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Research Article

Exploring the relationship between ecological footprint and economic and environmental indicators: Evidence from developing eight (D-8) countries

Meltem Altın¹ Yusuf Bahadır Kavas² Batuhan Medetoğlu³ Sümeysra Uzun⁴ Arif Saldanılı⁵ Fatih Günay⁶ **ABSTRACT**

This research targets sheds light on the dynamic nexus between the ecological footprint of D-8 member states, including Türkiye, Iran, Pakistan, Bangladesh, Indonesia, Malaysia, Egypt, and Nigeria, economic growth (GDP), carbon dioxide emissions, the proportion of renewable energy consumption, and the level of the Financial Development Index by using panel data between 1990 and 2021. The Swamy S test and the Breusch-Pagan LM assumption tests were applied, besides the Seemingly Unrelated Regression (SUR) model, in order to derive country-specific estimates. The VIFs, the Pesaran CD test for cross-sectional dependency, the second-generation panel unit root test (CIPS), and the panel cointegration test of Westerlund reinforce the methodology, and to reinforce robustness, the CCE Mean Group estimator is employed for each individual country's SUR estimates. While GDP growth and financial development led to increased environmental pressures in economies like Türkiye and Malaysia, the proportion of renewable energy consumption decreased the ecological footprint of most economies, except in Nigeria, where it increased the ecological footprint. It was found that GDP growth contributed to the ecological footprint of Indonesia and Egypt, while renewable energies helped to decrease it for both of these countries. CO₂ emissions, GDP growth, and the proportion of the share of renewable energy in consumption helped explain the environmental pressures on Bangladesh. However, CO₂ emissions and GDP contributed more to the ecological footprint of Bangladesh, whereas CO₂ emissions contributed to fewer ecological pressures in Iran; it was also revealed that an efficient energy transition policy could explain it. Our results revealed that some policies toward sustainability and green finance may need to be tailored at the nation-state level due to the variety of economic structures. In conclusion, the study suggests the need for the D-8 member countries to adopt specific sustainability and green-finance policy mixes.

Keywords: Carbon

Dioxide Emissions, D-8 Countries; Ecological Footprint, Financial Development Index, GDP Growth, Renewable Energy Consumption

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1. Introduction

The Industrial Revolution has caused a huge influence on global ecology through innovation in mechanization, mass production, and the intensive use of raw materials. The advancement of science and technology in this area is speeding up the use, production, and consumption of available resources and has induced this trend at a faster pace, especially in quickly developing economies. In seeking a solution to make human life better, resources and their consumption have increased dramatically. Various wars, crises, and epidemics within the last century created a new world order where states have generally neglected the consequences and impacts on themselves and others caused by their actions and decisions.

The objective of reducing the effects of environmental problems has become the main goal and remains an important topic in the national policies of countries across the world, leading states to examine alternative policies. Measures to reduce the impact of economic activities on the biological environment constitute an important part of these alternatives. The term ecological footprint, which was coined by Wackernagel (1994), has been increasingly adopted and utilized in several international papers measuring the impact of economic activity on the biosphere. It is considered a measure of pollution in the biological environment originating from production meeting current consumption demand.

The most significant constituent for calculating the ecological footprint is carbon dioxide emissions, which are a prime contributor to climate change, as they are a direct result of the burning of fossil fuels, multiple production processes, and a variety of consumption activities. Over the past several decades, policies in many countries, as well as by several international organizations, have focused on limiting the impacts of CO₂ emissions (Zhou & Wang, 2016). There exists a large body of evidence for using renewable energy as a means to lower carbon emissions from fossil fuel use in the production sector (Wang et al., 2013; Ito, 2017; Alola et al., 2019; Charfeddine & Kahia, 2019; Shahbaz et al., 2020; Salari et al., 2021; Satrovic & Adedoyin, 2022). These energies, such as sunlight, wind, geothermal heat, and hydropower, are carbon-neutral and have a significantly smaller impact on the ecological footprint than fossil fuels. By transitioning to alternative energy, such as renewable energy, which is considered friendly to the environment, nations can rely less on the consumption of fossil fuels and move toward more sustainable development. Studies suggest that alternative energy is an environmentally beneficial solution to effectively improve performance and reduce the ecological footprint (Wang et al., 2013; Chang & Wang, 2021; Satrovic & Adedoyin, 2022).

