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ARTICLE

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# Human capital, economic complexity, and ecological footprints: Crafting a sustainable development policy framework for E7 nations

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## Abstract

Climate change is one of the most pressing challenges of our time, with far-reaching implications for ecosystems, economies, and societies worldwide. Human capital (HUC) and economic complexity (ECC) "understood as structural transformation toward more sophisticated and knowledge-based production" can be pivotal in curtailing ecological degradation. In this context, the study explores the intricate relationship between HUC, financial development, financial globalization, gross domestic product, ECC, and ecological footprints from 1995 to 2021. To achieve this objective, advanced econometric estimation methods are employed. The results indicate the presence of cross-sectional dependence and slope heterogeneity in the dataset. The variables present a mixed order of stationarity, while the Westerlund test indicates the presence of a long-run equilibrium association. The results from the Method of Moments Quantile regression indicate that ECC posed a positive but insignificant effect in the lower quantile ($\tau = 0.1$–$0.25$), while negative and significant in the middle ($\tau = 0.50$) and upper

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quantiles ($\tau = 0.75$–$0.90$). Moreover, financial globalization negatively and significantly affects ecological footprints through all the quantiles except the lower quantile ($\tau = 0.1$). Financial development, gross domestic product, and HUC enhance environmental degradation by escalating ecological footprints. Based on the results, the study suggested enhancing the ECC and financial globalization, while sustainable utilization of HUC and strict regulations for the financial sector to foster sustainable development in E7 countries.

**KEYWORDS**
ecological footprints, economic complexity, human capital, MMQR, sustainable development

## 1 | INTRODUCTION

Environmental degradation emerges as a nuanced phenomenon, presenting a spectrum of challenges, from the contamination of vital water and air resources to the depletion of our ecological treasures. Consequently, the mitigation of environmental deterioration has emerged as a substantial concern for nations globally, irrespective of their developmental stage. The substantial association between environmental deterioration and numerous macroeconomic indices makes it a severe danger to the sustainability of the worldwide economy. Adverse ecological conditions are allied to climate change, which is expected to have detrimental impacts on commercial activity, human well-being, the accumulation of natural and physical resources, and the availability of water, foodstuff resources, and land output (Wei et al., 2023). Consequently, these socioeconomic and ecological issues have prompted a universal effort to actively tackle climate variation. Practically every country throughout the globe has formally endorsed the Paris Climate Change Agreement and has pledged to decrease their greenhouse gas (GHG) emissions as a means to address climate change-related issues (Sadiq et al., 2023). Nevertheless, these countries have also been faithful to achieving the United Nations' Sustainable Development Goals agenda by 2030 through the execution of strategies that foster social, economic, and ecological sustainability (Çetin et al., 2023; Khan et al., 2022; Pata & Ertugrul, 2023). Environmental deterioration is a substantial global issue due to its direct influence on well-being and ecology (Aytun et al., 2024; Pata et al., 2023; Stephan, 2023). A primary driver of environmental degradation is the emission of GHGs, notably carbon dioxide ($CO_2$), resulting from energy consumption associated with economic activities (Çetin et al., 2022; Ozturk et al., 2022; Rafindadi & Usman, 2021).

The Paris Carbon Agreement, enacted in 2015, sought to alleviate the impacts of global warming and restrict the rise in the Earth's average temperature to less than two Celsius. Several studies have been devoted to exploring the determinants of environmental quality. For instance, Rafindadi and Usman (2019) argue that economic growth is the main cause of environmental degradation. The E-7 economies, along with other nations globally, have set goals to reach carbon peak and carbon neutrality. The target of neutrality is set by China, Russia, and Indonesia to be achieved by the year 2060, whilst India has set a target of accomplishing this objective by 2070. According to the report of CNCA 2019, Mexico and Brazil have both committed to achieving carbon neutrality by 2050, while Turkey has set an aim of attaining carbon neutrality by 2053.

Presently, policymakers of E-7 nations are striving to sustain a high level of economic growth while avoiding any negative impact on the environment. The resolution to this issue is to attain sustainable economic growth, commonly referred to as "green development." Sohag et al. (2019) emphasized that conventional economic growth solely reflects the economic aspect of the output process, disregarding its ecological concerns. On the contrary, green gross domestic product (GGDP) takes into account the monetized value of production that has been modified to reflect its environmental impact. Hence, it is essential to see GGDP as a pivotal measure for devising sustainable development policies. Moreover, Xu, Qiu, et al. (2023) analyzed the disparity in innovation between industry, research, and universities in China and discovered that China's innovation inequality has been consistently high over the previous decade. Several studies have investigated environmental quality issues (Murat & Eyup, 2017). Recent studies have examined different variables that impact GGDP, including economic devolution (Li & Xu, 2023), social development and green energy index (Wang et al., 2023), foreign direct investment (FDI) (Kong et al., 2022), ecological policy (Zhao et al., 2022), research and development (Song et al., 2019), and other relevant factors.

E-7 nations are classified as developing countries, but they are predicted to become strong economies like the G7 due to excellent economic growth and faster population growth rates. These economies account for 26% of world GDP, 44% of global $CO_2$, 47% of the global population, and 40% of global energy consumption. While these nations endeavor to achieve greater GDP figures and enhance economic complexity (ECC), they encounter difficulties in effectively managing environmental sustainability. Financial globalization (FIG) and human capital (HUC) are significant factors that greatly influence the development of environmental policies and practices in these economies. Hence, comprehending the complicated relationship between GDP, ECC, FIG, HUC, and environmental quality is crucial for promoting sustainable development paths in the E7 countries. This study answers the following questions: (i) Does HUC promote environmental sustainability? (ii) Can accelerating financial development (FND) help mitigate environmental degradation? (iii) What is the impact of FIG on environmental quality? (iv) Does ECC help to mitigate ecological footprints (EFP) in E7 countries?

