

Article

The Symmetric Effect of Financial Development, Human Capital and Urbanization on Ecological Footprint: Insights from BRICST Economies

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Abstract: Environmental degradation is a serious concern and its prevention strategies have become a central topic worldwide. It is widely accepted that improving environmental quality is essential for advancing sustainable development and societal well-being. From this perspective, the present research employed panel data from 1990 to 2022 from BRICST economies to assess the effects of financial development, human capital, urban population, energy consumption, and economic growth on environmental quality regarding ecological footprint. This study employs second-generation empirical techniques such as CIPS and CADF unit root tests, Westerlund bootstrap cointegration, and DFE/MG/PMG-ARDL models to examine the connections among the studied variables. The empirical findings of this study uncover that in the BRICST countries, environmental quality is exacerbated by human capital, urban population, energy consumption, and economic growth. On the other hand, financial development and GDP² help improve environmental quality. Additionally, the interaction of the term financial development results with the terms human capital and urban population has a negative effect and reduces ecological footprint by improving environmental quality. From the policy perspective, the selected countries must implement policies that promote equitable financial resources, plan sustainable urbanization to promote compact cities and green infrastructure, and invest in green energy to address the adverse environmental consequences in BRICST economies.

Keywords: ecological footprint; financial development; human capital; urbanization; PMG-ARDL; BRICST countries



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1. Introduction

Earth faces major environmental problems, such as climate change and global warming. These problems also include atmospheric changes, inadequate food sources for human survival, the extinction of several species, and extreme weather changes [1]. These issues also present a significant barrier to achieving sustainable development. The 2021 United Nations (UN) report highlights the exacerbation of environmental problems, emphasizing their considerable hindrance to implementing sustainable development policies and social well-being [2]. The significance of environmental deterioration as a pressing issue has led to its prominence in global discussions on strategies for prevention. This framework asserted that there is a universal agreement that enhancing environmental quality is imperative for promoting sustainable development and societal well-being [3]. Hence, researchers and policymakers exert significant efforts to ascertain the underlying factors contributing to environmental degradation. Environmental economics literature has long sought to comprehend the underlying factors contributing to environmental degradation. Several economic, social, and sector-specific aspects have been associated with environmental quality by researchers who have historically tried to specify the link between these variables [4]. BRICST countries—Brazil, Russia, India, China, South Africa, and Turkey—have

experienced profound economic development in recent decades, whereby millions have been lifted out of poverty and global economic expansion boosted. However, this rapid development has taken a toll on the environment since there has been a surge of pollution and resource exhaustion that has destroyed the vital essence of these countries. The research context depicts the necessity of sustainable growth patterns to detach economic development from ecological growth. Therefore, determining the factors of the ecological footprint (hereafter EF) in BRICST economies is essential to make policy decisions centered on promoting sustainable growth while avoiding environmental hazards [5].

The mingling of economic development and environmental sustainability has emerged as a crucial focus for study in recent times, especially in BRICST economies. BRICST economies account for a larger share of global economic activity and are becoming increasingly urbanized, industrialized, and populous. The growth of BRICST has raised environmental concerns about its footprint, making several researchers and policymakers embark on this endeavor to investigate the interconnection between selected macroeconomic factors and overall ecologic footprint [6]. This research, therefore, seeks to contribute to this debate by examining the effect of financial development (hereafter FD), human capital (hereafter HC), urbanization (hereafter UP), energy consumption (hereafter EC), and economic growth on the EF in BRICST economies. Given the high levels of economic growth, it is driven by the need to understand the dynamics in diverse economies to reveal their sustainability factors. The motivation of the study is the need to know how to manage the environmental challenges BRICST economies face. Economic growth is a significant factor for improved living standards and poverty eradication, but it has environmental consequences, a fact that is becoming increasingly evident. This study is essential to ensure sustainability in the face of environmental deterioration in BRICST countries. Additionally, these countries' economic growth is shaping the course of the global economy, and the environmental impact of their actions significantly affects worldwide sustainability initiatives [7]. The main objective of this research is to study the effects of FD, HC, UP, EC, and economic growth on the EF in BRICST economies. More specifically, the goals of this paper include investigating the impacts of the selected economic indicators on the EF, discussing the effects of the interaction between FD with HC and UP on countries' sustainability levels and suggesting essential policy implications for BRICST economies to promote sustainable development.

The BRICST economies were chosen for this study due to their vital status as leading emerging economies globally, making them impactful contributors to the global economic system. The size of the countries covered, the vast population, economic potential, and differences in the UP, EC, and stages of FD contribute to the EF [8]. The variation of economic and policy environments among the BRICST states offers a suitable background to examine how the varying growth paths and development policies shape environmental quality. For example, rapid urbanization is associated with high consumption and waste generation, thereby emerging as a source of challenges and opportunities for urban sustainability [9]. EC differs from country to country, ranging from higher levels of coal and oil use to significant investments in green energy, directly impacting environmental policies and EF [10]. Another factor to consider is the financial systems of these countries, which can restrict their capacity to finance environmental management and sustainable infrastructure projects, thus affecting their overall EF [11]. By considering such a wide range of countries, this research seeks to obtain information used in policymaking in these states, opening the door to a more extensive discussion regarding sustainable development and environmental protection in rapidly growing economies. This multidimensional aspect allows for a better comprehension of the intricate interplay between economic growth and environmental health in a global environment.

Following a comprehensive examination of the introductory debate, it has been widely acknowledged that previous research has explored the connections between environmental degradation and various factors [12–14]. Historically, assessing the state of the environment has predominantly relied on examining variables such as carbon dioxide emissions [15].

However, employing a comprehensive metric that incorporates all essential aspects of environmental degradation is imperative. The EF (used in this study as a proxy of environmental quality) is a valuable tool for evaluating the impact of human activities on the ecosystem. It is of great importance as it enables the assessment of the effects of human activities on many domains, such as agriculture, grazing, forest lands, built-up regions, and carbon demand on land [16,17]. Moreover, it is worth noting that a limited amount of scholarly literature has investigated the combined impact of HC, UP, EC, and economic growth on exacerbating environmental degradation in BRICST countries while highlighting the roles of FD and economic growth square (GDP^2), which indicates the Environmental Kuznets Curve (EKC) hypothesis on environmental quality. Moreover, the study unveils the nuanced effects of interaction terms, revealing that combining FD with HC and UP affects the EF. The empirical findings of this study reveal that in the BRICST countries, environmental quality has deteriorated in HC, UP, EC, and economic growth. On the other hand, FD and GDP^2 help improve environmental quality. Additionally, the interaction term FD results with HC and UP has a negative effect and reduces the EF by improving environmental quality. After conducting thorough empirical research, this study presents practical policy recommendations that could help achieve sustainable development goals in BRICST countries.

Figure 1 shows the BRICST countries' EF contributions by percentages from 1990–2022. China has 13.7%, as a result of it having the most extensive industrial activity and population. India is 4.7% due to its large population and increasing industrial base. Turkey, 16.4%, and Brazil, 15.5%, are significant contributors because they have extensive agricultural and industrial activities. Russia, 31.3%, functions as a large energy producer and extractor. South Africa, 18.4%, has a growing economy and industrial activity compared to other countries [18]. These figures show the differences in EF of these countries regarding environmental sustainability. Figure 2 shows the year-wise values of EF in BRICST Economies, 1990–2022. The built-up land, the area covered by infrastructure like buildings and roads, provides information about the urbanization level. A carbon footprint is a forested area required to absorb carbon emissions from burning fossil fuels—the number of life-supporting ecozones. Cropland is an area of land occupied by food crops. Fishing grounds are land covered by marine and freshwater bodies used for fishing and other purposes. Forest products are forested areas used for harvesting timber and other products. Grazing land and pasture are used per facet of the land, including farms, production, and animal livestock [19]. Understanding how these values evolve allows us to analyze these economies' sustainability and environmental impact.

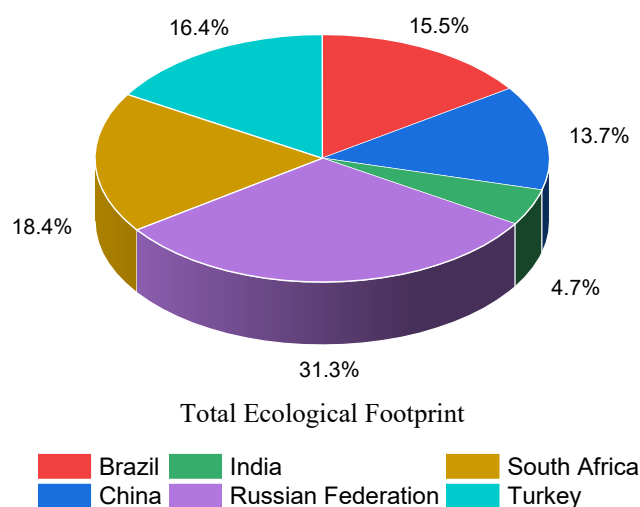


Figure 1. Ecological footprint in BRICST countries (country-wise). Source: Global Footprint Network [17].