A country's economic growth is measured by its production within its borders. Annual economic growth is determined by the Gross Domestic Product (GDP) (Fricker, 1998; Hanley et al., 1999; Ahmed et al., 2021). A growing economy can also be a source of higher energy consumption and unsustainability of the environment as it is a main factor of ecological footprints in the developing nations (Rehman et al., 2021; Konya, 2022). Research on Egypt's economic growth and ecological footprints indicates that growth is associated with mounting pressures on biological resources, providing evidence of a direct relationship between economic activities and environmental action (Eissa, 2023). Moreover, findings from different countries show that although GDP growth could increase quality of life, it does not produce a proportional increase in ecological sustainability, as can be observed through an asymmetric causal relationship between economic development and the expansion of the ecological footprint (Ulucak & Apergis, 2018; Onakposeha et al., 2025).

The financial development index, calculated by the International Monetary Fund (IMF), measures the depth, accessibility, and efficiency of a country's financial markets and intermediary institutions. The relationship between financial development and the ecological footprint has been examined in various samples (Omri et al., 2015; Baloch et al., 2019; Rahman et al., 2019; Ruza & Caro-Carretero, 2022). Theories of environmental interaction within the framework of financial development focus on two perspectives. On one hand, it is argued that the number of new industrial enterprises will increase as a result of financial developments, which may lead to environmental degradation. On the other hand, the transfer of financial resources to green finance or R&D investments in environmentally friendly technologies could positively impact environmental sustainability. The direction in which D-8 countries allocate their financial resources plays a crucial role in determining which of these perspectives is adopted. Based on the theoretical framework, this study conducts an empirical analysis to assess the impact of these factors on the ecological footprint by testing the relevant hypotheses (Ruza & Caro-Carretero, 2022; Trabelsi & Fhima, 2024; Jóźwik et al., 2025).

The Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995) claims that, to reduce unemployment in their countries, governments give primacy to the increase of GDP, leading to increasing environmental pollution at the earlier stage of economic development, as long as this development comes without strong environmental regulation to curb the environmental pollution coming from unregulated industrialization. In addition, when countries develop enough, they reverse the trend of environmental degradation by changing legislation and policies that aim at environmental protection, as the Environmental Kuznets Curve states: with economic development comes environmental degradation until a certain turning point, after which it declines and the quality of the environment increases. As far as development and pressure concerns are involved, we expect that, in D-8 countries, environmental pollution grows during the phase of rapid growth (Martínez-Zarzoso & Bengochea-Morancho, 2004; Icen, 2020; Koçak, 2024). It is, however, worthy to point out that the relationship between economic development and environmental pollution stated by the EKC might vary from country to country. Therefore, there is a need to study the case of each country included in the group of D-8 countries to have an accurate picture. Although the EKC states that environmental quality decreases initially and then increases with rising incomes, the validity of such a condition is still under debate, particularly in the case of developing countries (Destek et al., 2018; Konya, 2022).

Based on the existing knowledge of the EKC, this study will seek to explore the association among carbon dioxide emissions, GDP growth, renewable energy consumption, the Financial Development Index, and the ecological footprint in D-8 countries. Much of the literature examines developed countries or global settings. The novelty of this research stems from the determination of these relationships using recently available datasets for the case of D-8 countries, and a detailed description of this issue can be reported both from a scientific perspective and from country-specific issues related to environmental sustainability. One specific contribution of the research is to address the ecological footprint in addition to the Financial Development Index; the other included variables were also analysed previously in the literature. In brief, the objectives of the current study are to contribute to the literature, to investigate a fresh dataset from D-8 countries, to estimate both general and country-specific models explaining the dependent and independent variables, to consider country-specific impacts, and to propose some recommendations to the policymakers of D-8 countries. In a nutshell, the main research question addressed by this article is: How do CO₂ emissions, GDP growth, renewable energy consumption, and the Financial Development Index affect the ecological footprint? From a scientific standpoint, and depending on the main question, this is an attempt to promote economic and environmental partnership in this regard with appropriate frameworks and approaches to meet the requirements.