The study contributes significantly to academic discourse by addressing the complex interplay between HUC, FND, globalization, ECC, and EFP from 1995 to 2021 amidst the backdrop of climate change in E7 economies. Through rigorous analysis using the MMQR approach, it fills a crucial gap by providing empirical evidence and rigorous analysis to support its conclusions. By emphasizing the importance of sustainable growth strategies and advocating for green ecological activities, the research offers actionable recommendations for policymakers and stakeholders. Overall, it contributes to advancing our understanding of the intricate relationship between economic development and environmental conservation, paving the way for informed decision-making and policy formulation in addressing the challenges of climate change. This research is driven by a deep understanding of the crucial influence exerted by the E7 countries in influencing global dynamics. The E7, exerts substantial influence, acting as a major driver of global economic advancement. Nevertheless, in addition to their impressive expansion, these countries also present a significant ecological dilemma. Their swift industrialization and growing populations have resulted in increased levels of environmental degradation, necessitating the exploration of inventive solutions that harmonize economic progress with ecological practices. Gaining a comprehensive understanding of the complex connection between the E7's economic strength and their influence on the environment is essential in determining a path toward a more balanced and environmentally friendly future for our world. This study is a crucial effort to understand the complex relationship between many fundamental variables and their effect on the environment. EFP is a comprehensive measure of ecological degradation in environmental sustainability modeling studies. Unlike solely considering atmospheric pollution, it takes into account various other forms of environmental worsening caused by demands for ecological means.

The choice of HUC, GDP, FIG, ECC, and FND as factors in the study was deliberate. These variables were selected to fill gaps in the current literature about their impact on environmental quality in E7 economies. The importance of HUC lies in its ability to encompass the expertise, intelligence, and creative potential of a workforce, which can have a significant influence on environmental management and sustainable development efforts. GDP functions as a complete measure of economic activity, providing valuable information on the magnitude of resource utilization and environmental consequences. The incorporation of FIG acknowledges the interdependence of economies and the capacity for international financial transactions to impact environmental results. FND is an indicator of the complexity and availability of financial systems, which can influence the way investments are made and resources are allocated to environmentally friendly projects. Through the examination of these variables, our research seeks to enhance the current body of knowledge by providing a thorough comprehension of the diverse elements that promote enhancements in environmental quality within the E7 economies. This comprehensive analysis offers significant perspectives for policymakers, scholars, and stakeholders who are looking for effective approaches to foster sustainable development in this rapidly changing environment.

## 2 | LITERATURE REVIEW

Numerous prior studies have examined the correlation between macroeconomic factors and environmental deterioration (Bhowmik et al., 2022; Hashmi et al., 2022; Husnain et al., 2022; Olaoye, 2023). Specifically, Pata et al. (2023) investigate the relationship of clean energy and HUC with load capacity factor in the USA. Their results showed that clean energy does not have any relation with the load capacity factor; however, HUC improves the environmental quality. Rafindadi and Ozturk (2017) have examined the relationship between GDP, trade, and FND with energy consumption in South Africa, and they found that FND stimulates the energy demands there.

The research primarily focuses on investigating the influence of economic growth on the atmosphere through the analysis of variations in ecological quality through diverse stages of economic development. These studies have mostly meant to analyze the correlation between financial growth and the environment, employing the Environmental Kuznets Curve (EKC) model introduced by Grossman and Krueger (1991). According to this notion, the environment declines as a less-developed economy begins to thrive due to the effects of its scale and composition (Balsalobre-Lorente et al., 2018). At the onset of development, there is a process of industrialization that takes place, resulting in a rise in the need for energy, namely for fossil fuels, in developing nations. Consequently, this leads to detrimental environmental consequences. Once the economy achieves a particular threshold of commercial growth, the method effect becomes relevant. This phenomenon mitigates the trade-off between economic growth and environmental deterioration by means of technological advancements (Tenaw & Beyene, 2021). The EKC testing posits a correlation between economic growth and ecological quality, demonstrating a U-shaped association (Grossman & Krueger, 1991). Ecological quality is thought to be impacted by several elements, including ECC, globalization, HUC, and FND, in addition to economic growth.

Previous research in the literature examining the correlation between FIG and EFP has shown that globalization has both favorable and unfavorable ecological consequences, resulting in an ambiguous overall impact. Kirikkaleli et al. (2021) argue that globalization in Turkey leads to ecological deterioration by increasing the EFP. In a similar vein, Sabir and Gorus (2019) discovered that developing countries in South Asia have seen a deterioration in their environmental circumstances as a result of their choices pertaining to globalization. This is apparent from the notable rise in their EFP data, which can be ascribed to the amplified activities of globalization. In comparison, Ibrahiem and Hanafy (2020) utilized data from 1971 to 2014 and established that globalization had a significant impact in dipping the EFP levels in Egypt. Ulucak et al. (2020) examined the correlation between globalization and footprint. It has been found that globalization has a beneficial effect on the environmental well-being of emerging countries by decreasing their long-term ecological imprint. The study of Yilanci and Gorus (2020) in the Middle East and North Africa region discovered that globalization can account for the variations in footprint levels among these nations. According to Doytch, 2020, there is a correlation between FIG-driven FDI inflows and the rise in EFP measures in emerging countries. This is due to the inadequate environmental legislation and regulations in these nations, which fail to effectively restrict the inflow of environmentally detrimental FDI. On the contrary, Duan et al. (2022) investigated the relationship between FDI on economic resilience and found a positive association between them.

