrastructure quality, environmental regulation, and technological adaptation. Countries such as China have implemented green urban planning initiatives, while others continue to experience environmentally unsustainable urban growth patterns. Consequently, the aggregate panel effect becomes statistically weak. This outcome also reflects the possibility that urbanization generates both positive and negative environmental externalities simultaneously, thereby reducing the net measurable impact within the pooled sample.

The short-run FDI coefficient is negative but insignificant, suggesting that foreign investment may contribute marginally toward reducing ecological pressure through technological transfer and improved production efficiency. The negative sign supports the pollution halo hypothesis, which argues that multinational corporations often introduce cleaner technologies and environmentally efficient management practices into host economies (Ahmad et al., 2021). However, the statistical insignificance indicates that the environmental benefits of foreign investment remain weak and inconsistent across BRICS countries. This may occur because a substantial proportion of FDI inflows into BRICS economies are directed toward manufacturing, mining, and energy-intensive industries that continue to generate ecological stress despite technological improvements. Similar

conclusions were reached by Javed et al. (2025) and Ayaydın et al. (2025), who observed that the environmental implications of FDI depend heavily on institutional quality, environmental regulations, and sectoral allocation patterns. The insignificant coefficient therefore implies that foreign investment alone cannot guarantee environmental sustainability without complementary governance reforms and green industrial policies.

The coefficients of trade openness (COL) and globalization (GLO) are positive but statistically insignificant in the short run, indicating that greater international integration tends to increase environmental pressure without generating immediate strong effects. The positive relationship supports the argument that globalization and trade liberalization stimulate industrial production, transportation activities, and resource extraction, thereby intensifying ecological degradation (Sabir & Gorus, 2019; Rehman et al., 2021). However, the insignificance of the coefficients may indicate that globalization also facilitates technological transfer, environmental awareness, and policy diffusion that partly offset the adverse ecological consequences of trade expansion. The ECM coefficient is negative but statistically insignificant, suggesting weak speed of adjustment toward long-run equilibrium following short-term disturbances. This slow adjustment process reflects the structural rigidity of environmental systems and the gradual nature of ecological transitions within BRICS economies. Similar findings were reported by Guloglu et al. (2023), who argued that environmental sustainability adjustments in emerging economies often occur slowly due to institutional inertia, infrastructural constraints, and persistent dependence on fossil-fuel-driven growth models.

Panel B of Table 4 presents the long-run coefficients derived from the CCE-ARDL model. The long-run GDP coefficient remains negative though economically small, implying that sustained economic growth may gradually contribute to reducing ecological pressure over time. This finding supports the long-run environmental modernization perspective, which suggests that economic development eventually enhances environmental quality through technological advancement, energy efficiency, and institutional strengthening (Acheampong, 2019). Nevertheless, the magnitude of the coefficient remains weak, implying that BRICS economies continue to experience environmentally costly growth trajectories. Similar results were documented by Ahmed et al. (2022), who found that technological innovation and democratic accountability are essential conditions for translating economic growth into environmental sustainability. The limited long-run

impact of GDP further suggests that industrialization within BRICS economies remains heavily dependent on carbon-intensive sectors despite gradual progress toward cleaner technologies.

The long-run population coefficient is positive, indicating that persistent urban expansion contributes to increasing environmental pressure over time. This outcome reflects the cumulative ecological effects of urban sprawl, industrial clustering, transportation congestion, and rising household consumption associated with rapid population growth. Previous studies have consistently argued that urbanization remains one of the most important drivers of ecological degradation in emerging economies (Dada et al., 2022; Nathaniel & Khan, 2020). However, the relatively modest magnitude of the coefficient suggests that the environmental consequences of urbanization are partly moderated by improvements in infrastructure and technological adaptation within some BRICS economies. China's investments in renewable energy infrastructure and public transportation systems may have reduced the adverse ecological effects of urban concentration relative to other member states. Nonetheless, the positive long-run relationship confirms that uncontrolled urban expansion continues to represent a major sustainability challenge within BRICS economies.