2. Literature Review and Hypotheses

The Ecological Footprint is an accounting tool that comes from human demand on natural capital and the regenerative capacity of the biosphere; it represents the amount of biologically productive land and water required to produce the resources that the population consumes and absorbs the corresponding waste. The carbon footprint, which is a part of the ecological footprint, measures the emissions of greenhouse gases derived from human energy use and other acts (Galli et al., 2012). Numerous studies have revealed that the relationship between EF and carbon dioxide (CO₂) emissions is statistically significant. Sharif et al. (2020) argued that energy consumption enlarges the ecological footprint and CO₂ emissions. Similarly, Destek et al. (2018) highlighted carbon as one of the critical elements of the eco-footprint that implies the direct relationship between higher eco-demands and higher CO₂ production. More recently, Nathaniel & Adeleye (2021) have also emphasized the linkages between the ecological footprint and CO₂ emissions with respect to sustainability assessments in African nations.

In terms of decoupling (Tapio, 2005), despite many economic and energy trends in which decoupling could conceptually be detected, persistent decoupling cannot be concluded for all of the studied countries—especially not for those still relying on fossil fuels for transportation in the face of economic development trends. For example, Konya (2022) pointed out that increasing GDP does not always mean a decrease in carbon emissions or environmental damage, and several other reports elaborated upon these issues. For instance, Nathaniel and Khan (2020) researched interactions of several factors, including human behavior, urbanization, and renewable energy deployment, on ecological footprints, whereas Unal and Unal (2023) specifically focused on the role of energy consumption in Türkiye and confirmed that personal behavior is of the highest importance for ecological footprints. Additionally, Xue et al. (2021) also mentioned that just measuring CO₂ would not offer an accurate picture of

environmental health, and in this regard, an ecological footprint seems like a more realistic assessment of the human impacts on our environment.

The connections between GDP and ecological footprints have been much discussed in the context of the EKC (Environmental Kuznets Curve) hypothesis. This explanation holds that at low levels of development, economic growth yields greater environmental degradation, but at higher levels of income, societies progress to more sustainable outcomes and ecological footprints are reduced. Kubiszewski et al. (2013), in which the per capita GDP rises while the Index of Sustainable Economic Welfare (ISEW) starts to flatten out by considering damage to the environment over the longer term and differences in socio-economic status. Aye & Edoja (2017) also show that environmental degradation increases as GDP increases; however, such an increase is not consistent across all income classes, that is, socioeconomic context matters for this dynamic. Wackernagel et al. (2004) note that although the total global GDP has increased significantly, ecological footprints have not increased accordingly. The fact that natural capital demand continues to grow despite GDP growth is crucial, as it highlights the cyclical relationship between economic expansion and environmental degradation. Destek et al. (2018) confirmed this also for the context of the EU, establishing in addition an inverse U-shaped relationship where damage to the natural environment disimproves at the beginning with economic growth and, with a certain threshold of income, improves instead.

Sun et al. (2022) showed that there is negative relationship between renewable energy consumption and carbon emissions and highlighted that renewable energy consumption has a significant inhibitory effect on carbon emissions of a local region. Khan et al. (2019) emphasized fossil fuel dependence in worsening ecological consequences the trend suggests GDP growth is positively associated with growing ecological footprints, but they intended that the relationship greatly depends on the consumption patterns of energy, especially from fossil fuels. The environmentally friendly alternative to fossil fuels is renewable energy. In order to reduce environmental impact, the world is increasingly shifting towards renewable energy sources. For example, Destek & Sinha (2020) examined the data of the OECD countries to demonstrate that the increase in the use of renewable energy sources led to a reduction in ecological footprints while the use of non-renewable sources tended to increase ecological impacts. Similar trends have been found in ASEAN countries by Nathaniel & Khan (2020), which indicate that renewable energy consumption contributes to the reduction of the ecological footprint. Sharif et al. (2020) validated the study and showed a bidirectional causal relationship, in which renewable energy consumption has not only helped to lower ecological footprints but also contributed positively to sustainable development. Koseoglu et al. (2022) found a statistically significant negative relationship between renewable energy consumption and ecological footprint, suggesting that renewable energies may be crucial in efforts to limit environmental damage. This evidence is consistent with the EKC theory that holds that increased renewable energy consumption could mitigate the negative effects of economic growth on the environment (Destek & Sarkodie, 2019). Pata (2021) confirmed this notion, identifying renewable energy consumption as an important factor in reducing ecological footprints in BRIC countries.