Researchers have explored the correlation between the increase in real income and the decline in the environment by applying the theoretical framework of the EKC hypothesis, building upon the influential research conducted by Grossman and Krueger (1995). The majority of research that supports the EKC theory has found that as an economy reaches a significant degree of development, it acquires the economic capability to limit the expansion of EFP measurements. This was not possible during the early phase of low economic growth. Yasin et al. (2020) used the EFP as a metric to assess ecological quality. They utilized the Generalized Method of Moments methodology and determined that the EKC hypothesis is valid for a set of underdeveloped nations over an extended duration. Chen et al. (2024) found a negative association between energy depletion and economic growth but a positive association with EFP in the 10 most energy-efficient countries using data from 1990 to 2019. Few studies combined EFP and biocapacity to study the relationship between economic variables with environmental quality. For example, Pata and Isik (2021) have to combine EFP and biocapacity to see the relationships between HUC and natural resource rents in China. Li et al. (2024) investigated the correlation between fintech and natural resources with environmental quality. They discovered that natural resources are contributing to the degradation of the environment in China. Furthermore, Li et al. (2023) examined the relationship of green energy with environmental sustainability in a panel of 33 developed and developing countries and found a positive association between the variables. Zeraibi et al. (2021) conducted a study in five Southeast Asian countries, which revealed a constant rise in EFP measurements as economic expansion advances. By contrast, numerous preceding studies have also examined the EKC hypothesis and argued that this theory does not apply universally to all economies. These studies have demonstrated that despite a country attaining the requisite level of economic growth to reduce its footprint, further economic expansion may paradoxically lead to an enlarged EFP instead. Ajmi and Inglesi-Lotz (2021) found a U-shaped relationship between economic extension and environmental deterioration in Tunisia. Hence, the EKC hypothesis, positing that environmental deterioration follows an initial rise and subsequent decline with economic growth, is not applicable to this particular emerging nation. Khan et al. (2021) found that there is a U-shaped correlation between commercial growth and footprint in China and India. Consequently, the EKC hypothesis, proposing a direct correlation between economic progress and ecological deterioration, lacks evidence in these developing nations. In a similar vein, the research carried out by Yilanci and Pata (2020) in China revealed that the EKC theory lacked support.

Danish et al. (2019) employed yearly values from Pakistan covering the period from 1971 to 2014 to forecast the association between the advancement of HUC and EF. The data indicate that the growth of HUC has a transient impact on reducing a country's EFP. The writers contend that allocating resources towards education in order to cultivate HUC can enhance understanding of the adverse ramifications of environmental degradation. Similarly, Iorember et al. (2021) and Pata and Caglar (2021) established that improving HUC results in a decrease in long-term footprint measures in South Africa and China, respectively. A study conducted by Ahmed and Wang (2019) in an emerging country like India found evidence that higher levels of HUC are associated with a reduction in EFP measurements. By contrast, Kassouri and Altıntaş (2020) identified a relationship between HUC and EF in their research including 13 Middle East and North Africa countries. The authors argued that the growth of HUC is connected to greater financial prospects and social welfare, leading to a projected rise in ecological demand and its corresponding footprint. Hence, it can be concluded that the ecological consequences of the expansion of human resources are uncertain.

Previous studies have also noted diverse environmental impacts linked to financial growth, especially in less-developed nations. According to Yasin et al. (2020), the expansion of the financial sector in industrialized countries can result in increased EFP levels. However, it can also have the opposite effect by reducing the long-term EFP of less-developed states. Hence, the authors contended that fostering the expansion of the financial sector is a more dependable strategy to attain environmental sustainability in developing countries as opposed to developed ones. The authors suggested that in developing nations, there exists an inverse relationship between FND and EFP. They proposed that the insufficiently developed financial sectors in these nations might not adequately promote the demand for natural resources. As a result, a restricted growth of the financial industry does not result in increased EFP. Conversely, the research carried out by Mrabet and Alsamara (2017) revealed that the progress of financial growth in Qatar has a detrimental effect on the overall state of the environment. This is due to the fact that it amplifies the ecological impact in both the immediate and extended periods. Destek and Sarkodie (2019) conducted a study on 11 recently industrialized economies, utilizing the AMG estimator to examine the relationship between economic growth and environmental harm. The results revealed a diverse range of outcomes. Empirical evidence demonstrates a strong correlation between the degree of FND and the EFP in Singapore over an extended duration. Nevertheless, China and Malaysia have a detrimental correlation. In addition, the statistical study indicated that there was no significant link among the entire panel, which included India, Brazil, Philippines, Mexico, South Korea, South Africa, Thailand, and Turkey. However, a recent study undertaken by Naqvi et al. (2021) has provided empirical evidence suggesting that the level of FND does not have a significant impact on the sizes of EFP in nations categorized as poor, lower-middle, and upper-middle income. Hence, the study that has shown a negative relationship between FND and the environment has primarily concluded that FND could result in increased demand for ecological resources. Therefore, the use of these resources can significantly enhance EFP evaluations.

The ongoing discussion explores the relationship between the quality of the environment and ECC. Our analysis of the current literature reveals that scholars have given contradictory findings about the connection between ECC and ecological quality. Bashir et al. (2022) investigated the correlation between environmental deterioration and ECC. It has been discovered that ECC has a role in the decline of ecological quality, as the industrial sector produces and exports things that are damaging to the atmosphere. Okamoto (2013) established a clear relationship between GHG emissions and shifts in industry composition in a prior investigation. This implies that when there are changes in the methods by which industries manufacture items, it has the potential to exacerbate environmental issues. Sadiq et al. (2023) investigate the relationship of ECC with $CO_2$ in BRICS-1 countries using CS-ARDL approaches between 1990 and 2020. They conclude that ECC negatively impacts environmental sustainability. Nan et al. (2022) examined the correlation between $CO_2$, ECC, and globalization in their research. It has been observed that there is a positive correlation between ECC and a decrease in environmental deterioration, as long as the level of degradation remains below a specific threshold. Moreover, the consumption of renewable energy reduces environmental deterioration and the release of GHG emissions. In Neagu (2019) study, the author studied the relationship between carbon emissions and the EKC hypothesis, demonstrating a non-linear association over an extended period of time. Khezri et al. (2022) conducted a study that investigated 29 countries located in the Asia-Pacific area. The researchers examined the correlation between energy transition, ECC, and $CO_2$ emissions. The researchers discovered that ECC exerts a detrimental influence on environmental quality because of its reliance on fossil energy. Boleti et al. (2021) observed how ECC affects the environmental performance of industrial economies in their research. Their proposal suggests that ECC possesses a mitigating influence on the enduring consequences of environmental pollutants. By contrast, Romero and Gramkow (2021) revealed contradictory findings about the relationship between ECC and GHG emissions in 67 emerging economies spanning the years 1976 to 2012. Neagu and Teodoru (2019) utilized FMOLS and DOLS to provide equivalent findings for several EU economies in their research. The ECC was suggested to expedite the process of ecological deterioration. In their earlier research, Xu and Lin (2015) investigated the relationship between green quality and structural changes. They discovered that industrial transformation through ECC can result in detrimental effects on the environment. To summarize, the connection between ecological sustainability and ECC is still unclear and requires further investigation for scholars to come to a consensus.