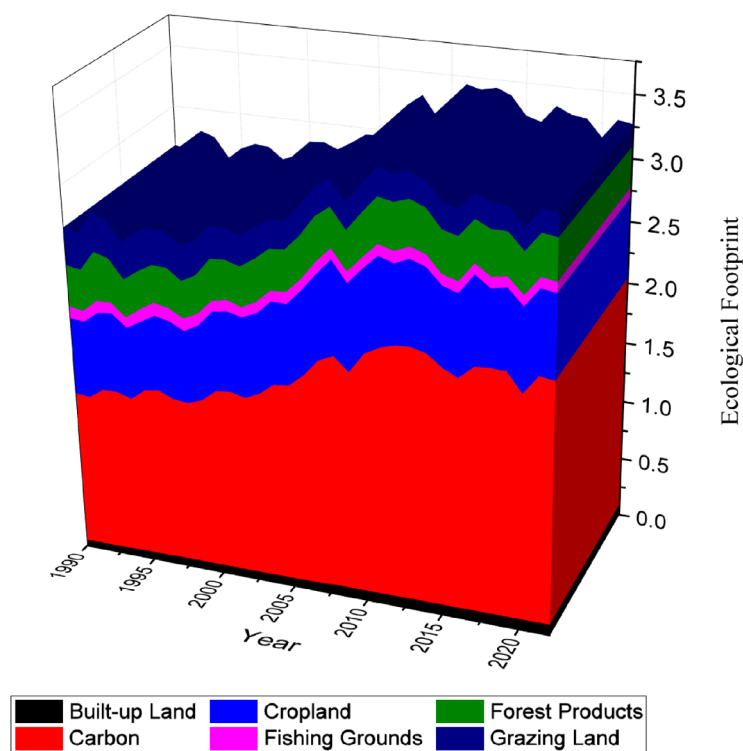


Figure 2. Ecological footprint in BRICST countries (year-wise). Source: Global Footprint Network [17].

This study is further categorized as follows: Section 2 displays the literature review. Section 3 specifies a theoretical understanding of the selection of variables, includes data sources, and discusses the research methodology. Section 4 empirically presents the results and discusses those results in detail. Section 5, the last part of this study, briefly concludes and presents policy recommendations to improve environmental quality in BRICST economies.

2. Literature Review

Over the past few decades, the surge in environmental degradation has led scholars and policymakers to examine the multifaceted link between economic growth and ecological sustainability across the global community. This literature review examines empirical works about profound factors, namely FD, HC, UP, EC, and economic growth on the EF, focusing on the BRICST nations. FD, usually characterized by the depth, efficiency, and usage of financial markets and institutions, has been well-researched regarding its environmental implications. The proponents of a clean environment claim that FD enables technological advancement and cleaner output through investments in manufacturing process technology [20,21]. In contrast, others believe that expanding financial services leads to increased utilization and extraction of environmental resources [11]. Fan et al. [22] found a direct positive link between FD and EF in BRICST countries, implying that rapid expansion of financial markets perpetuates resource demand and exacerbates environmental degradation. Paun et al. [23], using panel regression methodology, confirm the significant impact of financial sector development on economic growth, aligning with economic theory, in 45 low-income, middle-income, and high-income countries. The value added in production depends on the ease of access and cost of capital, emphasizing the importance of the financial sector in sustainable growth. Through advanced econometric methods, Zhang [24] examined the effect of China's FD on carbon emissions. Results show that FD has a strong positive impact on the increase in carbon emissions. The effectiveness of financial intermediation is less powerful than the scale factor. The volume of China's stock market also matters; however, the efficiency factor does not work well since the stock market is less liquid. Yang et al. [25] investigate the impacts of natural resources, renewable

energy, and FD on ecological quality within the BRICS nations. Although economic growth, FD, and exploiting natural resources worsen ecological conditions, adopting renewable energy sources positively affects environmental quality. Figure 3 shows the FD trend in BRICST economies.

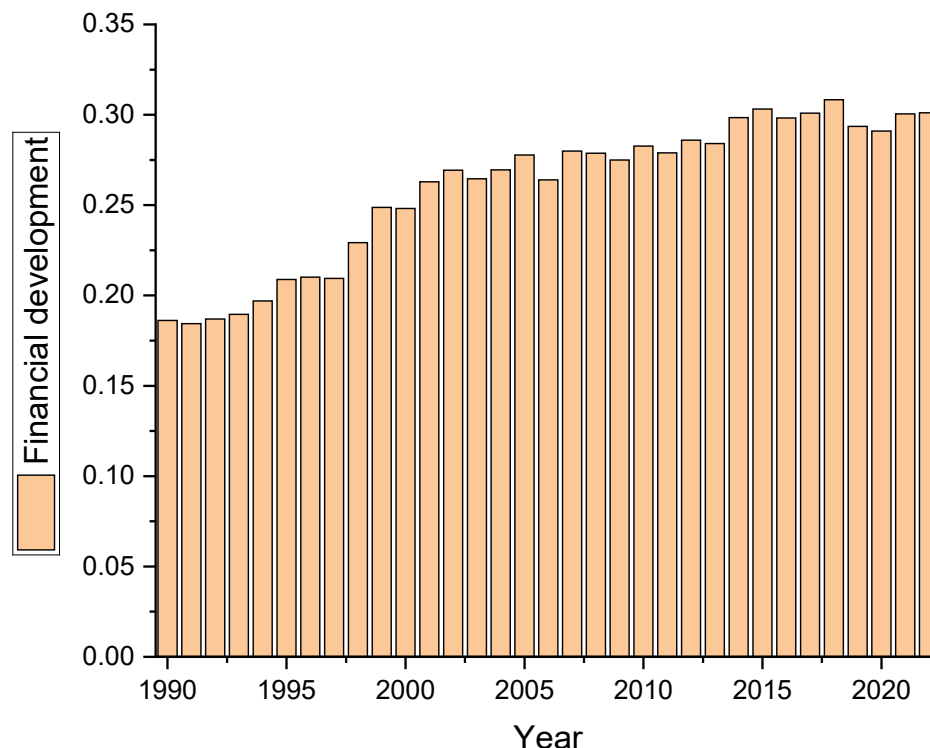


Figure 3. Financial development in BRICST economies. Source: International Monetary Fund [26].

HC, understood as individuals' knowledge, skills, and abilities, is a crucial determinant of sustainable development. This is because highly educated people have more possibilities to develop innovative, environmentally friendly technologies that are more resource-efficient [27]. However, Dogan et al.'s [6] analysis of BRICST economies showed mixed results between HC and EF. While higher education levels were associated with greater environmental awareness and adopting eco-friendly practices, rapid UP and industrialization accompanied rising educational attainment, leading to increased EC and pollution. HC accumulation is essential for environmental sustainability because it reduces the EF. Ritu and Kaur [28] study the test of the EKC hypothesis in the Indian economy, emphasizing the role of key variables by using an augmented ARDL approach with a structural break from 1997 to 2020. The results show that globalization, open trade, and income pollute the environment while increasing HC reduces the EF in the long run. Ganda [29] examined the effect of HC on environmental quality in BRICS between 1990 and 2017. The article used advanced econometric models and demonstrated that HC has a statistically significant and highly positive short- and long-term effect on environmental metrics. The researchers recommended governments encourage efforts to acquire green skills. Moreover, there is empirical evidence that the impact of HC on CO₂ emissions is negative in the long run. According to Haseeb et al. [30], BRICS countries reduce their CO₂ emissions by augmenting their HC to mitigate pollution in the long run. Given the aforementioned, Li and Ullah [31] analyzed the impact of the HC on CO₂ emissions within the BRICS economies from 1991 to 2019. Based on the results generated by the non-linear panel autoregressive distributed lag analysis approach, it was revealed that changes to the educational quality contribute to CO₂ reduction. For individual BRICS countries, it was confirmed that positive educational changes had a limited effect in Brazil but strongly impacted Russia, China, and

South Africa. In turn, it proposed that educational infrastructure investments reduce CO₂ emissions. Figure 4 shows the HC curve in BRICST economies.

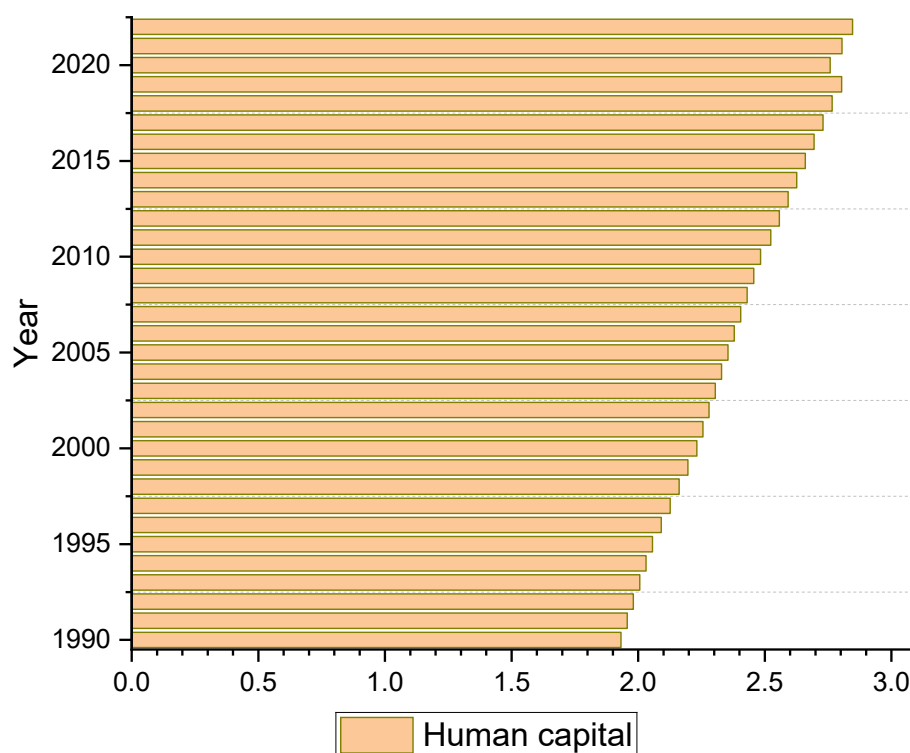


Figure 4. Human capital in BRICST economies. Source: Penn World Table [32].