A second, critically important factor, widely recognized as responsible for ecological footprint values, is financial development. While certain research indicates that the growing growth rate, as well as the level of financial development, aggravates environmental contamination, other studies suggest contrary results. The investigation on the EKC theory conducted by Koseoglu et al. (2022) and published in *The World Economy* indicates that financial development negatively influences the ecological footprint, using data from eleven newly industrialized economies, and identifies a co-directional correlation between these variables. Therefore, economic progression with rising levels of the financial sector may result in an increase or abatement in environmental pollution. A related finding by Wang et al. (2025) reported a similar effect of financial development on the increment of the environmental footprint of selected OECD economies. Baloch et al. (2019) investigated the implications of financial development on ecological footprint values in countries of the BRI, finding significant evidence that financial sector improvement increases ecological footprint levels in many of the surveyed nations. Likewise, Dada et al. (2022) proved that high financial development greatly influences the ecological footprint through the influence of consumer behaviors, etc.; yet the contrary result has been found, showing higher financial development with a lower ecological footprint by influencing effective resource management processes, as in Nathaniel et al. (2019) and Shahbaz et al. (2020). Similar findings have been reported with respect to different nation blocs. In addition to BRICS economies (Yang et al., 2021) and Asian economies, several others, including Yao et al. (2021), indicate that, along with the level of corruption, the development of the financial sector significantly leads to a higher ecological footprint in many developing

economies. Given the divergent views, the hypotheses formulated to examine the ecological footprints due to financial development are:

H1: An increase in carbon dioxide emissions will increase the ecological footprint in D-8 countries.

H2: GDP growth will increase the ecological footprint in D-8 countries.

H3: An increase in renewable energy consumption will reduce the ecological footprint in D-8 countries

H4: A higher financial development index will reduce the ecological footprint in D-8 countries.

3. Materials and Methods

3.1. Study Sample

The concept of the ecological footprint has been developed as one way to estimate the damage inflicted by human activities, as a measure of the consequences. When compared against various other indicators related to sustainable use and estimated according to the degree to which it is being pushed, it should assist in formulating new and more sustainable approaches to production and consumption. The study considers countries that are categorized as developing. More precisely, it compares ecological footprints in the countries of the D-8 group of Muslim majority nations: Türkiye, Iran, Pakistan, Bangladesh, Indonesia, Malaysia, Egypt, and Nigeria. Further details with country-specific analyses regarding the trend of the ecological footprint in the D-8 countries are given in the Appendix (Open Data Platform).

While the trends of the ecological footprint of Türkiye and Malaysia are showing increases, primarily due to economic and fossil-fueled development, especially the former shows some recent slowing down and even stabilization in its footprint, most possibly induced by efforts to increase reliance on renewable sources. Bangladesh and Pakistan have relatively low footprint sizes, yet they also indicate an upward trend, mainly driven by industry and increasing population sizes. The latter shows an even greater degree of increase than its regional neighbor, while the former is increasing at an approximately even pace with the overall trend in the Middle East and South Asia region. Türkiye's development patterns are well reflected by its trend, although the recent slight decrease may be considered a positive sign, suggesting some success of its renewable energy development policy, for example. Egypt shows a quite distinct decrease in its trend after 2017, mostly resulting from renewable energy initiatives and policy reforms. Although fossil-fueled development, particularly through oil and gas, continues to play an important role in Egypt's energy and economic activities, this may be counterbalanced by renewable energy development strategies and, potentially, economic stagnation or downturns as well.

In Iran, the footprint is generally increasing, although the rate of increase is slightly reducing for now, and it is based on the exploitation of natural resources, namely fossil fuels. The footprint of Nigeria shows a considerable decrease after 2009, which seems to be associated with the economic downturn experienced by the oil-producing country, as well as a significant change in energy production as a resource.

3.2. Data

This study aims to determine the relationship between the ecological footprint of these countries and the following variables: carbon dioxide emissions, gross domestic product growth, renewable energy consumption, and the financial development index. The dataset was compiled from the Global Footprint Network, World Bank and International Monetary Fund (IMF) (IMF Data; Open Data Platform; World Bank Open Data) databases for the period 1990-2021. The country group and period of analysis used in the study are detailed in Table 1.