Table 4: *CCE-ARDL Model Results – Dependent Variable: efp*

Variable	Coefficient	Std. Error	p-value
Panel A: Short-Run Coefficients			
GDP	-0.001440	0.010097	0.8935
POP	0.110595	0.967881	0.9145
FDI	-0.744655	1.439302	0.6322
COL	0.002481	0.003857	0.5551
GLO	0.004417	0.025945	0.8731
Const	-3.024159	13.466355	0.8333
L1_efp (ECM)	-0.065046	0.238591	0.7986
Panel B: Long-Run Coefficients			
Model's Variable	Short-Run Coefficient	Long-Run Coefficient	
GDP	-0.001440	-0.001352	
POP	0.110595	0.103840	
FDI	-0.744655	-0.699176	

Variable	Coefficient	Std. Error	p-value
COL	0.002481	0.002330	
GLO	0.004417	0.004148	

Note. Speed of adjustment (1 - ρ) = 1.0650. Long-run coefficients are derived as short-run coefficient divided by (1 - ρ). CCE-ARDL = Common Correlated Effects – Autoregressive Distributed Lag model. Dependent variable: efp (economic freedom index). Number of countries = 5. Lag structure not explicitly shown. None of the coefficients are statistically significant at conventional levels.

Source: Author's computation (2026)

Table 5 presents the sensitivity analysis based on the CCEMG estimator. The GDP coefficient remains negative and statistically insignificant, thereby confirming the robustness of the CCE-ARDL findings. The consistency of the negative coefficient across estimation techniques indicates that economic growth may exert mild environmentally improving effects through efficiency gains and technological modernization. However, the absence of significance demonstrates that these benefits remain insufficient to offset the ecological pressures generated by industrial expansion and energy-intensive production. Similar conclusions were reached by Fakher et al. (2023), who emphasized that economic growth alone cannot guarantee environmental sustainability unless accompanied by renewable energy adoption and technological transformation. The insignificant GDP effect also suggests substantial heterogeneity among BRICS economies regarding the environmental consequences of growth. While China has increasingly transitioned toward green industrialization, other BRICS economies continue to rely heavily on extractive and resource-intensive sectors that undermine ecological sustainability.

The CCEMG results further show that population growth and trade openness maintain positive but statistically insignificant relationships with environmental pressure. These findings reinforce the earlier conclusion that urbanization and trade integration continue to exert ecological pressure, although their aggregate effects differ across countries. The insignificant coefficients may reflect differences in environmental governance quality, infrastructure investment, and renewable energy adoption among BRICS economies. Studies by Hossain et al. (2026) and Yurtkuran et al. (2025) similarly found that institutional effectiveness and renewable energy policies play critical moderating roles in determining whether globalization and urbanization worsen or improve environmental sustainability outcomes. The globalization coefficient becomes negative under the

CCEMG estimator, suggesting that international integration may contribute to environmental improvement through technology diffusion and global environmental cooperation. Although statistically insignificant, this reversal in sign highlights the multidimensional nature of globalization, where economic openness may simultaneously intensify production activities while encouraging green technological innovation and environmental awareness.