UP, which refers to the increased intensity of population and economic activities in an urban area, is a fundamental aspect of environmental sustainability. UP contributes to the improvement of economies of scale, efficient resource allocation, and access to public services, aspects that have the potential to reduce per capita EF [33]. However, rapid urban expansion leads to high rates of habitat destruction, air and water pollution, and escalated need for natural resources and energy; the study by Danish et al. [18] indicated that UP was highly associated with the EF in BRICST economies. The findings implied that UP could be sustained through integrated urban planning, sustainable infrastructure development, and environmental governance. Wang et al. [34] examined the effect of UP on environmental sustainability by utilizing a STIRPAT model on BRICS countries between 1995 and 2019. The results indicate that UP reduces EF and PM_{2.5} pollution. Mookherjee and Dutta [35] explore the issue of UP, EC, and environmental deterioration in BRICS from 1992 to 2014. The panel data model outlines the relationship between these three factors. Findings show sustainable urban development combines ecological, social, and economic factors to ensure sustainability. During urbanization, BRICS countries have faced EC and subsequent environmental deterioration. Khan et al. [36] investigated the dynamic relationship between UP, EC, and environmental pollution in India from 1971 to 2018. Results show that UP has a positive effect on the environment in the long run, while EC has a negative effect. It was noticed that the impact on the EF was asymmetrical. Chen et al. [37] investigate whether and how UP influences the relationship between HC and EF, employing data from 110 economies from 1990–2016. Results found that HC influences the EF and negatively moderates at different degrees of UP. More specifically, a higher level of UP increases the HC required to improve environmental quality. The results confirm that the improvement of HC advances industrial upgrading, green technology, and energy-saving life. Still, we cannot overlook its adverse impact on environmental quality through its effect on large populations and rapid UP. Figure 5 shows the UP tendency in BRICST economies.

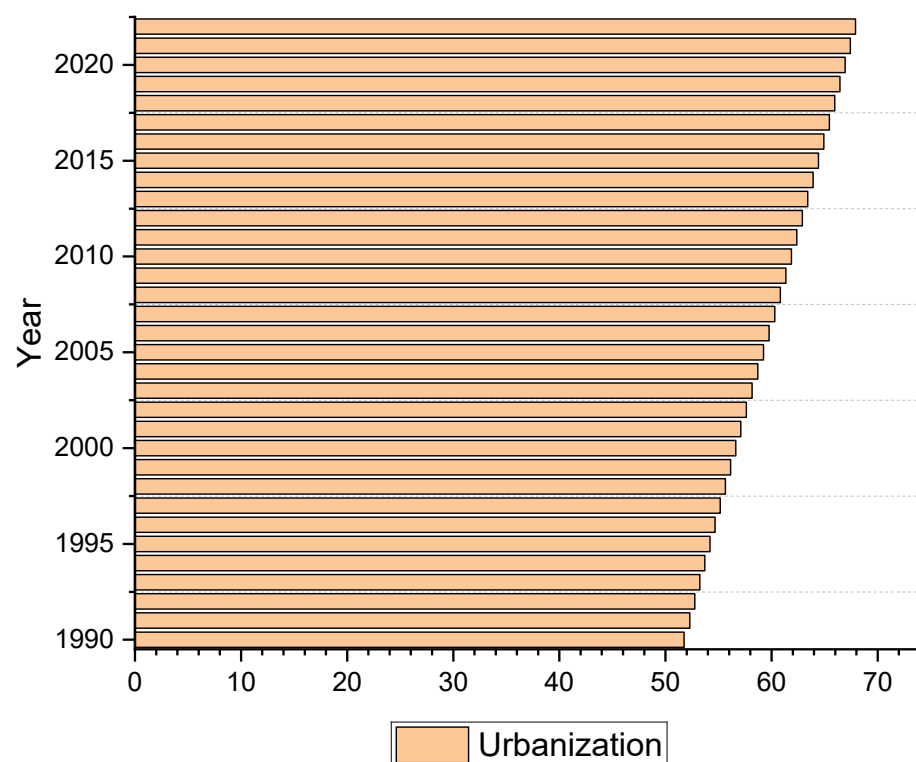


Figure 5. Urban population in BRICST economies. Source: World Development Indicator [38].

The relationship between EC and EF has recently been the focus of several studies. In many developing economies, EC is primarily driven by fossil fuels; thus, it is accountable for a large share of greenhouse gas emissions and environmental degradation. Using renewable energy sources and energy efficiency is essential to reducing the EF and combating climate change [33]. A study by Kongbuamai et al. [39] in BRICST nations revealed a positive connection between the EC and the EF, emphasizing that renewable energy, energy conservation, and sustainable urban transportation policies must be prioritized to solve this problem. Moreover, Öcal et al. [40] investigated the long-run relationship between EC, economic growth, and environmental pollution in Turkey between 1968 and 2016, adopting the ARDL bounds test approach. The outcomes from the study indicate that EC has a positive impact. Thus, the findings propose that the measure of environmental degradation must include green EC to mitigate the EF. Moreover, Caglar et al. [41] explored the impact of information and communications technology (ICT), renewable and non-renewable EC, FD, and economic growth on the environment in 10 countries most affected by environmental degradation. Based on the results obtained, non-renewable EC negatively impacts environmental quality, while renewable energy, ICT, and FD have a positive influence. Li et al. [42] investigated the effects of green environmental policies on renewable EC in the BRICST economies from 1991 to 2019. Using panel quantile regression, they found that green environmental policies positively influence renewable EC. Topcu [43] explored the influence of exports, imports, and renewable EC on the EF of Turkey between 1990 and 2015. According to the results of the long-term elasticity analyses, renewable EC and exports decrease the EF, while imports increase it. As a result, Turkey needs to alleviate its dependency on imports, expand biological capacity through selective investments, and favor renewable resources over fossil-based ones to mitigate the ecological deficit and ensure sustainable development. These considerations are crucial for structuring effective environmental policies. Figure 6 shows the upward tendency of EC in BRICST economies.

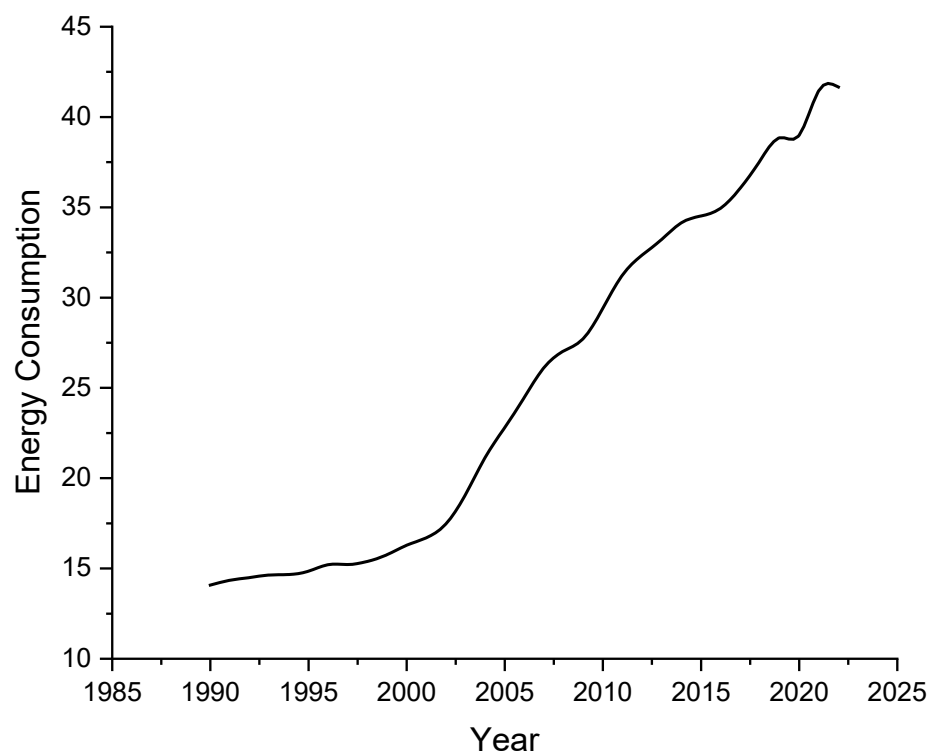


Figure 6. Energy consumption in BRICST economies. Source: Energy Institute Statistical Review of World Energy [44].

Economic growth improves living standards and reduces poverty, which is always achieved through lowered environmental quality. The conventional growth paradigm, driven by an indiscriminate push for GDP expansion with minimal regard for environmental externalities, is associated with general environmental degradation and ecological imbalances [45]. Many studies analyze the relationship between economic growth and the EF under varying conditions. For example, Sadorsky [46] found evidence of an Environmental Kuznets Curve, reporting an inverted U-shaped relationship between economic growth and EF. Usman et al. [47] tested the dynamic effect of renewable EC, economic growth, biocapacity, and trade policy on environmental degradation in the United States. They observed a two-sided causal relationship between economic growth and EF. Ahmed et al. [48] explored democracy, environmental regulations, and economic growth on the EF curve of G7 countries. They found that economic growth increased the EF and that democracy and environmental regulations promoted ecological sustainability. UP and the coupling of economic growth and environmental quality in 134 countries across the world by Wang et al. [49] tested the relational mechanism of economic growth on EF. The above studies contribute to understanding economic growth and the EF linked under completeness among and within different regions. Despite the diverse literature encompassing the relationship between FD, HC, UP, EC, economic growth, and EF, several research gaps remain. There is a dearth of macro-research incorporating long-term longitudinal data and contemporary econometric modeling techniques that would help identify changing causal relationships. In addition, there is also a need for increased case complexity with a focus on regional and sectoral disparities, a more rigorous focus on policy-based initiatives on development, and integration of more qualitative behavioral research. As a result, filling these research gaps allows a better understanding of the complex nature of sustainable care in BRICST economies and the development of evidence-based policies promoting environmental resilience. Figure 7 shows the GDP flow in BRICST economies.