Table 1. D-8 Countries, Codes and Years

Country	Codes	Years
Türkiye	Y ₁₁	1990-2021
Indonesia	Y ₁₂	1990-2021
Egypt	Y ₁₃	1990-2021
Bangladesh	Y ₁₄	1990-2021
Iran	Y ₁₅	1990-2021
Malaysia	Y ₁₆	1990-2021
Nigeria	Y ₁₇	1990-2021
Pakistan	Y ₁₈	1990-2021

Within the scope of the study, the D-8 countries were taken as a sample, and a broad analysis was carried out using data between the years 1990-2021. Information on the variables analysed in this study is presented in Table 2.

Table 2. Variables, Codes and Sources

Variables	Codes	Source
Ecological Footprint vs Biocapacity (gha per person) (EFConsPerCap)	y ₁	Open Data Platform
Carbon Dioxide (CO ₂) Emissions from Industrial Combustion (Energy) (Mt CO _{2e})	x ₁	World Bank Open Data
GDP growth (annual %)	x ₂	World Bank Open Data
Renewable Energy Consumption (% of total final energy consumption)	x ₃	World Bank Open Data
Financial Development Index	x ₄	IMF Data

The variables in Table 2 constitute the panel dataset covering the annual frequency data of the D-8 countries for 1990-2021. The descriptive statistics of the variables are presented in Table 3.

Table 3. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
Ecological Footprint (EFConsPerCap)	256	1.537	1.240	0.084	5.046	0.958	2.774
CO ₂ Emissions (Mt CO _{2e})	256	37.627	29.892	1.465	147.007	1.187	4.244
GDP Growth (annual %)	256	4.575	3.439	-13.127	15.329	-1.011	6.507
Renewable Energy Consumption (%)	256	31.370	28.254	0.400	88.600	0.623	2.116
Financial Development Index	256	0.317	0.138	0.120	0.730	1.031	3.509

3.3. Econometric Methodology

The model established for the five variables obtained from the D-8 countries within the scope of the study is given in Equation 1.

$$y_{1it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \beta_3 x_{3it} + \beta_4 x_{4it} + \varepsilon_{it} \quad (1)$$

Econometric analyses use various data types, including time series, panel, and cross-sectional data. The appropriate data type was determined based on the characteristics of the variables. This study employs panel data, which consists of N units (countries) and T observations (time periods). Therefore, data characteristics were carefully considered during the application phase, leading to the selection of a panel data analysis (Yerdelen Tatoğlu, 2020). Panel data analysis requires several assumption tests to determine the appropriate estimation methods. In this context, to select the appropriate estimator for the model, the first step was to test for heterogeneity using Swamy S test (Swamy, 1971). The Swamy S test is performed using Equation 2:

$$\hat{S} = \chi^2_{k(N-1)} = \sum_{i=1}^N (\hat{\beta}_i - \bar{\beta}^*)' \hat{V}_i^{-1} (\hat{\beta}_i - \bar{\beta}^*) \quad (2)$$

The next assumption test, the Breusch-Pagan LM test (Breusch & Pagan, 1980), was used to test for cross-sectional dependence (the correlation between units). This test is commonly employed to determine the presence of a correlation between residuals in cointegration or error correction models. The test was performed using Equation 3.

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

The result of Swamy S test, and the results of the Breusch-Pagan LM test are presented in Table 4.

Table 4. Swamy S and Breusch-Pagan LM Test Results

Test of parameter constancy	Breusch-Pagan test of independence
chi2(35) = 45264.35	chi2(28) = 62.431
Prob > chi2 = 0.0000	Prob > chi2 = 0.0002

The Swamy S test results indicate that the model was heterogeneous. The results of the Breusch-Pagan LM test indicate that the model exhibits heterogeneity and cross-sectional dependence.

Before proceeding with estimation, the explanatory variables were tested for multicollinearity with Variance Inflation Factors (VIF). From Table 5, all the values of VIF are well below the cut-off value of 5 (with highest value is

1.84), so this is discarded as problem. There appears to be no multicollinearity, thereby suggesting that the low correlation between CO₂ emissions and the Ecological footprint is not simply as a result of correlated regressors.