The increasing influence of human activities on the environment has led to a growing recognition of environmental concerns and their significant consequences on our ecosystem and the world as a whole. Notwithstanding this consciousness, the current corpus of study on environmental quality in the E7 economies uncovers noteworthy deficiencies and constraints. Firstly, there is a significant lack of research that uses EFP as a complete measure of environmental quality in these countries. Moreover, there is a lack of panel studies that investigate the complicated connection between ECC and EFP in the E7 countries. Existing research generally concentrates on particular nations rather than wider patterns. In addition, previous research has primarily focused on examining the individual effects of globalization, ECC, and development on EFP, without considering their combined influence. Thus far, there has been no study that has thoroughly examined the collective impact of HUC, FND, GDP, FIG, and ECC on EFP in E7 nations. Furthermore, the existing literature does not sufficiently investigate these associations utilizing the MMQR technique. In order to fill these deficiencies, this study utilizes the most recent data from 1995 to 2021 to thoroughly examine the interaction between these factors and their combined impact on environmental quality in the E7 economies. The objective is to make a substantial contribution towards addressing the limitations identified in the existing literature.

## 3 | MODEL SPECIFICATION AND METHODOLOGY

This study aims to examine the immediate and long-term relationship between EFP, HUC, FIG, FND, GDP, and ECC in the E7 countries. The study relied on the panel time series data from 1995 to 2021 of E7 countries, namely, China, Russia, India, Brazil, Türkiye, Mexico, and Indonesia. The duration of the study is purely based on the available data for the ECC index, as it starts in 1995 and ends in 2021.The EFP is determined by combining the carbon, farmland, built-up land, forest land footprint, fishing grounds, and grazing land in units of global hectares per person. The HUC Index is based on average years of schooling and the return to education. FIG is the FIG index. GDP is evaluated using constant 2010 US dollars. The FND index is a relative ranking of nations based on efficiency, access, and depth of financial markets and financial institutions. The data for EFP are sourced from the Global Footprint, whereas the data for FIG are derived from the KOF Globalization Index. The HUC Index data are obtained from the Penn World Table. The ECC data are obtained from the Atlas media group, while the data on FND are acquired from the IMF database.

Following the study of Ahmad, Ahmed, et al. (2021) and Balsalobre-Lorente et al. (2023), the study constructed the following model.

$$\mathrm{EFP} = f(\mathrm{HUC}, \mathrm{FIG}, \mathrm{FND}, \mathrm{GDP}, \mathrm{ECC}). \tag{1}$$

HUC stands for Human capital, FIG stands for financial globalization, FND stands for financial development, GDP stands for Gross domestic product, and ECC stands for ECC. To ensure precise and statistically robust results, we employed logarithmic representation for the data indicators except for ECC.

Before employing the MMQR regression, the study conducted an initial diagnostic analysis. The study on panel statistics recognizes the presence of interaction among cross-sectional units. This correlation can be ascribed to both observable and shared disturbances. Cross-sectional dependency is mostly caused by variables such as trade advancements, globalization, monetary or commercial integration, and the harmonization of economic policies. Considering cross-sectional dependence is crucial as ignoring it might result in inconsistent and erroneous findings, as well as decreased estimation effectiveness. This study employed the CS dependency test, a newly developed technique introduced by Pesaran (2004), to evaluate the extent of CS dependence among entities. The test is mathematically written as:

$$\mathrm{CD}_{\mathrm{TM}} = \left[\frac{TN(N-1)}{2}\right]^{\frac{1}{2}} \bar{\rho}_N. \tag{2}$$

In Equation (2), the word $\hat{\bar{\rho}}_N$ represents the correlation coefficient, $T$ represents time, and $N$ indicates the CD units.

Panel data analysis can be compromised by the presence of slope heterogeneity, which can lead to erroneous conclusions. It stems from the existence of varied economic and demographic structures, rendering it a pivotal issue in panel statistics econometrics. Heterogeneity refers to the variation of the parameter of interest among distinct CD units. The study did the slope heterogeneity test to see whether there was variation in slopes among the CD. The precise formulation of this test for heterogeneity is as follows:

$$\tilde{\triangle} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - K}{\sqrt{2K}}\right), \tag{3}$$

$$\tilde{\Delta}_{\mathrm{adj}} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - E\left(\tilde{Z}_{\mathrm{iT}}\right)}{\sqrt{\mathrm{var}\left(\tilde{Z}_{\mathrm{iT}}\right)}}\right). \tag{4}$$

$\tilde{\Delta}$ denote delta tilde where adj $\tilde{\Delta}$ denote adjusted delta tilde in the above equation. Additionally, the study used Westerlund's (2008) panel co-integration test to check the long-run equilibrium association.

Based on the initial diagnostic test, the study opted MMQR (Machado & Santos, 2019) model to examine the relationships among the variables. Conventional linear econometric techniques have mostly concentrated on modeling the average of panel data, instead of modeling the conditional distribution. Koenker (2005) is commonly employed to estimate the connections between many components at various quantiles. As stated in reference Binder and Coad (2011), the approach remains consistent even in the presence of multicollinearity. This technique is beneficial in situations where explanatory factors have a strong association and endogenous behavior. It internally captures the dynamics of data, which makes it superior to other non-linear modeling methods (Shin et al., 2011). The quantile model is expressed with the following equation:

$$Q\tau\left(\frac{\tau}{X}\right) = (\beta_{\mathrm{i}} + \delta i_{\mathrm{p}}(\tau)) + X_{\mathrm{it}}\alpha + U_{\mathrm{it}\gamma\mathrm{p}}. \quad (5)$$

$X_{it}$ is going to represent the variables ECC, FIG, FND, GDP, and HUC, while $Q\tau\left(\frac{\tau}{X}\right)$ is used to denote the dependent variable EFP. The symbols $(\beta_{\mathrm{i}} + \delta i_{\mathrm{p}}(\tau))$ are representing the quantiles. The parameter reaches a stable state and has diverse impacts, allowing the quantile model $\tau$th to be expressed using $q(\tau)$ obtained from the linearity issue.

$$\min_{q} \sum_{i} \sum_{t} \pi_{\tau}(W_{\mathrm{it}} - (\vartheta_{\mathrm{it}} + Z_{\mathrm{it}}\theta)q). \quad (6)$$

Moreover, to check the robustness of the results, the study employed CuP-FM and CuP-BC which counter the issue of endogeneity and CSD and serial correlation.