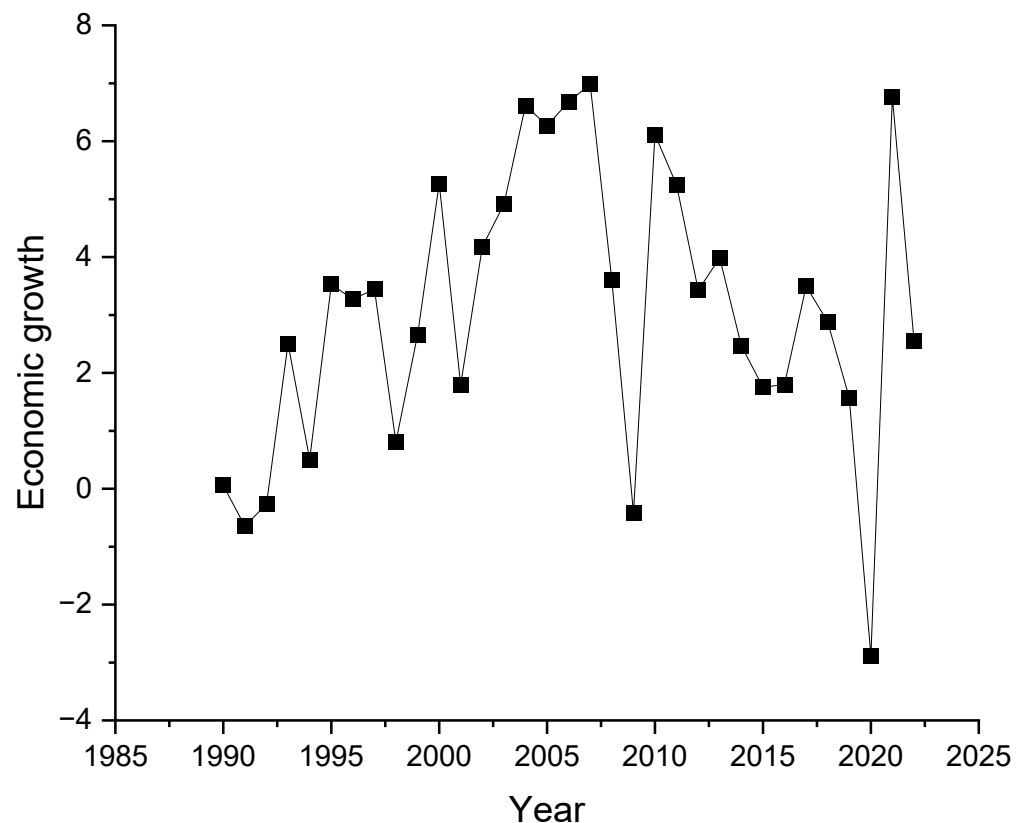


Figure 7. Economic growth in BRICST economies. Source: World Development Indicator [38].

The interaction between FD and HC is crucial in understanding the comprehensive impacts on environmental quality. FD enhances access to capital, facilitating investments in education and skills development, subsequently improving HC. Enhanced HC, characterized by a more educated and skilled workforce, leads to greater awareness and adoption of environmentally friendly technologies and practices, potentially reducing the EF. Several studies provide empirical evidence supporting the significant impact of the interaction between FD and HC on environmental outcomes. For instance, Kirikkaleli and Adebayo [50] found that human capital investments substantially improve environmental quality in economies with advanced financial sectors. This is because a well-developed financial sector offers the necessary resources for innovation and the adoption of green technologies, which are more effectively utilized by a skilled and knowledgeable workforce.

Furthermore, Jalil and Feridun [51] highlighted that FD and a higher level of HC result in better environmental management practices. This combination enables more efficient allocation of resources towards sustainable development initiatives, reducing the negative impact on the environment. Similarly, Tamazian et al. [52] demonstrated that countries with robust financial systems and high HC indices tend to show better environmental performance, as financial markets facilitate investments in green technologies, and human capital ensures their effective implementation. Our study's findings align with these perspectives. Our model's interaction term between FD and HC indicates a negative effect on the EF, suggesting that these factors contribute significantly to improved environmental quality when combined. Specifically, our results show that FD enhances the capacity for environmental investments and innovations, while HC ensures that these investments are effectively deployed, reducing EF.

3. Empirical Model, Data, and Methodology

3.1. Empirical Models of the Study

The primary objective of this research is to examine the effect of FD, HC, UP, EC, and economic growth on EF among BRICST countries. The general empirical representation of the studied model is given in Equation (1).

$$EF_{i,t} = f(FD_{i,t} + HC_{i,t} + UP_{i,t} + EC_{i,t} + GDP_{i,t}) \quad (1)$$

where environmental quality determined by ecological footprint $EF_{i,t}$ is equal to the function of the regressors: financial development $FD_{i,t}$, human capital $HC_{i,t}$, urban population $UP_{i,t}$, energy consumption $EC_{i,t}$, and economic growth $GDP_{i,t}$. To address the complexity concerns, we used natural logarithmic adjustments on all variables used in the research. Hence, the log-transformed model of this study is expressed in Equation (2).

$$EF_{i,t} = \Omega_1 + \sum_p^q \Omega_2 \ln R_{i,t} + v_{i,t} \quad (2)$$

where “ $EF_{i,t}$ ” represents the measure of environmental quality, specifically the level of per capita ecological footprint in its log form, and “ i and t ” denotes cross sections and period of the study. The symbols “ Ω_1 and Ω_2 ” refer to the model’s intercept and slope coefficients, respectively. Additionally, $\ln R_{i,t}$ incorporates all the given explanatory indicators, namely FD, HC, UP, EC, and economic growth, in their natural logarithmic form. Lastly, the variable $v_{i,t}$ refers to the stochastic error term, which signifies the unexplained portion of the model.

$$\Delta EF_{i,t} = \Omega_0 + \Omega_1 EF_{i,t-j} + \Omega_2 FD_{i,t-j} + \Omega_3 HC_{i,t-j} + \Omega_4 UP_{i,t-j} + \Omega_5 EC_{i,t-j} + \Omega_6 GDP_{i,t-j} + \Omega_7 GDP_{i,t-j}^2 + v_{i,t} \quad (3)$$

In Equation (3), the variables mentioned are adequately described above. Specifically, ‘ Ω_0 ’ represents the measure of the constant term. ‘ Ω_1 ’ represents the coefficient for the lag-dependent variable (EF) and ‘ Ω_2 to Ω_7 ’ represents the slope coefficients for discussed regressors. The symbols p and q denote the lags of dependent and independent variables, respectively. Lastly ‘ $v_{i,t}$ ’ denotes the stochastic error term in the model, which captures the unexplained portion of the study. This study employed the interaction term between FD and HC, explained in Equation (4) and the EKC hypothesis. The interaction term helps in understanding whether better financial systems combined with a more educated workforce led to more sustainable development patterns, potentially altering the expected environmental impacts at different levels of economic growth.

$$\Delta EF_{i,t} = \Omega_0 + \Omega_1 EF_{i,t-j} + \Omega_2 FD_{i,t-j} + \Omega_3 HC_{i,t-j} + \Omega_4 UP_{i,t-j} + \Omega_5 FD * HC_{i,t-j} + \Omega_6 EC_{i,t-j} GDP_{i,t-j} + \Omega_8 GDP_{i,t-j}^2 + v_{i,t} \quad (4)$$

$$\Delta EF_{i,t} = \Omega_0 + \Omega_1 EF_{i,t-j} + \Omega_2 FD_{i,t-j} + \Omega_3 HC_{i,t-j} + \Omega_4 UP_{i,t-j} + \Omega_5 FD * UP_{i,t-j} + \Omega_6 EC_{i,t-j} GDP_{i,t-j} + \Omega_8 GDP_{i,t-j}^2 + v_{i,t} \quad (5)$$

Similarly, Equation (5) explains the interaction between FD and UP. The EKC hypothesis also examines how UP interacts with FD to influence environmental outcomes as economies grow. UP is crucial because urbanization processes often lead to increased consumption and different EC patterns, significantly affecting environmental quality.

$$\begin{aligned} \Delta EF_{i,t} = & Y_0 + \sum_{i,t=1}^p Y_1 \Delta EF_{i,t-j} + \sum_{i,m=1}^q Y_2 \Delta FD_{i,t-j} + \sum_{i,n=1}^q Y_3 \Delta HC_{i,t-j} + \sum_{i,p=1}^q Y_4 \\ & \Delta UP_{i,t-j} + \sum_{i,r=1}^q Y_5 \Delta EC_{i,t-j} + \sum_{i,0=1}^q Y_6 \Delta GDP_{i,t-j} + \sum_{i,0=1}^q Y_7 GDP_{i,t-j}^2 + Y_8 ECM_{i,t-1} + v_{i,t} \end{aligned} \quad (6)$$

where the variable ‘ Y_0 ’ represents the long-term component that explains the deviation of the short-term model in Equation (6). In a similar vein, the parameter for the lag-dependent variable ‘ Y_1 ’ exhibits a shorter time frame. The slope coefficients for various discussed variables, specifically in the short run, are represented by ‘ Y_2 to Y_7 ’. The symbol ‘ p and q ’ represent the inclusion of time delays in the context of EF and all the independent variables.