Table 5. Variance Inflation Factors (VIF)

Variable	VIF
CO ₂ Emissions	1.293
GDP Growth	1.010
Renewable Energy Consumption	1.841
Financial Development Index	1.628

Due to the long-time structure of our data, cross-sectional independence was further tested through the application of Pesaran (2004) CD test, additional to the Breusch-Pagan LM test. As can be seen from Table 6, we find significant evidence of rejecting the null hypothesis of no cross-sectional dependence for ecological footprint and for all of the independent variables, suggesting the shock propagating to other D-8 members. We cannot therefore use any first-generation panel estimation that assumes the absence of cross-sectional dependence, instead warranting for a second-generation test and estimator robust to this cross-sectional dependence.

Table 6. Pesaran's (2004) Cross-Sectional Dependence (CD) Test

Variable	CD statistic	p-value
Ecological Footprint	2.225	0.026
CO ₂ Emissions	21.267	0.000
GDP Growth	4.933	0.000
Renewable Energy Consumption	17.319	0.000
Financial Development Index	16.336	0.000

Due to the fact that cross sectional dependence is detected, we use second-generation panel unit root testing, for a cross-sectionally augmented panel unit root test (CIPS) from Pesaran (2007). Table 7 shows that the variables are non-stationary at their level but after taking first difference they turn out to be stationary since the absolute value of all the CIPS statistics are beyond the 1% level critical value of -2.85. Hence most of the series are integrated in order one, which is also referred as I(1).

Table 7. CIPS Second-Generation Panel Unit Root Test

Variable	CIPS (level)	CIPS (first difference)
Ecological Footprint	-1.806	-4.416
CO ₂ Emissions	-2.590	-3.880
GDP Growth	-2.645	-4.342
Renewable Energy Consumption	-1.749	-4.041
Financial Development Index	-2.128	-4.587
Critical values	1%=-2.85; 5%=-2.57; 10%=-2.42 (Pesaran, 2007)	

As a check of long-run equilibrium relationship, we employed error-correction based panel cointegration test developed by Westerlund (2007) with bootstrap robust p-values which account for cross-section dependence in bootstrap. Group-mean statistic rejects the null of no cointegration at 1% level (Table 8). Therefore, we concluded that there exist long run equilibrium relationships between the variables and can now estimate the level relationships.

Table 8. Westerlund (2007) Panel Cointegration Test

Statistic	Value	Bootstrap p-value
Gt (group-mean)	-2.051	0.000
Ga (group-mean)	-29.482	0.000

The choice of the estimator was informed by several empirical factors: heterogeneity of slopes (Swamy S test), cross-sectional dependence (Breusch-Pagan LM and Pesaran CD tests), I(1) variables, and panel cointegration. Standard heterogeneous-panel mean-group estimators like Common Correlated Effects (CCE) and Augmented Mean Group (AMG) were set to recover a common average long-run effect for the panels. The present study seeks not a common average, but individual relationships, since the average across the D-8 would mask the sign inversions of the long-run impact of renewables and CO₂ on the footprint illustrated below. Hence, the Seemingly Unrelated Regression (SUR), which delivers country-specific coefficients and explicitly models the contemporaneous cross-equation error term induced by cross-sectional dependence, is applied. A further CCE Mean Group (CCE-MG) estimator is also provided as a robustness check (Table 11). Note finally that while the Environmental Kuznets Curve logic of a turning

point is applied as a conceptual and literature context, an actual EKC test is not implemented, since only the linear impact of the flow variable GDP growth is tested on the ecological footprint; its quadratic term is not included, since testing a turning point for income level would include squares of absolute income level instead of GDP growth. A brief analysis based on this extended model is conducted, where the squared term is statistically detectable (coefficient -0.0009, $p = 0.037$), but it does not alter individual results.

4. Findings

To test the hypotheses, and based on the results of the assumption tests, the model designed to determine the relationships was estimated using the Seemingly Unrelated Regression (SUR) estimator. The results of the analysis are presented in Table 9.