## 4 | RESULTS AND DISCUSSIONS

Descriptive statistics is essential for comprehending, summarizing, and communicating the fundamental characteristics of a dataset. It is a necessary prerequisite for conducting thorough analysis and making well-informed decisions, making it an essential component of statistical analysis in various fields such as research, business, and everyday data interpretation. The study variables in descriptive statistics have been analyzed and shown in Table 1. The average EFP value was found to be 2.787455, with a max value of 6.374417 and a lowest value of 0.719917. The standard deviation was calculated to be 1.456066. The skewness and kurtosis values were found to be 0.723018 and 2.956161, respectively. The statistics revealed that the highest value for GDP was 6788.123, while the lowest value was observed for FIG at −0.287525. According to the research conducted by Mensah et al. (2019), a series can be categorized as having a normal distribution if its skewness is 0 and its kurtosis is 3. The datasets ECFP, FND, and HUC display positive skewness, indicating a preference for values on the right side of the distribution. The GDP, ECC, and FIG datasets exhibit negative skewness, indicating a leftward shift in the distribution. All of the datasets exhibit non-zero skewness values, indicating that none of them adhere to a normal distribution. The kurtosis value of FIG and FND exceeds 3, indicating a leptokurtic distribution. The EFP, ECC, GDP, and HUC values are all below 3, indicating a platykurtic distribution. None of the variables display a kurtosis value of 3, suggesting the lack of a mesokurtic distribution. From the results of Jarque-Bera, it is clear that the null hypothesis is rejected, and hence, no normal distribution has been observed. Therefore, it is concluded that the dataset does not exhibit a normal distribution.

Furthermore, we also conducted a correlation matrix test to check the correlations among the variables. The results are presented in Table 2. It can be seen from the results that all the variables have positive relationships with the EFP. However, the variables ECC, FIG, and FND have shown weak correlation as the value of correlation is less

**TABLE 1** Descriptive statistics.

| Measures | EFP | ECC | FIG | FND | GDP | HUC |
|---|---|---|---|---|---|---|
| Mean | 2.783 | 0.482 | 50.225 | 0.438 | 6069.006 | 2.445 |
| Median | 2.778 | 0.386 | 50.998 | 0.428 | 6742.712 | 2.369 |
| Maximum | 6.374 | 1.394 | 76.427 | 0.674 | 13250.659 | 3.465 |
| Minimum | 0.720 | −0.352 | 19.453 | 0.253 | 618.368 | 1.601 |
| SD | 1.456 | 0.448 | 10.329 | 0.101 | 3338.746 | 0.441 |
| Skewness | 0.722 | 0.540 | −0.331 | 0.446 | −0.192 | 0.624 |
| Kurtosis | 2.962 | 2.236 | 3.105 | 2.451 | 1.701 | 2.723 |
| Jarque-Bera | 16.445* | 13.788* | 3.541 | 8.650** | 14.450* | 12.860* |
| Probability | 0.000 | 0.001 | 0.170 | 0.013 | 0.001 | 0.002 |

*Note*: The asterisks *, and ** indicate the significance level of 1% and 5%, respectively.
Abbreviations: ECC, economic complexity; EFP, ecological footprints; FIG, financial globalization; FND, financial development; GDP, gross domestic product; HUC, human capital.

**TABLE 2** Correlation matrix.

| | EFP | ECC | FIG | FND | GDP | HUC |
|---|---|---|---|---|---|---|
| EFP | 1.000 | | | | | |
| ECC | 0.177 | 1.000 | | | | |
| FIG | 0.361 | 0.112 | 1.000 | | | |
| FND | 0.309 | 0.102 | −0.192 | 1.000 | | |
| GDP | 0.689 | 0.453 | 0.427 | 0.381 | 1.000 | |
| HUC | 0.815 | 0.099 | 0.452 | 0.419 | 0.575 | 1.000 |

Abbreviations: ECC, economic complexity; EFP, ecological footprints; FIG, financial globalization; FND, financial development; GDP, gross domestic product; HUC, human capital.

than 0.5. However, the variables GDP and HUC have shown a positive and strong correlation with EFP as the value of correlation is more than 0.5.

Pesaran (2004) test is employed to analyze cross-sectional dependency, and results are given in Table 3. The null hypothesis of the non-existence of CSD is rejected for all variables except ECC. This indicates that any modification in one of the variables within one nation will be detectable in the other E7 countries. Therefore, these countries are interlinked.

After confirming the CSD, we tested for slope homogeneity and the findings are given in Table 4. The null hypothesis of this test says that there is slope homogeneity in the slope against the alternative the alternative hypothesis of slope heterogeneity. From the results of Table 4, we can see that it rejects the null hypothesis, evidencing that there is slope heterogeneity in the dataset.

Once the CSD and slope homogeneity tests have been analyzed, it is crucial to predict the level of stationarity for the data using approaches that consider the CSD. Stationarity is a crucial notion in the analysis of panel time series data, suggesting that the statistical properties remain constant during the whole time period. A stationary time series is characterized by a stable mean, variance, and autocorrelation structure that remains constant across time. As there is CSD, we could not use the Levin-Lin-Chu first-generation test. In order to address the CSD, we used the CIPS unit root test to check for stationarity. Table 5 presents the findings of the panel unit root test. The results unambiguously demonstrate that all variables display stationarity at level $I(1)$, with a significance threshold of 1%.