Table 5: Sensitivity Analysis (*CCEMG Model Results – Dependent Variable: efp)*

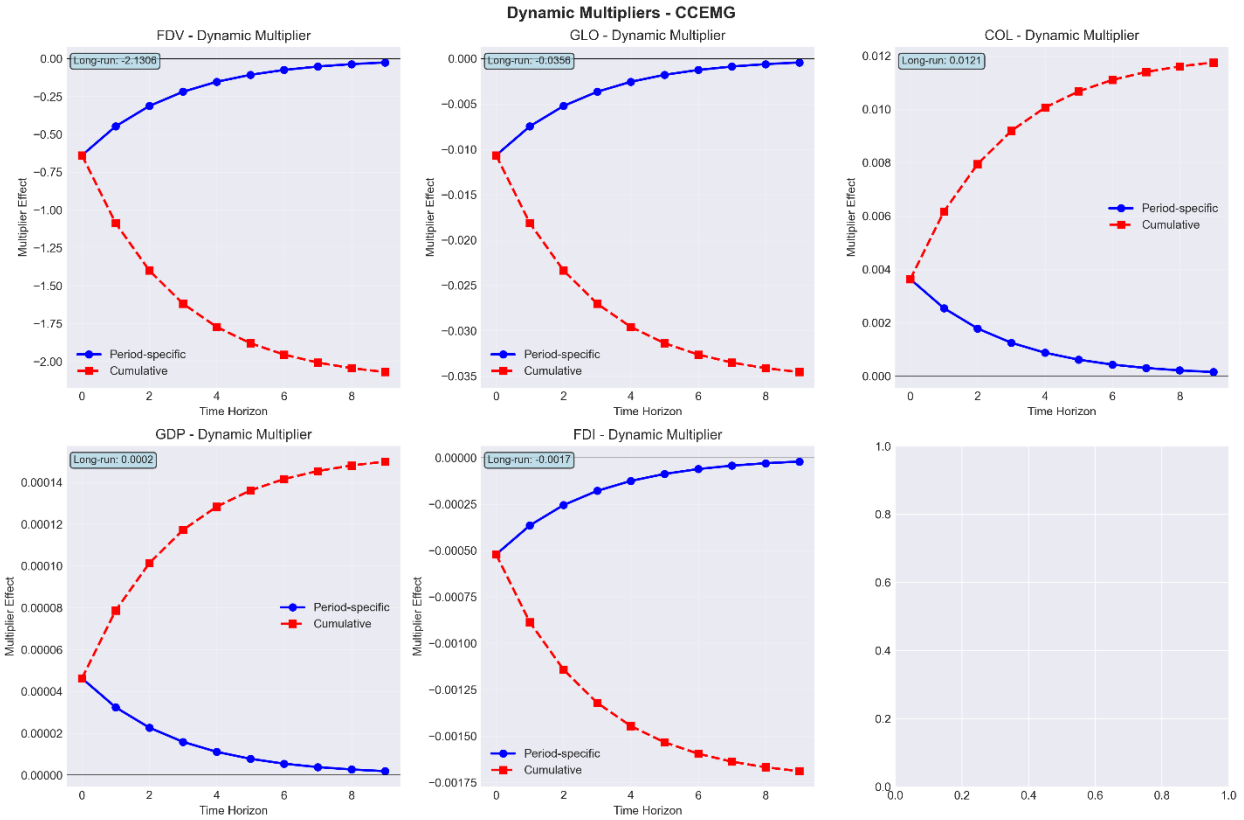
Variable	Coefficient	Std. Error	p-value
Const	-1.6535	7.6527	0.8395
GDP	-0.5407	0.6839	0.4734
POP	0.0033	0.0122	0.8001
FDI	0.0020	0.0036	0.6099
COL	0.0001	0.0001	0.7518
GLO	-0.0079	0.0161	0.6503

Note. CCEMG estimator based on Pesaran (2006). Dependent variable: efp (economic freedom index). Independent variables: fdv (financial development), glo (globalization), col (trade openness), gdp (gross domestic product), fdi (foreign direct investment). Number of countries = 5. Observations = 140. Success rate = 100%.

Source: Author's computation (2026)

The post-estimation dynamic multiplier plots provide additional insights into the short-run and long-run responses of ecological pressure to shocks in globalization, trade openness, GDP, financial development, and foreign direct investment within BRICS economies. The period-specific responses gradually converge toward equilibrium, indicating that the environmental effects of macroeconomic shocks diminish over time. Financial development (FDV) exhibits a persistently negative cumulative multiplier, suggesting that improvements in financial systems may support environmentally efficient investments, green financing, and technological modernization that reduce ecological pressure in the long run. Similarly, the negative cumulative response associated with globalization (GLO) implies that international integration may facilitate technology transfer, environmental awareness, and cleaner production practices across BRICS economies. These findings are consistent with studies emphasizing the environmental benefits of institutional modernization and technological diffusion under globalization processes (Zafar et al., 2019; Hussain et al., 2022; Balsalobre-Lorente et al., 2023).

The dynamic multipliers further reveal that trade openness (COL) and GDP generate positive cumulative responses over time, indicating that increased production, industrial expansion, and international trade activities may intensify ecological pressure through higher resource consumption and environmental exploitation. Although the GDP effect remains relatively small, the upward cumulative trajectory suggests that sustained economic expansion without adequate environmental safeguards may gradually worsen ecological sustainability conditions. Conversely, foreign direct investment (FDI) displays a weak but negative cumulative response, supporting the argument that foreign capital inflows can improve environmental quality when associated with cleaner technologies and environmentally responsible production systems. The gradual stabilization of the multiplier paths also reflects the adaptive capacity of BRICS economies to absorb macroeconomic shocks over time. These findings align with earlier studies linking globalization, urban expansion, and industrial growth to long-run ecological dynamics in emerging economies (Nathaniel & Khan, 2020; Wang et al., 2023; Javed et al., 2025).