Table 9. Analysis Results

Equation	Obs	Params	RMSE	R-squared	chi2	P>chi2
y ₁₁	32	4	0.115886	0.8903	309.82	0.0000*
y ₁₂	32	4	0.036444	0.9435	627.83	0.0000*
y ₁₃	32	4	0.064794	0.8826	291.37	0.0000*
y ₁₄	32	4	0.017958	0.9786	1671.63	0.0000*
y ₁₅	32	4	0.017100	0.7491	135.72	0.0000*
y ₁₆	32	4	0.305925	0.4035	24.88	0.0001*
y ₁₇	32	4	0.073454	0.4847	33.28	0.0000*
y ₁₈	32	4	0.030426	0.2322	17.43	0.0016*

*Note: *, ** and *** indicate 1%, 5% and 10% significance.*

An examination of the model's significance on a per-unit basis in Table 6 reveals that the model is statistically significant for all countries. The R-squared values, which indicate the explanatory power of the independent variables on the dependent variable, vary by country. Bangladesh exhibits the highest explanatory power (97%), whereas Pakistan has the lowest (23%). The results of the analyses by country are presented in Table 10.

Table 10. Analysis Result by Country

Variables	Coefficient	Std. err.	z	p>z
y₁₁ – Türkiye				
x ₁	0.001148	0.002024	0.57	0.571
x ₂	0.016547	0.004102	4.03	0.000*
x ₃	-0.0393	0.013214	-2.97	0.003*
x ₄	1.483744	0.594659	2.5	0.013**
cons.	2.907086	0.456037	6.37	0.000*
y₁₂ – Indonesia				
x ₁	-0.00026	0.000306	-0.85	0.396
x ₂	0.004407	0.001366	3.23	0.001*
x ₃	-0.0142	0.001104	-12.87	0.000*
x ₄	-0.18784	0.166418	-1.13	0.259
cons.	2.020315	0.103702	19.48	0.000*
y₁₃ – Egypt				
x ₁	-0.00221	0.002669	-0.83	0.407
x ₂	0.016534	0.005675	2.91	0.004*
x ₃	-0.11358	0.008942	-12.7	0.000*
x ₄	-0.16435	0.180183	-0.91	0.362
cons.	2.362263	0.128786	18.34	0.000*
y₁₄ – Bangladesh				
x ₁	0.005608	0.00132	4.25	0.000*
x ₂	0.00581	0.0029	2	0.045**
x ₃	-0.00553	0.000532	-10.4	0.000*
x ₄	0.113402	0.092129	1.23	0.218
cons.	0.696793	0.047874	14.55	0.000*
y₁₅ – Iran				
x ₁	-0.00165	0.000205	-8.04	0.000*
x ₂	-2.3E-05	0.000507	-0.04	0.964
x ₃	0.009526	0.008563	1.11	0.266
x ₄	0.104118	0.058108	1.79	0.073***
cons.	0.192371	0.014458	13.31	0.000*

Table 10. Continued

y₁₆ – Malaysia				
x ₁	0.013398	0.011012	1.22	0.224
x ₂	0.027078	0.012708	2.13	0.033**
x ₃	0.027119	0.031038	0.87	0.382
x ₄	2.232905	0.852628	2.62	0.009*
cons.	2.015425	0.478061	4.22	0.000*
y₁₇ – Nigeria				
x ₁	0.012356	0.011222	1.1	0.271
x ₂	0.009877	0.002848	3.47	0.001*
x ₃	0.025362	0.007756	3.27	0.001*
x ₄	-0.11487	0.393695	-0.29	0.770
cons.	-1.21237	0.712044	-1.7	0.089***
y₁₈ – Pakistan				
x ₁	-0.00186	0.001809	-1.03	0.303
x ₂	0.003955	0.002716	1.46	0.145
x ₃	-0.00286	0.004928	-0.58	0.561
x ₄	0.226076	0.079007	2.86	0.004*
cons.	0.904371	0.304422	2.97	0.003*

Note: *, ** and *** indicate 1%, 5% and 10% significance.

Table 10 presents the results of the country-specific analyses. These results reveal a statistically significant relationship between the ecological footprint and a maximum of three, and a minimum of one, independent variable for each country. The analysis also determined the direction (positive or negative) of the relationship between the ecological footprint and the independent variables. This provides a quantitative assessment of the relationship between the ecological footprint and carbon dioxide emissions, GDP growth, renewable energy consumption, and financial development index indicators both overall and on a country-by-country basis.