**TABLE 3** Pesaran (2004) CSD test.

| Variable | CD test | *p*-Value | Mean abs (ρ) |
|---|---|---|---|
| EFP | 5.611*** | .000 | .56 |
| ECC | 0.411 | .681 | .56 |
| FIG | 5.09*** | .000 | .42 |
| FND | 15.408*** | .000 | .65 |
| GDP | 21.464*** | .000 | .90 |
| HUC | 21.663*** | .000 | .91 |

Abbreviations: ECC, economic complexity; EFP, ecological footprints; FIG, financial globalization; FND, financial development; GDP, gross domestic product; HUC, human capital.
***Indicates significance level of 1%.

**TABLE 4** Slope homogeneity test.

| | Statistics | *p*-Value |
|---|---|---|
| Delta | 7.088*** | .000 |
| Adj. Delta | 8.236*** | .000 |

***Indicates a significance level of 1%.

**TABLE 5** Panel unit root (CIPS).

| Variables | At *I*(0) | At *I*(1) |
|---|---|---|
| EFP | −2.894** | −5.185*** |
| ECC | −2.367 | −5.531*** |
| FIG | −2.744* | −4.909*** |
| FND | −2.661 | −5.688*** |
| GDP | −1.284 | −3.581*** |
| HUC | −1.068 | 5.365*** |

*Note*: *, **, and *** indicate the significance level at 10%, 5%, and 1%, respectively. Critical values at: −2.73 (10%), −2.86 (5%), −3.1, (1%).
Abbreviations: ECC, economic complexity; EFP, ecological footprints; FIG, financial globalization; FND, financial development; GDP, gross domestic product; HUC, human capital.

Co-integration testing is essential in econometrics, specifically in the study of panel data. This technique is an essential instrument for evaluating the enduring connections between variables. The primary objective is to ascertain whether non-stationary variables demonstrate a persistent and enduring long-term correlation. Researchers can determine the presence of a substantial long-term connection between variables by performing co-integration tests. Consequently, this enhances the robustness and credibility of econometric research and model estimations, laying the groundwork for more reliable results and policy consequences. The use of co-integration greatly enhances the accuracy of the model's findings (Uzar, 2020). The present study utilizes the Westerlund (2008) panel co-integration test, and findings are given in Table 6. The results from Table 6 demonstrate the presence of co-integration among the variables, hence reinforcing the concept of a long-term association between them.

It is essential to verify the presence of structural fractures in the model in long panels since there is a significant probability that certain disruptive events would cause changes in the model parameters. In order to achieve this objective, we utilize the panel data methodology which was created by Ditzen (2021) and Karavias et al. (2023).

This approach offers numerous benefits. For example, it enables the identification of several structural changes at unspecified locations. This test can be utilized even in the presence of robust CSD and correlation. We have calculated the number of breaks using the sequential testing method. Furthermore, the maximum number of potential intervals is dictated by the minimum durations permitted between two intervals, and it is regulated by the "trimming parameter." Table 7 shows that there is clear evidence of a significant change in the structure of the time series data around the year 2003 and 2012.

After the initial diagnostics test results, it is necessary to select the appropriate method that can effectively manage the non-linearity, non-normality, slope heterogeneity, and CSD in the variables. The first-generation estimation methods such as OLS and panel ARDL regression models are not suitable for this particular situation. Therefore, we have chosen the innovative MMQR model, which is capable of addressing the non-linearity problem in the current variables. This paper uses the MMQR technique for long-term analysis. This approach quantifies the effects of independent variables on the dependent component at various quantiles. The findings of the MMQR can be found in Table 8. The results indicate that ECC posed a positive effect on EF in the initial quantile ($\tau = 0.1$–$0.25$), while the coefficient value is insignificant. However, at the middle and upper quantiles, the effect is negative and significant. These results portray that during the initial stage of ECC, the effect may not be strong enough to affect the footprint. However, after some time, the ECC can effectively mitigate the environmental degradation. This implies that, as the E7 countries progressed further in their higher levels of ECC, their EFP tended to decrease significantly. This negative relationship suggests that the diversification of their economies and structural changes may have enabled these countries to become more resource-efficient and environmentally sustainable, thereby reducing their environmental degradation. These findings are consistent with Ahmad, Ahmed, et al. (2021), while contrary to the results of Hassan et al. (2023).

Whereas, FIG demonstrates a negative coefficient with EFP throughout all quantiles ranging from 0.10 to 0.90, with values ranging from −0.215 to −0.270. These findings are in line with the outcomes of Ahmad, Jiang, et al. (2021). Based on these findings, FIG can also be a viable way to improve environmental quality in the E7 nations. FIG can result in increased capital inflows, the transfer of advanced technologies, and the promotion of sustainable development. FIG might potentially enable the transfer of green technologies, investment in sustainable infrastructure, and the adoption of environmentally friendly practices in the context of environmental quality. Policymakers should implement a well-rounded strategy that optimizes the advantages of FIG while minimizing its possible adverse

**TABLE 6** Westerlund (2008) panel co-integration test.

| | Value | *p*-value |
|---|---|---|
| dh_g | −1.793** | .036 |
| dh_p | −1.654** | .049 |

**Denotes 5% significance level.

**TABLE 7** Ditzen et al. (2021) sequential test for multiple breaks at unknown breakpoints.

| | | Critical values are taken from Bai & Perron | | | |
|---|---|---|---|---|---|
| supW (tau) | Test statistic | Estimated break points | 1% Critical value | 5% Critical value | 10% Critical value |
| $F_{(1,0)}$ | 13.52*** | 2012 | 4.48 | 3.65 | 3.23 |
| $F_{(2,1)}$ | 4.25*** | 2003, 2012 | 3.67 | 3.12 | 2.87 |
| $F_{(3,2)}$ | 0.85 | 1999, 2004, 2012 | 3.23 | 2.79 | 2.58 |
| $F_{(4,3)}$ | 1.63 | 1999, 2004, 2012, 2016 | 2.85 | 2.48 | 2.30 |