Source: Author's Plot (2026)

4.2. Policy Implications

The findings of this study provide important policy implications for BRICS economies seeking to balance urban expansion, foreign investment inflows, and environmental sustainability. The insignificant but persistent positive influence of population pressure and globalization on ecological footprint suggests that rapid urbanization without adequate environmental planning may gradually intensify ecological stress over time. Policymakers in BRICS countries should therefore prioritize sustainable urban governance frameworks emphasizing green infrastructure, compact city planning, efficient waste management systems, and low-carbon public transportation networks. Investments in sustainable housing and smart urban technologies can reduce the ecological burden associated with population concentration and industrial clustering. Previous studies have shown that environmentally sustainable urbanization significantly improves ecological resilience and resource efficiency in emerging economies (Nathaniel & Khan, 2020; Danish et al., 2020). Strengthening urban environmental regulations and integrating ecological considerations into metropolitan planning strategies will therefore be essential for reducing long-run environmental pressure in BRICS economies.

The negative long-run relationship between foreign direct investment and ecological footprint, although statistically insignificant, suggests the possibility that environmentally friendly investments may contribute to technological upgrading and improved environmental management in BRICS countries. Governments should therefore design selective FDI attraction policies that prioritize green industries, renewable energy projects, low-carbon manufacturing, and environmentally responsible multinational corporations. Regulatory agencies should establish environmental performance standards for foreign firms while offering incentives for green technology transfer and sustainable industrial practices. Such policies would help BRICS economies avoid the pollution haven effect commonly associated with unrestricted industrial investment inflows (Ahmad et al., 2021; Wang et al., 2023). Furthermore, institutional mechanisms encouraging environmental accountability among foreign investors can strengthen sustainable production systems and reduce ecological degradation. Green investment screening frameworks and sustainability-oriented industrial policies can therefore improve the environmental benefits derived from international capital inflows.

The study also demonstrates that globalization and trade openness exert weak but positive influences on environmental pressure, implying that increased economic integration may intensify ecological consumption if environmental safeguards remain weak. Policymakers should therefore pursue environmentally responsible globalization strategies by integrating sustainability standards into trade agreements, industrial policies, and international investment frameworks. Trade liberalization policies should be accompanied by stricter environmental monitoring systems, cleaner production incentives, and technology-driven emission reduction strategies. Previous studies have emphasized that globalization can either worsen or improve environmental quality depending on institutional capacity and environmental governance effectiveness (Sabir & Gorus, 2019; Hussain et al., 2022). Accordingly, BRICS economies should strengthen cross-border environmental cooperation mechanisms, encourage green trade practices, and expand renewable energy collaboration initiatives. Such measures would ensure that globalization contributes to sustainable development rather than reinforcing environmentally harmful industrial expansion and resource depletion.

Another major implication relates to the importance of institutional quality and environmental governance in managing ecological sustainability within rapidly industrializing economies. The existence of cointegration between FDI, globalization, and macroeconomic variables suggests that environmental outcomes are deeply interconnected with long-run structural economic changes. BRICS governments should therefore strengthen institutional coordination across environmental agencies, urban planning authorities, trade ministries, and investment promotion institutions. Environmental regulations must be consistently enforced to prevent excessive resource exploitation associated with industrial growth and urban concentration. Evidence from recent studies indicates that governance effectiveness and policy coordination significantly improve ecological sustainability outcomes in emerging economies (Hasan et al., 2025; Wang et al., 2024). Strengthening environmental monitoring institutions, improving policy transparency, and increasing investments in environmental data systems can therefore support long-term ecological management. Institutional reforms promoting sustainable governance structures will further enhance the environmental efficiency of economic modernization processes.

The insignificant short-run relationships identified in the CCE-ARDL and CCEMG estimations further imply that environmental pressure in BRICS economies may be shaped more strongly by

structural and long-term developmental processes than by temporary macroeconomic fluctuations. This finding highlights the importance of long-term environmental transition strategies rather than short-term policy interventions. Governments should therefore prioritize structural transformation toward renewable energy adoption, green industrialization, sustainable technological innovation, and resource-efficient production systems. Investments in research and development related to clean energy technologies, energy-efficient infrastructure, and sustainable manufacturing can substantially reduce ecological footprint pressures over time. Earlier empirical studies have similarly emphasized the role of technological innovation and renewable energy transition in improving environmental sustainability across emerging economies (Javed et al., 2024; Khan et al., 2020). Long-term environmental planning frameworks should therefore become central components of national development strategies across BRICS countries.