The symbol ‘ Y_8 ’ represents a parametric calculation of the error correcting term (ECM). Finally, the variable $v_{i,t}$ represents the model’s stochastic error term, which accounts for the unexplained portion of the study.

$$\Delta EF_{i,t} = Y_0 + \sum_{i,t=1}^p Y_1 \Delta EF_{i,t-j} + \sum_{i,m=1}^q Y_2 \Delta FD_{i,t-j} + \sum_{i,n=1}^q Y_3 \Delta HC_{i,t-j} + \sum_{i,n=1}^q Y_4 \Delta FD * HC_{i,t-j} + \sum_{i,p=1}^q Y_5 \Delta UP_{i,t-j} + \sum_{i,r=1}^q Y_6 \Delta EC_{i,t-j} + \sum_{i,0=1}^q Y_7 \Delta GDP_{i,t-j} + \sum_{i,0=1}^q Y_8 GDP_{i,t-j}^2 + Y_9 ECM_{i,t-1} + v_{i,t} \quad (7)$$

$$\Delta EF_{i,t} = Y_0 + \sum_{i,t=1}^p Y_1 \Delta EF_{i,t-j} + \sum_{i,m=1}^q Y_2 \Delta FD_{i,t-j} + \sum_{i,n=1}^q Y_3 \Delta HC_{i,t-j} + \sum_{i,n=1}^q Y_4 \Delta FD * UP_{i,t-j} + \sum_{i,p=1}^q Y_5 \Delta UP_{i,t-j} + \sum_{i,r=1}^q Y_6 \Delta EC_{i,t-j} + \sum_{i,0=1}^q Y_7 \Delta GDP_{i,t-j} + \sum_{i,0=1}^q Y_8 GDP_{i,t-j}^2 + Y_9 ECM_{i,t-1} + v_{i,t} \quad (8)$$

Equations (7) and (8) elucidate the short-term effects of the interaction terms between FD and HC ($FD*HC$) and FD and UP ($FD*UP$), respectively.

3.2. Theoretical Framework

The theoretical basis for examining the symmetric effects between FD, HC, UP, EC, economic growth, and environmental quality (measured by EF) is grounded in multiple economic and environmental literature strands. For instance, the EKC hypothesis suggests that the relationship between economic growth and environmental degradation initially worsens but improves after reaching a certain level of income [53]. It implies a symmetric effect where economic growth has negative and positive impacts on environmental quality depending on the income level. On the other hand, FD is theorized to influence environmental quality through various channels. It can promote investments in cleaner technologies and more efficient production processes, reducing the EF. Conversely, it increases consumption and industrial activity, exacerbating environmental degradation. Previous studies, such as those by Zhang [24] and Guru and Yadav [54], have provided empirical evidence for these dual effects in different contexts, supporting the notion of symmetric impacts.

HC and UP similarly exhibit symmetric effects. Higher levels of HC lead to greater environmental awareness and innovation in sustainable practices, as evidenced by studies like Samour et al. [55]. However, increased UP strains resources and infrastructure, leading to higher pollution levels, as discussed by [56]. Our study employs advanced econometric techniques such as CIPS and CADF unit root tests, Westerlund bootstrap cointegration, and DFE/MG/PMG-ARDL models to capture these symmetric effects empirically. The findings reveal that while FD and GDP^2 improve environmental quality, HC, UP, EC, and economic growth negatively impact it. Thus, our theoretical framework and empirical evidence collectively support the symmetric effects mechanism, providing a solid basis for the observed relationships between the studied variables and environmental quality in BRICST economies.

3.3. Data

A comprehensive and rigorous analysis uses a dataset spanning three decades in BRICST (Brazil, Russia, India, China, South Africa, and Turkey) economies from 1990 to 2022. The selection of the study duration and countries is purely based on the availability of the relevant data required to carry out the analysis. The EF is calculated based on built-up land, carbon, cropland, fishing grounds, forest products, and grazing land, measured by consumption per capita. The EF data is extracted from the Global Footprint Network [17]. At the same time, economic growth is measured by GDP per capita, namely the growth of domestic product per person. UP is the ratio of people living in the city or town to the overall population. The data for UP and economic growth was acquired from the World Development Indicator [38]. FD is defined based on financial institutions and financial markets in terms of their depth, access, and efficiency. The HC index uses schooling years and education returns. EC is defined as total EC from all sources (fossil fuels, nuclear,

and renewables) before any transformation to other forms of energy. The data on FD, HC, and EC are extracted from the International Monetary Fund [26], Penn World Table [32], and Energy Institute Statistical Review of World Energy [44], respectively. Table 1 aims to provide a concise overview of the variables used in our analysis.

Table 1. Description of variables.

Variable	Abbreviation	Measurement	Expected Sign	Source
Ecological Footprint	EF	Global hectares per capita	–	Global Footprint Network
Financial Development	FD	FD is based on financial institutions and financial markets in terms of their depth, access, and efficiency.	±	International Monetary Fund
Human Capital	HC	Average years of schooling and education returns	±	Penn World Table
Urban Population	UP	Urban population (% of total population)	+	World Development Indicator
Energy Consumption	EC	EC from all sources (fossil fuels, nuclear, and renewables).	+	Energy Institute Statistical Review of World Energy
Economic Growth	GDP	GDP per capita (constant 2010 US\$)	+	World Development Indicator

3.4. Methodology

3.4.1. Cross-Sectional Dependence Test

Investigating the cross-sectional interdependence among the dependent and independent variables in every empirical panel study is imperative. Therefore, to assess accurate outcomes and mitigate the risk of more general inaccuracies, we consider the Lagrange multiplier method projected by Breusch and Pagan [57]. This test is empirically formulated in Equation (9) as follows:

$$B\&P_{LMCD} = Z_{i,t} \sum_{t=1}^{i-1} \sum_{k=t+1}^i \Gamma^2_{k,t} \quad (9)$$

The Lagrange multiplier test adheres to a rigorous procedure, explicitly utilizing the Chi-square distribution with a degree of freedom to determine the acceptance or rejection of the null hypothesis. This test assumes the absence of cross-sectional dependency among variables.

3.4.2. Homogeneity Test

The calculation of slope homogeneity is conducted in a panel series when there is a logical confirmation of individual and collective cross-sectional dependency among variables. This metric plays a critical role in assessing the substantial remaining issue of heteroscedasticity [58]. Two widely recognized approaches, namely delta and adjusted delta, as proposed by Pesaran and Yamagata [59], are commonly employed to examine the homogeneity of variable slopes individually and collectively. These methods are utilized to test the null hypothesis that there is no homogeneity in the individual and collective slopes among variables.

$$\Delta_{i,t} = \frac{1}{\sqrt{N_{i,t}}} \left(\frac{\sum_{i,t=1}^N S_{i,t} - y_{i,t}}{\sqrt{2y_{i,t}}} \right) \quad (10a)$$

$$\Delta_{adj_{i,t}} = \sqrt{N_{i,t}} \left(\frac{N^{-1} \sum_{i,t}^N S_{i,t} - y_{i,t}}{\sqrt{\text{var}(x_{i,t} T_{i,t})}} \right) \quad (10b)$$

In Equation (10a), the variable denoted ' $N_{i,t}$ ' signifies the number of cross-sections included. $S_{i,t}$ correspond to the weighted difference between two distinct regression models: the unit-specific cross-sectional and fixed effect pooled models. In the revised delta

Equation (10b), the variable ‘var’ represents the distributed error of the mean-variance that is empirically defined as $var = 2y(t - y - 1)/(t + 1)$.

3.4.3. Stationarity Test

In order to examine the stationary condition of the variable in a set of tests, when data exposes issues related to cross-sectional dependency and slope homogeneity, researchers frequently employ two recently established stationary tests, namely CADF and CIPS, to estimate the level of integration of the variable [60]. These tests are backed by literature, widely accepted, and likely to be uncontested globally.

$$\Delta R_{i,t} = \Omega_{i,t} + \Psi_{i,t}R_{i-1} + Y_{i,t}\hat{R}_{i-1} + Y_{i,t}\Delta\hat{R}_{i-1} + \mu_i \quad (11)$$

Here, the “ Δ ” in Equation (11) denotes the first difference, “ μ_i ” is the residual term, and $R_{i,t} = \frac{1}{N} \sum_{i,t=1}^N R_t$; $\Delta R_{i,t} = \frac{1}{N} \sum_{i,t=1}^N \Delta R_t$, respectively. Additionally, by taking an individual-level mean of CADF estimates, we get the CIPS measure statistically written as in Equation (12).

$$CIPS_{it} = \sum_{i,t=1}^N R_{i,t}(N, T) \quad (12)$$

The “ $R_{i,t}$ ” is ($R_{i,t} = 1/N * \Sigma(i, t = 1)$) in Equation (12). The equation provided is rewritten more academically as follows: N divided by the sum of the changes in R over time, denoted as ΔR . Furthermore, the computation of the CIPS measure involves aggregating individual-level CADF estimations.

3.4.4. Cointegration Test

The Westerlund Bootstrap LM panel test [61] is employed to assess a long-run relationship between the variables in the presence of cross-sectional dependence and slope homogeneity. The null hypothesis posits that no cointegration exists between the variables under examination, whereas the alternative hypothesis suggests a statistically significant cointegration relationship among the variables. Generally, the Bootstrap LM test is expressed as in the equation below.

$$\text{Bootstrap } LM_n^+ = \frac{1}{nt^2} \sum_{i,t=1}^n \sum_{i,t=1}^t \hat{Q}_{i,t}^{-2} L_{i,t}^2 \quad (13)$$

Here, Equation (13) illustrates that the variable ‘ n & t ’ denotes the total number of cross-sections and periods. The symbol ‘ Q ’ represents the long-run variance of the residual, whereas ‘ L ’ specifies the partial sum of the residual. After conducting the Westerlund Bootstrap LM test to validate the stance authentically, it has been determined that the collective variable of the study shows cointegration.