***Denotes significance at 1%. Trimming at 15%.

TABLE 8 MMQR results.

| Variables | $\tau = 0.1$ | $\tau = 0.25$ | $\tau = 0.50$ | $\tau = 0.75$ | $\tau = 0.90$ |
|---|---|---|---|---|---|
| ECC | 0.019 | 0.007 | −0.031** | −0.044*** | −0.054*** |
| | [0.027] | [0.022] | [0.014] | [0.016] | [0.019] |
| FIG | −0.215 | −0.224* | −0.253*** | −0.262*** | −0.270** |
| | [0.151] | [0.120] | [0.070] | [0.085] | [0.106] |
| FND | 0.075 | 0.100 | 0.179*** | 0.206** | 0.228** |
| | [0.147] | [0.117] | [0.069] | [0.083] | [0.104] |
| GDP | 0.472*** | 0.490*** | 0.545*** | 0.564*** | 0.579*** |
| | [0.041] | [0.033] | [0.020] | [0.023] | [0.029] |
| HUC | 1.360*** | 1.430*** | 1.646*** | 1.717*** | 1.778*** |
| | [0.231] | [0.185] | [0.112] | [0.130] | [0.163] |

Abbreviations: ECC, economic complexity; FIG, financial globalization; FND, financial development; GDP, gross domestic product; HUC, human capital.
***$p < .01$,**$p < .05$,*$p < .10$.

effects on the environment and society. Further, the results from Table 8 indicate that there is a positive and significant relationship between FND and EFP in all quantiles ranging from 0.075 to 0.228 with increasing magnitude of the coefficient. This phenomenon can be linked to the fact that the progress of the financial sector stimulates the desires of individuals, while the financial sector itself gives capital to companies, so promoting manufacturing activities. However, this increase in industrial production also leads to a rise in the generation of waste and the degradation of the environment. Furthermore, FND facilitates infrastructure projects through the provision of loans. These infrastructure projects encompass the construction of highways, railway tracks, and seaports, necessitating substantial land, water, and air resources, so contributing to an expansion of the EFP. Another potential factor could be that financial growth enhances the purchasing capacity of the general population through the provision of affordable loans. This allows individuals to purchase high-end commodities, which subsequently place significant strain on the environment. Hence, it is imperative for the E7 countries to acknowledge and address the significant environmental consequences resulting from financial prosperity. The results align with the research conducted by Charfeddine and Mrabet (2017). Nevertheless, Uddin et al. (2017) present a contrasting viewpoint by asserting that FND diminishes EFP.

Moreover, the results show that there is a positive and substantial association between HUC and EFP across all quantiles, with the coefficient magnitude increasing. Our findings are consistent with the research conducted by Danish et al. (2019) but contrary to the findings of Pata et al. (2024). The correlation between HUC and EFP can be ascribed to various linked causes. Firstly, persons who have achieved higher levels of education and skill acquisition typically enjoy more access to economic opportunities and higher wages. Consequently, individuals have a tendency to utilize a greater amount of resources and participate in activities that have larger environmental impacts, such as heightened energy usage, transportation, and consumption of products and services. Moreover, individuals possessing greater HUC are more inclined to live in metropolitan regions, which tend to have higher resource consumption as a result of denser populations and increased industrial activity. Moreover, there is a strong correlation between education and skill enhancement with technical advancement and industrial growth. However, it is important to note that without the implementation of sustainable practices, these developments might lead to environmental deterioration. Advancements in technology can result in the creation of manufacturing processes that require more resources or the widespread acceptance of ecologically damaging practices if environmental factors are not properly included in decision-making processes. Finally, the GDP estimations showed a positive and statistically significant coefficient, ranging from 0.490 to 0.579, as we moved from lower to higher quantiles. Therefore, it is evident that economic events are predominantly detrimental to the environment. It means that economic growth in the E7 nations is putting strain on the environment because of the increase in energy consumption. Therefore, the influence of GDP on EFP is determined to be positive and significant, which aligns with the findings of the present study. The findings are consistent with the work of Xu, Zhang, et al. (2023). The results of MMQR are visually presented in Figure 1.

The study utilized CUP-FM and CUP-BC approaches to cross-verify the results of MMQR as a robustness check. The results of CUP-FM and CUP-BC are presented in Table 9. The evidence reveals that ECC is negatively associated with EFP under CUP-FM as well as under CUP-BC. The findings show that a 1% increase in ECC will decrease the EFP to 0.016% in CUP-FM and 0.027% in CUP-BC. The ECC is having a negative impact on the environmental conditions in E7 countries. The same relationship was shown by MMQR. FIG has shown a negative relationship with EFP both in CUP-FM and CUP-BC. The evidence indicates that a 1% rise in FIG will improve the environmental quality at 0.011% under CUP-FM and 0.014% under CUP-BC. Whereas all other variables, namely FND, GDP, and HUC, have shown significant positive relationships with EFP under CUP-FM and CUP-BC. All the results of the MMQR test have been verified and cross-checked for robustness, as presented in Table 9.

## 5 | CONCLUSION AND POLICY IMPLICATION

The deterioration of the environment, characterized by the exhaustion of natural resources, decline in biodiversity, and contamination, presents a significant danger to the welfare of our planet and its inhabitants. The significance of tackling environmental degradation is of utmost importance since it has a direct impact on ecosystems, human