Finally, the methodological findings of the study underscore the importance of accounting for cross-sectional dependence and heterogeneous country dynamics when designing environmental policies for BRICS economies. Since these economies are interconnected through trade, investment flows, commodity markets, and globalization processes, environmental shocks originating in one country may generate spillover effects across the entire bloc. Policymakers should therefore strengthen regional environmental cooperation through coordinated sustainability targets, shared green financing initiatives, and joint climate governance mechanisms. Regional collaboration in renewable energy development, sustainable infrastructure financing, and environmental technology transfer would improve collective ecological resilience across BRICS economies. Previous studies have emphasized that coordinated environmental governance and regional sustainability partnerships are essential for managing ecological risks in integrated emerging markets (Balsalobre-Lorente et al., 2020; Zafar et al., 2019). Enhanced regional environmental integration can therefore help BRICS economies achieve sustainable growth while minimizing long-run ecological pressure.

5. Conclusions

This study examined the relationship among foreign direct investment, urban expansion, globalization, trade openness, economic growth, and environmental pressure in BRICS economies over the period 1995–2024 using advanced panel econometric techniques. The findings from the

descriptive statistics revealed substantial variations in ecological footprint, trade openness, and macroeconomic indicators across the BRICS countries, reflecting differences in industrial structure, demographic transition, and globalization intensity. Panel unit root results indicated mixed integration properties among the variables, thereby justifying the adoption of second-generation panel techniques capable of addressing heterogeneity and cross-sectional dependence. The Westerlund cointegration results further demonstrated the existence of long-run equilibrium relationships among selected macroeconomic variables, particularly between foreign direct investment, globalization, and economic growth. These findings suggest that environmental dynamics in BRICS economies are strongly linked to long-run structural economic transformation and international economic integration processes.

The CCE-ARDL and CCEMG estimations showed that the explanatory variables exerted relatively weak and statistically insignificant effects on ecological footprint in both the short and long run. Nevertheless, the coefficient signs provide important economic insights into the environmental implications of globalization, urbanization, and foreign investment within emerging economies. Population growth and trade openness exhibited positive associations with environmental pressure, implying that rapid urban concentration and expanding trade activities may intensify ecological stress through increased resource consumption and industrial expansion. Conversely, foreign direct investment and economic growth demonstrated negative long-run relationships with ecological footprint, suggesting that technological advancement, efficiency gains, and improved production systems may partially offset environmental degradation. The robustness of the CCEMG estimates further confirms the importance of accounting for heterogeneous country-specific dynamics and cross-sectional dependence when analyzing environmental sustainability within interconnected emerging economies.

Overall, the study concludes that environmental sustainability in BRICS economies depends not only on economic growth patterns but also on the quality of globalization, urban governance, institutional effectiveness, and investment structures. The absence of strong statistically significant relationships does not diminish the policy relevance of the findings; rather, it highlights the complexity of ecological transitions in rapidly industrializing economies undergoing structural transformation. Sustainable development strategies in BRICS countries should therefore prioritize environmentally responsible urban planning, green foreign investment, renewable energy

transition, and stronger environmental governance systems. In addition, regional cooperation among BRICS economies remains essential for addressing shared ecological challenges arising from globalization, industrialization, and trade integration. By adopting long-term sustainability-oriented policies and strengthening institutional capacity, BRICS countries can achieve economic modernization while minimizing environmental pressure and promoting ecological resilience over the coming decades.

References

Abid, M. (2020). The long-run and short-run effects of oil price on energy consumption in Tunisia: Evidence from structural breaks analysis. *Energy Sources Part B: Economics, Planning, and Policy, 15*(4), 252–277. https://doi.org/10.1080/15567249.2020.1785054

Abid, N., Aftab, J., & Javed, A. (2025). The impact of green technological innovation and environmental policy on ecological sustainability: Evidence from leading economies. *Letters in Spatial and Resource Sciences, 18*(1), 14. https://doi.org/10.1007/s12076-025-00405-2

Acheampong, A. O. (2019). Modelling for insight: Does financial development improve environmental quality? *Energy Economics, 83*, 156–179. https://doi.org/10.1016/j.eneco.2019.06.025

Adams, S., & Acheampong, A. O. (2019). Reducing carbon emissions: The role of renewable energy and democracy. *Journal of Cleaner Production, 240*, 118245. https://doi.org/10.1016/j.jclepro.2019.118245

Ahmad, M., Jabeen, G., & Wu, Y. (2021). Heterogeneity of pollution haven/halo hypothesis and environmental Kuznets curve hypothesis across development levels of Chinese provinces. *Journal of Cleaner Production, 285*, 124898. https://doi.org/10.1016/j.jclepro.2020.124898