3.4.5. Long Run and Short Run Regression

In the subsequent phase, individual calculations of each regressor’s long-term and short-term efficacy on EF were conducted. The study employed three widely recognized second-generation tests, namely the mean group (MG), dynamic fixed effect (DFE), and pooled mean group (PMG) autoregressive distributed lag (ARDL) models, to conduct specific measurements chosen for their robustness in handling panel data that exhibit variability in integration levels among variables. However, the study by Mensah et al. [62] includes the Hausman test to determine which model’s measures are appropriate and well-presented, particularly for the discussed research. The ARDL model has gained preference over alternative second-generation models for two well-established reasons. First, its results are robust, logical, and widely accepted, particularly in cases where the sample size is insignificant. Furthermore, this method yields satisfactory and indisputable results when variables exhibit different levels of integration. Specifically, some variables are stationary at the level $I(0)$ and some at the first difference $I(1)$ [63].

4. Empirical Results

The summary statistics presented in Table 2 illustrate the characteristics of the dependent and independent variables. It has been discovered that the standard deviation of each variable is significantly smaller and closer to the mean values. This observation reveals that the distribution of every variable, whether dependent or independent, is very close to a normal distribution. Finally, confirming a specific normal spread or distribution is further substantiated by employing a set of meticulously structured and comprehensive normalcy metrics, namely skewness and kurtosis [64]. The calculated values for these measures about the variables under examination exhibit proximity to the benchmark values of ‘0’ and ‘3’, thereby supporting the discourse, as mentioned earlier, on the normal distribution of the data.

Table 2. Descriptive statistics summary.

Statistics	Observation Count	EF	FD	HC	UP	EC	GDP
Mean	198	0.392	4.140	8.152	3.112	1.266	0.112
Min.	198	−0.166	3.445	7.554	2.566	0.515	−1.492
Max.	198	0.845	4.575	8.989	3.732	1.778	0.598
Std. Deviation	198	0.258	0.28	0.355	0.296	0.386	0.296
Skewness	198	−0.366	−0.787	0.485	0.425	−0.656	−1.357
Kurtosis	198	2.386	2.419	2.344	2.742	2.321	6.532

NOTE: “Min.” denotes minimum, “Max.” denotes maximum, and “Std.” denotes standard.

Following the descriptive statistics of the variable, this study performed a correlation analysis of the variables. Table 3 reports the results of the correlation matrix and multicollinearity conducted through variance inflation factor (VIF) analysis. The empirical findings of the correlation analysis imply that the relationship between several variables and EF is complex. Specifically, FD correlates negatively with EF, whereas other variables show a positive correlation. The correlation between explanatory variables is logically sound, indicating a significant association without giving rise to multicollinearity concerns. It is supported by the fact that the value of each variable is below the recommended threshold of 0.80, as proposed by Gujarati [65]. Moreover, Miles [66] also supports the relationship between explanatory variables by employing VIF and Tolerance measures. These measures confirm that multicollinearity issues do not affect the variables, as each variable’s VIF measure is significantly lower than the established benchmark of ‘1’.

Table 3. Results of the correlation matrix.

Variables	EF	FD	HC	UP	EC	GDP
EF	1.000					
FD	−0.732	1.000				
HC	0.355	0.567	1.000			
UP	0.654	0.723	0.265	1.000		
EC	0.772	0.576	0.276	0.898	1.000	
GDP	0.166	0.312	0.054	0.048	0.166	1.000
Variance inflation factor analysis						
VIF		4.267	1.887	7.565	6.178	1.723
1/VIF		0.239	0.528	0.132	0.176	0.587
Mean VIF					4.33	

NOTE: VIF denotes the variance inflation factor.

In the context of the present study, in order to mitigate the potential issues arising from ambiguous or unreliable outcomes, the Breusch and Pagan Lagrange Multiplier (LM) test, purported by Breusch and Pagan [57], has been employed for assessing CD. The analysis shown in Table 4 indicates that the null hypothesis of no CD is significantly rejected at the 1%, 5%, and 10% levels when considering individual and collective contexts

and employing various CD methods. It suggests that the panel series under examination exhibits a substantial problem of CD. After confirming the presence of CD among the study variables, the homogeneity of the slope of the coefficient was examined using the method suggested by Pesaran and Yamagata [59]. The statistical analysis of the data in Table 5 provides evidence to reject the null hypothesis. Additionally, the results indicate that the slope coefficients exhibit heterogeneity, specifically at a significance level of 1%.

Table 4. Cross-sectional dependence test results.

Variables	B-P LM	PS LM	BCS LM	PCD
EF	654.752 ^a	92.963 ^a	93.855 ^a	24.254 ^a
FD	354.135 ^a	52.465 ^a	51.364 ^a	17.565 ^a
HC	366.344 ^a	53.554 ^a	53.396 ^a	16.853 ^a
UP	312.955 ^a	45.765 ^a	45.622 ^a	11.326 ^a
EC	288.112 ^a	41.565 ^a	41.477 ^a	15.120 ^a
GDP	495.910 ^a	73.667 ^a	73.543 ^a	13.298 ^a

NOTE: B-P LM: Breusch–Pagan LM test; PS LM: Pesaran Scaled LM; BCS LM: Bias-Corrected Scale; PCD: Pesaran CD test; ^a represents 1% significance level.

Table 5. Slope homogeneity estimate of variables.

	Delta	<i>p</i> -Value
H ₀ : slope coefficients are homogenous	8.968 ^a	0.000
adjusted	10.245 ^a	0.000

NOTE: ^a denotes significance level at 1%.

The estimated results presented in Table 6 demonstrate the mixed stationary situation of the variables, as specified by the CADF and CIPS measures. The significance levels of 1%, 5%, and 10% are widely considered. The findings reveal that the variables are stationary at the $I(0)$ and $I(1)$ levels. However, it has been seen that no variable has been integrated at $I(2)$. The existing study employed the Bootstrap LM method before applying the MG group of ARDL models to approximate the cointegration between variables. The results from using the Westerlund Bootstrap LM method, specifically through the analysis of Table 7 and the G_t , G_a , P_t , and P_a statistics, indicate a stable cointegration relationship among the variables. It is evident from rejecting the null hypothesis of no stable cointegration at the 1% and 5% significance levels.

Table 6. CADF and CIPS tests for the variable's stationary calculation.

Variables	CIPS		CADF		Decision
	$I(0)$	$I(1)$	$I(0)$	$I(1)$	
EF	−2.166	−3.055 ^a	−2.040	−4.435 ^a	$I(1)$
FD	−1.822	−2.923 ^a	−2.277	−4.412 ^a	$I(1)$
HC	−2.353 ^b	---	−3.558 ^b	---	$I(0)$
UP	−2.715 ^a	---	−4.322 ^a	---	$I(0)$
EC	−2.366 ^b	---	−3.688 ^b	---	$I(0)$
GDP	−2.186	−3.868 ^a	−2.972	−7.214 ^a	$I(1)$

NOTE: CIPS: cross-section augmented IPS; CADF: cross-section augmented Dickey-Fuller; $I(0)$: at level; $I(1)$: at first difference; ^a, and ^b represents significance level at 1% and 5% significance level.

Table 7. Bootstrap LM cointegration estimates.

Statistics	Drift	p-Value
G _a	−2.78 ^a (−4.018)	0.000
G _t	−9.92 ^b (−1.752)	0.040
P _a	−7.88 ^b (−1.948)	0.028
P _t	−6.68 ^a (−3.56)	0.012

NOTE: significance levels have represented ^a and ^b at 1% and 5%.

To analyze specific long and short-run outcomes, three distinct second-generation panel models, mean group (MG-ARDL), pooled mean group (PMG-ARDL), and dynamic fixed effect (DFE-ARDL), have been employed. The Hausman test was used to choose the best model [67]. The results presented in Table 8 indicate that Hausman tests yield insignificant values. It implies that the null hypothesis is accepted at a 1% significance level. Consequently, the PMG-ARDL model is deemed more suitable than the MG and DFE models for examining the symmetric impact of each regressor on the EF in the panel of BRICST economies, both in the short and long term. The study findings for the long-run and short-run are displayed in Table 8. The negative coefficients (−0.145 in the long run and −0.172 in the short—as per PMG-ARDL) for FD show that higher FD leads to the EF variable decrease in BRICST economies. In other words, it means that the more developed financial systems become, the lower the EF economic indicator tends to be [20].

Table 8. Long and short Run (MG, DFE, and PMG) ARDL measurements.