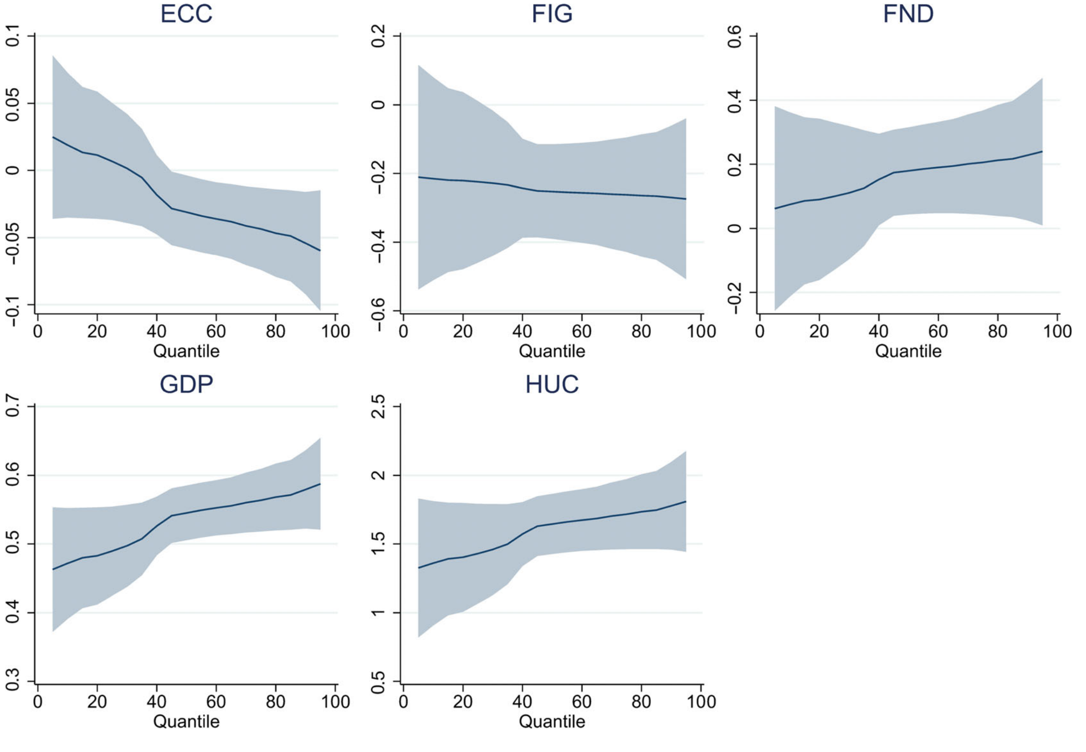


**FIGURE 1** MMQR graphical results. ECC, economic complexity; EFP, ecological footprints; FIG, financial globalization; FND, financial development; GDP, gross domestic product; HUC, human capital.

**TABLE 9** Robustness check (CUP-FM CU-BC).

| | CUP-FM | | CUP-BC | |
|---|---|---|---|---|
| | Coefficient | *T*-statistics | Coefficient | *T*-statistics |
| ECC | −0.016*** | −10.520 | −0.027*** | −15.123 |
| FIG | −0.011*** | −8.357 | −0.014*** | −8.896 |
| FND | 0.014*** | 10.125 | 0.018*** | 12.744 |
| GDP | 0.005*** | 4.169 | 0.010*** | 6.324 |
| HUC | 0.029*** | 22.170 | 0.014*** | 9.337 |

Abbreviations: ECC, economic complexity; FIG, financial globalization; FND, financial development; GDP, gross domestic product; HUC, human capital.
***Indicates the level of significance at 1%.

health, and the general sustainability of the Earth. The study uses HUC, FIG, FND, ECC, and GDP as independent variables, and their relationship has been examined with the dependent variable EF to measure the level of environmental quality in E7 countries. The results indicate that ECC and FIG significantly mitigate environmental degradation by lowering the EFP in E7 countries. Moreover, the FND, GDP, and HUC enhance environmental degradation.

Based on the results, the following policy implications are suggested. Firstly, ECC decreases the EFP. Therefore, the government should formulate relevant policies to support the development of emerging industries and improve product diversity and technological complexity. Cultivating scientific and technological innovation capabilities and strengthening the development of knowledge-intensive service industries will help promote the optimization and upgrading of the economic structure and increase the level of ECC. Formulate relevant industrial policies to create a favorable environment for the development of advanced industries that meet environmental protection requirements. Secondly, FIG also poses a favorable impact on environmental quality. This highlights the potential for global financial integration to contribute positively to environmental sustainability efforts. The government should encourage foreign-funded enterprises to increase investment in green projects. Additionally, policymakers should develop green financial products and services, provide diversified financing channels for corporate environmental protection projects, and cultivate professional environmental assessment institutions. In addition, the behavior of financial institutions should be regulated, environmental risks should be taken into account, and international financing for polluting enterprises should be restricted. At the same time, countries should strengthen international regulatory cooperation and promote the unification of environmental information disclosure standards and risk assessment systems.

To mitigate the negative impact of FND on environmental quality, policymakers should design policies to support green finance, innovate financial products and services such as green credit and green bonds, and provide financing facilities for environmental protection projects. They should improve environmental laws and regulations, strengthen environmental information disclosure requirements for financial institutions, and take environmental impact as an important consideration in loan approval. Strengthen financial regulation and limit financing support for high-emission and high-polluting industries to promote sustainable development and mitigate the impact of climate change. Additionally, to mitigate the negative impact of HUC on EFP, the government should incorporate environmental education into the national education system. At the same time, discourage the usage of energy-intensive products and encourage a lifestyle that saves resources and protects the environment.

Although the current study incorporates novel elements, it is not exempted from limitations, which offer potential avenues for future research to explore. One main limitation is the extent of data duration, as we propose broadening the dataset beyond the period of 1995–2021. Furthermore, it is crucial to integrate sophisticated econometric techniques such as machine learning and artificial intelligence. This will significantly improve the overall statistical validity of the analysis. In addition, it would be advantageous for future studies to employ a country-specific approach when analyzing the primary natural resource-exporting nations. This would enable the development of a more refined and nation-specific environmental strategy in the future, facilitating a more thorough comprehension of the complex interplay between economic issues and ecological sustainability.

## AUTHOR CONTRIBUTIONS

Tao Hong involved in conceptualization, methodology, software, data curation, formal analysis, and writing—original draft. Jie Yin involved in writing—review and editing, supervision, and project administration. Muhammad Nouman Latif involved in writing—review and editing. Mahmood Ahmad involved in writing—review and editing.

## CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## DATA AVAILABILITY STATEMENT

The datasets used and/or analyzed in this study are accessible from the corresponding author upon demand.

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