Ahmed, Z., Adebayo, T. S., Udemba, E. N., Murshed, M., & Kirikkaleli, D. (2022). Effects of economic complexity, economic growth, and renewable energy technology budgets on ecological footprint: The role of democratic accountability. *Environmental Science and Pollution Research, 29*(17), 24925–24940. https://doi.org/10.1007/s11356-021-17673-2

Ain, Q., Awan, A., & Bashir, F. (2024). Analyzing the intricate nexus of ecological footprint, urbanization, and economic growth in South Asia: A panel 2SLS analysis. *iRASD Journal of Economics, 6*(2), 598–619. https://doi.org/10.52131/joe.2024.0602.0226

Ashraf, A., Nguyen, C. P., & Doytch, N. (2022). The impact of financial development on ecological footprints of nations. *Journal of Environmental Management, 322*, 116062. https://doi.org/10.1016/j.jenvman.2022.116062

Aydin, M., & Turan, Y. E. (2020). The influence of financial openness, trade openness, and energy intensity on ecological footprint: Revisiting the EKC hypothesis for BRICS countries. *Environmental Science and Pollution Research, 27*(34), 43233–43245. https://doi.org/10.1007/s11356-020-10238-9

Ayaydın, H., Ergün, T., Barut, A., Erdem, A., & Pilatin, A. (2025). FinTech driven green energy transition, foreign direct investment and ecological footprint in BRICST countries. *Scientific Reports, 15*, 34838. https://doi.org/10.1038/s41598-025-18898-8

Bala, S., Ulfat, T. J., Hossain, H., Absy, M. S. M. A., Ridwan, M., Ridzuan, A. R., et al. (2025). From energy diversity to environmental resilience: The role of government efficiency in shaping ecological footprint in Bangladesh. *International Journal of Energy Economics and Policy, 15*(4), 189–203. https://doi.org/10.32479/ijeep.18955

Balsalobre-Lorente, D., Driha, O. M., Shahbaz, M., & Sinha, A. (2020). The effects of tourism and globalization over environmental degradation in developed countries. *Environmental Science and Pollution Research, 27*(7), 7130–7144. https://doi.org/10.1007/s11356-019-07372-4

Balsalobre-Lorente, D., Topaloglu, E. E., Nur, T., & Evcimen, C. (2023). Exploring the linkage between financial development and ecological footprint in APEC countries: A novel view under corruption perception and environmental policy stringency. *Journal of Cleaner Production, 414*, 137686. https://doi.org/10.1016/j.jclepro.2023.137686

Bekun, F. V., Emir, F., & Sarkodie, S. A. (2019). Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. *Science of the Total Environment, 655*, 759–765. https://doi.org/10.1016/j.scitotenv.2018.11.271

Çamkaya, S., & Karaaslan, A. (2024). Do renewable energy and human capital facilitate the improvement of environmental quality in the United States? A new perspective on environmental issues with the load capacity factor. *Environmental Science and Pollution Research, 31*(11), 17140–17155. https://doi.org/10.1007/s11356-024-32331-z

Çamkaya, S., Karaaslan, A., & Uçan, F. (2023). Investigation of the effect of human capital on environmental pollution: Empirical evidence from Turkey. *Environmental Science and Pollution Research, 30*(9), 23925–23937. https://doi.org/10.1007/s11356-022-23923-8

Dada, J. T., Adeiza, A., Noor, A. I., & Marina, A. (2022). Investigating the link between economic growth, financial development, urbanization, natural resources, human capital, trade openness and ecological footprint: Evidence from Nigeria. *Journal of Bioeconomics, 24*(2), 153–179. https://doi.org/10.1007/s10818-021-09323-x

Danish, & Wang, Z. (2019). Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. *Science of the Total Environment, 670*, 1075–1083. https://doi.org/10.1016/j.scitotenv.2019.03.268

Danish, Mahmood, N., & Zhang, J. W. (2019). Effect of natural resources, renewable energy and economic development on CO2 emissions in BRICS countries. *Science of the Total Environment, 678*, 632–638. https://doi.org/10.1016/j.scitotenv.2019.05.028

Danish, Ulucak, R., & Khan, S. U. D. (2020). Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization. *Sustainable Cities and Society, 54*, 101996. https://doi.org/10.1016/j.scs.2019.101996