Variables	MG-ARDL	DFE-ARDL	PMG-ARDL
Long-run			
FD	−0.358 (0.030)	−0.308 (0.000)	−0.145 (0.000)
HC	0.889 (0.027)	0.513 (0.000)	0.306 (0.000)
UP	0.140 (0.024)	0.401 (0.000)	0.505 (0.000)
EC	0.332 (0.034)	0.277 (0.000)	0.206 (0.000)
GDP	0.188 (0.082)	0.052 (0.090)	0.025 (0.031)
GDP ²	−0.192 (0.096)	−0.361 (0.008)	−0.131 (0.051)
Empirical Estimates of Short-Run			
Δ(FD)	−0.112 (0.024)	−0.280 (0.003)	−0.172 (0.021)
Δ(HC)	0.860 (0.004)	0.281 (0.075)	0.224 (0.045)
Δ(UP)	0.177 (0.096)	0.360 (0.008)	0.130 (0.051)
Δ(EC)	0.115 (0.028)	0.048 (0.099)	0.081 (0.073)
Δ(GDP)	0.051 (0.075)	0.066 (0.002)	0.040 (0.088)
Δ(GDP ²)	−0.142 (0.024)	−0.401 (0.000)	−0.505 (0.000)
ECM _{i,t−1}	−0.955 (0.000)	−0.455 (0.000)	−0.713 (0.000)
Constant	6.148 (0.062)	1.092 (0.014)	0.675 (0.000)
Hausman Test-1 (DFE to MG)	1.450 (0.918)		
Hausman Test-2 (DFE to PMG)	17.286 (0.004)		
Log Likelihood Ratio	628.798		

NOTE: MG/DFE/PMG-ARDL represents mean group/dynamic fixed effect/pool mean group autoregressive distributed lag model, () shows the significance value.

The positive coefficients of HC 0.306 in the long run and 0.224 in the short run show that an increase in HC leads to a positive value in the dependent variable EF [68]. The

positive coefficients of the UP at 0.505 in the long run and 0.130 in the short run mean that the UP has a positive effect on the EF variable. It implies that an increase in the UP increases the EF [18]. The positive coefficient of EC, 0.206 in the long run and 0.081 in the short run, shows that increased EC increases the EF variable [69]. GDP has a positive coefficient for the short-run, 0.040, and the long-run, 0.025. It indicates a promising effect on the EF variable. It implies that EF rises with GDP since economic activities increase with GDP [70]. However, there is a negative relationship between the coefficients of GDP² and EF. This means that GDP positively affects EF at the early stages, but when it proceeds to a higher level, it negatively affects it [71]. The PMG-ARDL results are consistent with the findings of DFE-ARDL and MG-ARDL. The large ECM coefficient indicates that the error correction mechanism of the model is robust and efficient in promptly restoring the system to equilibrium following a disturbance. It is justified by examining the significance level of the coefficient through hypothesis testing, typically with a *t*-test. A coefficient significantly different from zero implies a strong correction mechanism, supporting the model's reliability in capturing dynamic adjustments in the data. Therefore, the large negative ECM coefficient in the PMG-ARDL model indicates a prompt and significant adjustment towards long-term equilibrium following short-term disturbances, enhancing the model's predictive power and explanatory capability.

Discussion

In BRICST economies, FD has a negative effect on the EF for multiple reasons. First, as financial systems develop and become more sophisticated, they often direct funds to sectors and projects with high returns in the short term, neglecting environmental aspects. This results in increased financial support for manufacturing, energy, and infrastructure industries, which typically have a higher EF due to resource extraction, emissions, and habitat destruction [72]. Second, as a result of maximizing economic growth and FD, people are more likely to consume goods and services that are resource- and environment-intensive [73]. Third, the regulatory frameworks and enforcement mechanisms are not robust enough to offset the negative environmental impacts in many BRICST economies. Hence, FD catalyzes economic growth and raises living standards in the short run, creating negative externalities in the form of environmental challenges in the long term [74]. These results align with the findings of [75–77] and contradict those of [78,79]. However, the positive effect of HC on the EF in BRICST economies means the development of HC often results in increased income and consumption. The rise in affluence elevates individuals' consumption of goods and services, including energy-intensive products and services and processed food [80]. Second, an increase in the general educational attainment of workers often fosters the development of new technologies and innovation. No less important, highly educated people navigate nature and natural sources with ease and, consequently, make more of them in economic activity; they employ less well-educated persons; as mentioned, the advanced economy works more effectively than the use of a less-talented workforce [68]. The above findings aligned with [37,81] and opposed [29,31].

Figure 8 illustrates the relationships between FD, HC, UP, EC, economic growth, and its quadratic term (GDP²) and their impact on the EF in BRICST economies. The plus and minus signs indicate the direction of these effects. FD and GDP² have a negative relationship with the EF, suggesting they help improve environmental quality. In contrast, HC, UP, EC, and economic growth show positive relationships, indicating they exacerbate environmental degradation. The dotted lines represent interaction effects where FD, when combined with HC and UP, has a mitigating impact on the EF. It suggests that promoting FD alongside UP and HC improvements improves environmental outcomes. The findings from PMG-ARDL methods are aligned with those of MG/DFE-ARDL.

The positive impact of UP on the EF is that UP involves increased consumption, with urban living generally benefiting from more accessible goods and services. A more consumption-oriented lifestyle leads to greater use of resources, energy, and infrastructure [82]. Another mechanism through which rapid UP in BRICST economies contributes to

the growth of EF is the association of UP with industrialization and economic development. The same is true with industrialized export-oriented growth [83]. Finally, urban areas are often places of industrial activity, have comprehensive transportation systems, and use energy intensively. They emit pollutants, destroy habitats, and release greenhouse gases into the atmosphere [84]. The findings endorse the results of [18,37] while dissenting with [33,85]. The positive effect of EC on the EF indicates that as economies advance and populations increase, there is a natural demand for energy to support industrial, transport, and household activities. Economies and the substantial consumption of fossil fuels further exacerbate its naturally heightened consumption [86]. Fossil fuels are particularly emblematic due to significant environmental impacts, such as air pollution and greenhouse gas emissions. Moreover, inefficient consumption supported by outdated technologies that occur significantly in the BRICST economies intensifies the effect as more emissions and resources are wasted [42]. On the whole, EC is vital, and it aids in economic growth and lifestyle enhancement. Nonetheless, the positive effect of the result on EF underlines the urgency for countries to shift to renewable consumption patterns, increase efficiency levels, and develop policies that enforce the uptake of renewable sources and conservation [43]. The outcome is consistent with [69,87] and contradicts [88].

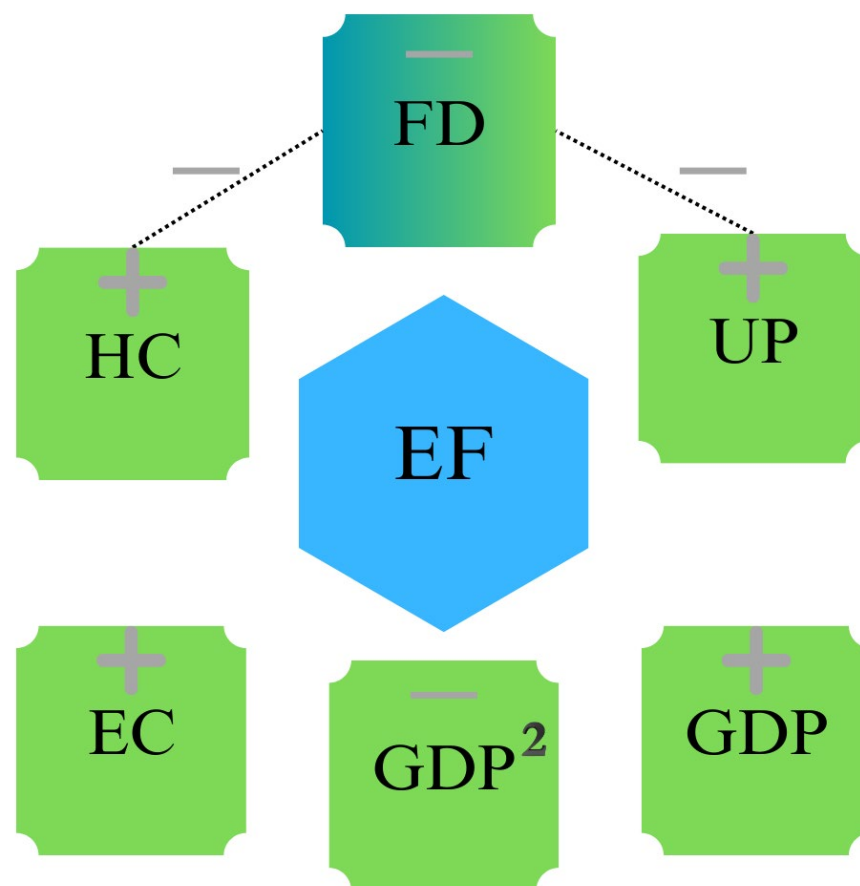


Figure 8. Findings from PMG-ARDL. Source: Author's calculation.

The positive effect of GDP is exhibited as GDP grows, contributing to overall consumption, production, and resource utilization. It creates more depleted resources, such as energy and minerals, and the area utilized for farming and settlement. Negative effects stem from higher GDP, implying higher industrialization, UP, and infrastructural development. These activities contribute to environmental degradation due to pollution, destruction, and natural resource utilization [70]. On the other hand, the negative impact of GDP² suggests that when economies reach certain levels of development, measures to protect the environment become tougher. Technologies help conserve wasted resources, and

individuals are more aware of the ecological effects of their actions. The GDP² coefficient is generally justified because economic growth, beyond a certain threshold, improves the environment's welfare [89]. These findings align with the results of [72,90] and are opposed to [91,92].

Moreover, the results illustrated in Table 8 show significance and magnitude, matching the outcomes displayed in Table 9 using different estimation techniques like MG-ARDL, DFE-ARDL, and PMG-ARDL. Further, the negative impact of the interaction term between FD and HC (FD*HC) on the EF is understood from the following interrelated mechanisms in Table 9. First, due to higher levels of FD and HC, investment is driven by green technologies, sustainable energy sources, and practices. As explained above, investment takes a more environmentally friendly turn with the development of financial institutions and generally better-educated people who are more aware of environmental issues [93]. Second, these two variables develop friendly sectors through innovation and entrepreneurship, the economic growth effect becomes more pronounced, and the negative impact on environmental issues is moderated [94]. Third, the FD*HC impact on the EF is negative, meaning that FD, with the help of more educated people, promotes policy and systemic reforms to reduce pollution, conserve natural resources, and mitigate and adapt to climate change [95]. The findings assess that the FD*HC negative effect on EF implies that the two factors are crucial for sustainable development and lower environmental pressures in BRICST countries.

Table 9. Long and short Run (MG, DFE, and PMG) ARDL measurements (FD*HC).

Variables	MG-ARDL	DFE-ARDL	PMG-ARDL
Long-run			
FD	−0.352 (0.030)	−0.303 (0.000)	−0.140 (0.000)
HC	0.882 (0.026)	0.506 (0.000)	0.298 (0.000)
UP	0.133 (0.022)	0.392 (0.000)	0.498 (0.000)
FD*HC	−0.044 (0.072)	−0.060 (0.002)	−0.033 (0.088)
EC	0.328 (0.033)	0.272 (0.000)	0.201 (0.000)
GDP	0.180 (0.080)	0.044 (0.090)	0.020 (0.031)
GDP ²	−0.172 (0.092)	−0.352 (0.008)	−0.126 (0.151)
Empirical Estimates of Short-Run			
Δ(FD)	−0.105 (0.022)	−0.278 (0.003)	−0.170 (0.021)
Δ(HC)	0.850 (0.004)	0.277 (0.072)	2.221 (0.345)
Δ(UP)	0.172 (0.092)	0.355 (0.007)	0.129 (0.151)
Δ(FD*HC)	−0.180 (0.080)	−0.048 (0.090)	−0.023 (0.031)
Δ(EC)	0.110 (0.022)	0.045 (0.095)	0.079 (0.273)
Δ(GDP)	0.048 (0.072)	0.060 (0.001)	0.038 (0.088)
Δ(GDP ²)	−0.136 (0.023)	−0.393 (0.000)	−0.502 (0.000)
ECM _{i,t−1}	−0.950 (0.000)	−0.451 (0.000)	−0.711 (0.000)
Constant	6.144 (0.061)	1.086 (0.013)	0.672 (0.000)
Hausman Test-1 (DFE to MG)		1.458 (0.915)	
Hausman Test-2 (DFE to PMG)			17.265 (0.003)
Log Likelihood Ratio			628.790

NOTE: MG/DFE/PMG-ARDL represents mean group/dynamic fixed effect/pool mean group autoregressive distributed lag model, () shows the significance value.

Additionally, the significance and magnitude of results seen in Tables 8 and 9 align with the findings presented in Table 10, using various estimation methods such as MG-ARDL, DFE-ARDL, and PMG-ARDL. Several closely interrelated mechanisms explain the negative effect of the interaction term between FD and UP (FD*UP) on the EF in BRICST economies. First, in interaction with the growing urbanization process, FD facilitated a more efficient allocation of resources and investments in environmentally friendly technologies and infrastructure construction [96]. In many cases, the UP creates demand for cleaner energy sources, more efficient public transport, and eco-friendly urban planning, making financial institutions more inclined to invest their funds in projects that allow them to reduce the EF. In addition, high UP levels promote environmental awareness and activism, which affects financial decision-making in favor of investing in environmentally responsible projects [97]. Second, applying the negative effect of the FD*UP shows the possible synergistic effects of the two variables on the implementation of regulatory measures and policy measures in the form of pollution reduction and land-use restrictions in BRICST. Furthermore, the interaction term FD*UP stimulates the development of entrepreneurship and innovation in green industries in such a way that simultaneously improves financial well-being and reduces EF [98].

Table 10. Long and short Run (MG, DFE, and PMG) ARDL measurements (FD*UP).

Variables	MG-ARDL	DFE-ARDL	PMG-ARDL
Long-run			
FD	−0.365 (0.040)	−0.318 (0.000)	−0.154 (0.000)
HC	0.898 (0.029)	0.522 (0.000)	0.314 (0.000)
UP	0.149 (0.028)	0.410 (0.000)	0.513 (0.000)
FD*UP	−0.059 (0.079)	−0.072 (0.004)	−0.048 (0.098)
EC	0.341 (0.038)	0.285 (0.000)	0.215 (0.000)
GDP	0.192 (0.092)	0.060 (0.094)	0.034 (0.035)
GDP ²	−0.185 (0.090)	−0.368 (0.009)	−0.140 (0.059)
Empirical Estimates of Short-Run			
Δ(FD)	−0.119 (0.028)	−0.290 (0.005)	−0.181 (0.028)
Δ(HC)	0.868 (0.009)	0.289 (0.079)	0.232 (0.048)
Δ(UP)	0.185 (0.099)	0.368 (0.009)	0.140 (0.058)
Δ(FD*UP)	−0.190 (0.085)	−0.058 (0.050)	−0.034 (0.038)
Δ(EC)	0.122 (0.032)	0.054 (0.091)	0.087 (0.078)
Δ(GDP)	0.060 (0.085)	0.073 (0.006)	0.046 (0.080)
Δ(GDP ²)	−0.150 (0.028)	−0.406 (0.000)	−0.513 (0.000)
ECM _{i,t−1}	−0.964 (0.000)	−0.464 (0.000)	−0.722 (0.000)
Constant	6.155 (0.066)	1.098 (0.018)	0.683 (0.000)
Hausman Test-1 (DFE to MG)		1.468 (0.922)	
Hausman Test-2 (DFE to PMG)			17.368 (0.005)
Log Likelihood Ratio			628.801

NOTE: MG/DFE/PMG-ARDL represents mean group/dynamic fixed effect/pool mean group autoregressive distributed lag model, () shows the significance value.

5. Conclusions and Policy Recommendations

Environmental pollution is a significant issue in contemporary society. The present research uses panel data from the BRICST countries from 1990 to 2022 to assess the influ-

ences of FD, HC, UP, EC, and GDP on environmental deterioration in EF. Econometric techniques such as DFE/MG/PMG-ARDL models check for empirical associations between the study's variables. In contrast to earlier related research studies on BRICST nations, the current study offers significant insight into the Sustainable Development Goals (SDGs) concurrent targets while providing empirical evidence on the impact of FD, HC, UP, EC, and GDP on EF. Furthermore, we employed the interaction terms of FD with HC and UP to compact their joint effect. The empirical findings of this study reveal HC, UP, EC, and GDP exacerbate environmental pollution by increasing EF, while FD and GDP² help improve environmental quality by reducing EF. The results indicate that combining FD*HC and FD*UP interaction terms negatively impacts environmental quality by reducing the EF in BRICST economies.

This study proposes innovative policies to enhance environmental quality while considering sustainable development goals. These policy recommendations require a coordinated effort from governments, international organizations, the private sector, and civil society to decrease the EF in BRICST nations effectively. The negative coefficients on the FD variables imply that it is essential for the current financial system to monitor its development by appropriately regulating the financial systems to prevent a negative prompt on the environment. FD is vital for economic growth, but the financial system becomes toxic to the environment if it is not well-regulated. BRICST countries should prioritize the development of regulatory standards and green financing options that promote the channeling of funds towards projects and technology that promote environmental conservation. Second, these countries must promote financial literacy campaigns and education among people. The reason is that when people have adequate knowledge, they invest in environmentally friendly innovations. Second, HC and UP have positive coefficients, suggesting that investment in HC, urban education, skill enhancement, and urban planning is critical for improving the environment's quality. Thus, priorities include universal access to education, quality education, and other lifelong learning opportunities. Sustainable urban development should focus on maximizing resource efficiency, reducing pollution, and promoting adaptation to climate change. In addition, environmental considerations should be integrated into urban planning policies and infrastructure. By creating an environment conducive to HC development and sustainable urban development, policymakers stimulate socially responsible growth by sparking innovation, entrepreneurship, and responsible consumption that promote environmental conservation.

In addition, in China, the development of financial mechanisms, such as green bonds and sustainable investment funds, must be encouraged, and financial policies must be assisted by intensive education for the workforce with the necessary skills for sustainable development. Sustainable city development and public transport development are several urban planning priorities, followed by an increased share of renewable energy and energy efficiency; sustainable policies are also required. Brazil needs investments in sufficient environmental education and financing policy, including sustainable investments and green financing. Russia should cultivate financial support for eco-projects and invest in urban development, paving the way for renewable energy and sustainable policy. India requires the development of financial mechanisms for green projects and encouraging renewable energy use and sustainable urbanization. South Africa needs enhancements in financial policies for green investments and environmental education, supported by intense renewable energy policy and sustainability promotion for economic planning. Finally, for Turkey, green financial support and investments in environmental education must be made, sustainable urban policy must be cultivated, and renewable energy and efficiency standards must be increased. These measures reduce EF and thus promote sustainable development in each BRICST country.

In conclusion, combatting the detrimental effect of the interaction terms between FD with HC and UP on environmental quality fundamentally rests on a comprehensive strategy that mainstreams environmental objectives into broader economic policies. Such a strategy implies adopting approaches that support green growth and resource productivity

and promoting innovations while promoting equal opportunities for economic activities and access to environmental benefits. It involves enacting policies and measures to push for green finance, sustainable urbanization, and inclusive economic development in targeted sectors, combating global environmental challenges through international partnerships. Propelled by an integrated approach to sustainable development, these measures ensure BRICST economies realize long-term economic prosperity while preserving the environment for posterity. The findings highlight constructive insights into the connection between economic indicators and EF in the BRICST economies. However, there are some limitations. First, the study considers a specific set of economic indicators and fertilizes the interactions between the factors. Future research fills this gap by utilizing longitudinal data and the country-based analysis approach, and it will preferably include variables to acquire the complexity of the link between economic development and environmental sustainability.

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