Destek, M. A., & Sarkodie, S. A. (2019). Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development. *Science of the Total Environment, 650*, 2483–2489. https://doi.org/10.1016/j.scitotenv.2018.10.017

Dogan, E., & Inglesi-Lotz, R. (2020). The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: Evidence from European countries. *Environmental Science and Pollution Research, 27*(11), 12717–12724. https://doi.org/10.1007/s11356-020-07878-2

Fakher, H. A., & Ahmed, Z. (2023). Does financial development moderate the link between technological innovation and environmental indicators? An advanced panel analysis. *Financial Innovation, 9*, 1–25. https://doi.org/10.1186/s40854-023-00513-2

Fakher, H. A., Ahmed, Z., Acheampong, A. O., & Nathaniel, S. P. (2023). Renewable energy, nonrenewable energy, and environmental quality nexus: An investigation of the N-shaped environmental Kuznets curve based on six environmental indicators. *Energy, 263*, 125660. https://doi.org/10.1016/j.energy.2022.125660

Guloglu, B., Emre Caglar, A., & Pata, U. K. (2023). Analyzing the determinants of the load capacity factor in OECD countries: Evidence from advanced quantile panel data methods. *Gondwana Research, 118*, 92–104. https://doi.org/10.1016/j.gr.2023.02.013

Hasan, M. A., Voumik, L. C., Mozumder, A. I., Esquivias, M. A., Verteramo-Chiu, L., & Das, M. K. (2025). Role of governance index, democracy, industrialization, and urbanization on environmental sustainability of BRICS countries: A novel PMG-ARDL approach. *Social Sciences & Humanities Open, 11*, 101242.

Hossain, I., Ridwan, M., Ko, J., Ayon, S. A., Pria, N. J., & Leung, C. K. (2026). Exploring the impact of renewable energy consumption, trade openness, and government effectiveness on ecological footprint in selected BRICS countries. *Discover Sustainability, 7*, 469. https://doi.org/10.1007/s43621-026-02842-5

Hussain, M., Usman, M., Khan, M. K., & Tarar, Z. H. (2022). The role of globalization and financial development in environmental sustainability: Evidence from BRICS economies. *Environmental Science and Pollution Research, 29*(18), 26351–26365. https://doi.org/10.1007/s11356-021-17772-9

Ike, G. N., Usman, O., Alola, A. A., & Sarkodie, S. A. (2020). Environmental quality effects of income, energy prices and trade: The role of renewable energy consumption in G7 countries. *Science of the Total Environment, 721*, 137813. https://doi.org/10.1016/j.scitotenv.2020.137813

Javed, A., Rapposelli, A., Adedoyin, F. F., & Arshad, Z. (2025). Examining the role of remittances, technological innovation, and foreign direct investment on environmental quality in

Pakistan: Fresh evidence from a novel dynamic ARDL simulation approach. *Social Indicators Research, 179*(1), 123–151. https://doi.org/10.1007/s11205-025-03599-6

Javed, A., Rapposelli, A., Khan, F., Javed, A., & Abid, N. (2024). Do green technology innovation, environmental policy, and the transition to renewable energy matter in times of ecological crises? A step towards ecological sustainability. *Technological Forecasting and Social Change, 207*, 123638. https://doi.org/10.1016/j.techfore.2024.123638

Khan, A., Muhammad, F., Chenggang, Y., Hussain, J., Bano, S., & Khan, M. A. (2020). The impression of technological innovations and natural resources in energy–growth–environment nexus: A new look into BRICS economies. *Science of the Total Environment, 727*, 138265. https://doi.org/10.1016/j.scitotenv.2020.138265

Kihombo, S., Ahmed, Z., Chen, S., Adebayo, T. S., & Kirikkaleli, D. (2021). Linking financial development, economic growth, and ecological footprint: What is the role of technological innovation? *Environmental Science and Pollution Research, 28*(43), 61235–61245.

Liu, X., Wang, H., Wu, X., Nasim, I., & Hedvicakova, M. (2024). The nexus between national governance, renewable energy, and ecological footprints: Evidence from the Chinese economy. *Polish Journal of Environmental Studies*. https://doi.org/10.15244/pjoes/193385

Lu, W.-C. (2020). The interplay among ecological footprint, real income, energy consumption, and trade openness in 13 Asian countries. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-020-10399-7

Mahmoodi, M., & Dahmardeh, N. (2022). Environmental Kuznets curve hypothesis with considering ecological footprint and governance quality: Evidence from emerging countries. *Frontiers in Environmental Science, 10*, 849676. https://doi.org/10.3389/fenvs.2022.849676

Nathaniel, S. P., & Khan, S. A. R. (2020). The nexus between urbanization, renewable energy, trade, and ecological footprint in ASEAN countries. *Journal of Cleaner Production, 272*, 122709. https://doi.org/10.1016/j.jclepro.2020.122709

Özbek, S., & Naimoğlu, M. (2025). The effectiveness of renewable energy technology under the EKC hypothesis and the impact of fossil and nuclear energy investments on the UK's ecological footprint. *Energy, 322*, 135351. https://doi.org/10.1016/j.energy.2025.135351

Pata, U. K. (2018). Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: Testing EKC hypothesis with structural breaks. *Journal of Cleaner Production, 187*, 770–779. https://doi.org/10.1016/j.jclepro.2018.03.236

Qing, L., Li, P., Mehmood, U., & Dagestani, A. A. (2024). Uncovering the potential impacts of financial inclusion and human development on ecological sustainability in the presence of natural resources and government stability: Evidence from G-20 nations. *Resources Policy, 88*, 104446. https://doi.org/10.1016/j.resourpol.2023.104446

Rehman, A., Radulescu, M., Ma, H., Dagar, V., Hussain, I., & Khan, M. K. (2021). The impact of globalization, energy use, and trade on ecological footprint in Pakistan: Does

environmental sustainability exist? *Energies, 14*(17), 5234. https://doi.org/10.3390/en14175234

Sabir, S., & Gorus, M. S. (2019). The impact of globalization on ecological footprint: Empirical evidence from South Asian countries. *Environmental Science and Pollution Research, 26*(32), 33387–33398. https://doi.org/10.1007/s11356-019-06458-3

Shahbaz, M., Dogan, M., Akkus, H. T., & Gursoy, S. (2023). The effect of financial development and economic growth on ecological footprint: Evidence from top 10 emitter countries. *Environmental Science and Pollution Research, 30*(29), 73518–73533. https://doi.org/10.1007/s11356-023-27573-2

Sinha, A., Sengupta, T., & Alvarado, R. (2020). Interplay between technological innovation and environmental quality: Formulating the SDG policies for next 11 economies. *Journal of Cleaner Production, 242*, 118549. https://doi.org/10.1016/j.jclepro.2019.118549

Usman, M., Kousar, R., Yaseen, R., Sohail, M., Makhdum, A., & Yaseen, M. R. (2020). An empirical nexus between economic growth, energy utilization, trade policy, and ecological footprint: A continent-wise comparison in upper-middle-income countries. *Environmental Science and Pollution Research, 27*, 38995–39018. https://doi.org/10.1007/s11356-020-09772-3

Usman, O., Akadiri, S. S., & Adeshola, I. (2020). Role of renewable energy and globalization on ecological footprint in the USA: Implications for environmental sustainability. *Environmental Science and Pollution Research, 27*(24), 30681–30693. https://doi.org/10.1007/s11356-020-09170-9

Wang, E., Padhan, H., Pruseth, S. K., & Ma, J. (2024). Government efficiency, green technology, and ecological footprint: Strategic framework for natural resource management efficiency targets. *Resources Policy, 91*, 104826. https://doi.org/10.1016/j.resourpol.2024.104826

Wang, Q., Zhang, F., & Li, R. (2023). Revisiting the environmental Kuznets curve hypothesis in BRICS countries: The role of globalization and foreign direct investment. *Environmental Research, 216*, 114594. https://doi.org/10.1016/j.envres.2022.114594

Yurtkuran, S., Yıkıcı, A., & Çolak, Ç. (2025). Do anti-corruption and renewable energy drive environmental sustainability? Testing the EKC hypothesis for G20 countries. *Sustainable Development, 33*(6), 8511–8526. https://doi.org/10.1002/sd.70108

Zafar, M. W., Saud, S., & Hou, F. (2019). The impact of globalization and financial development on environmental quality: Evidence from selected countries in the Organization for Economic Co-operation and Development (OECD). *Environmental Science and Pollution Research, 26*(13), 13246–13262. https://doi.org/10.1007/s11356-019-04761-7

Zhang, S., Xu, G., Shu, Y., Zhu, J., & Cheng, W. (2024). Comparing developed and emerging nations' economic development with environmental footprint for low-carbon competitiveness. *Heliyon, 10*(14), e34039. https://doi.org/10.1016/j.heliyon.2024.e34039