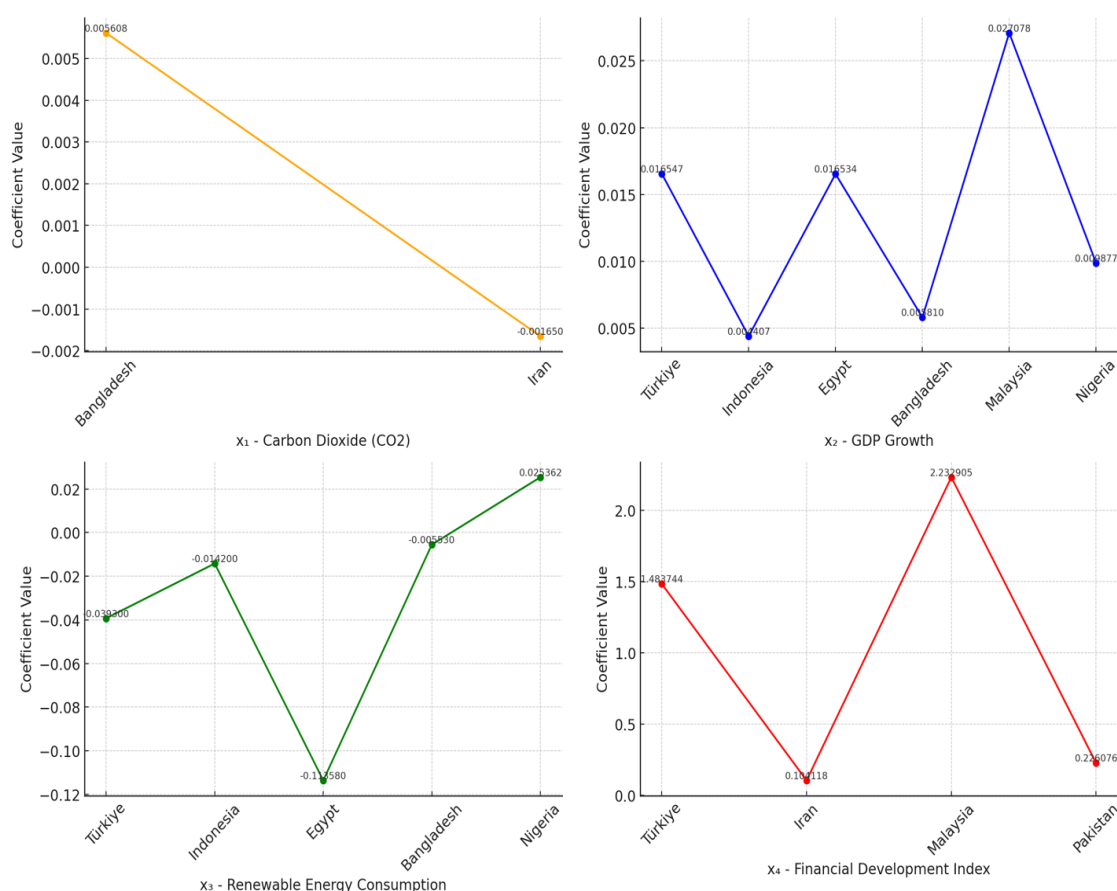


Figure 1. Coefficient Estimates of Environmental and Economic Indicators in D-8 Countries

Figure 1 presents the results of the country-specific analyses. A statistically significant relationship was found between the ecological footprint and GDP growth, renewable energy consumption, and the financial development index in Türkiye. The positive relationship between GDP growth, the financial development index, and the ecological

footprint suggests that economic activities and financial development in Türkiye increase environmental pressure. However, investments in renewable energy sources appear to have a mitigating or stabilizing effect on the ecological footprint. The relationship between the ecological footprint and both GDP growth and renewable energy consumption is statistically significant in Indonesia and Egypt. In both countries, GDP growth has a positive relationship with the ecological footprint, increasing it. Conversely, renewable energy consumption has a negative relationship, suggesting that these countries could benefit from policies promoting sustainable energy.

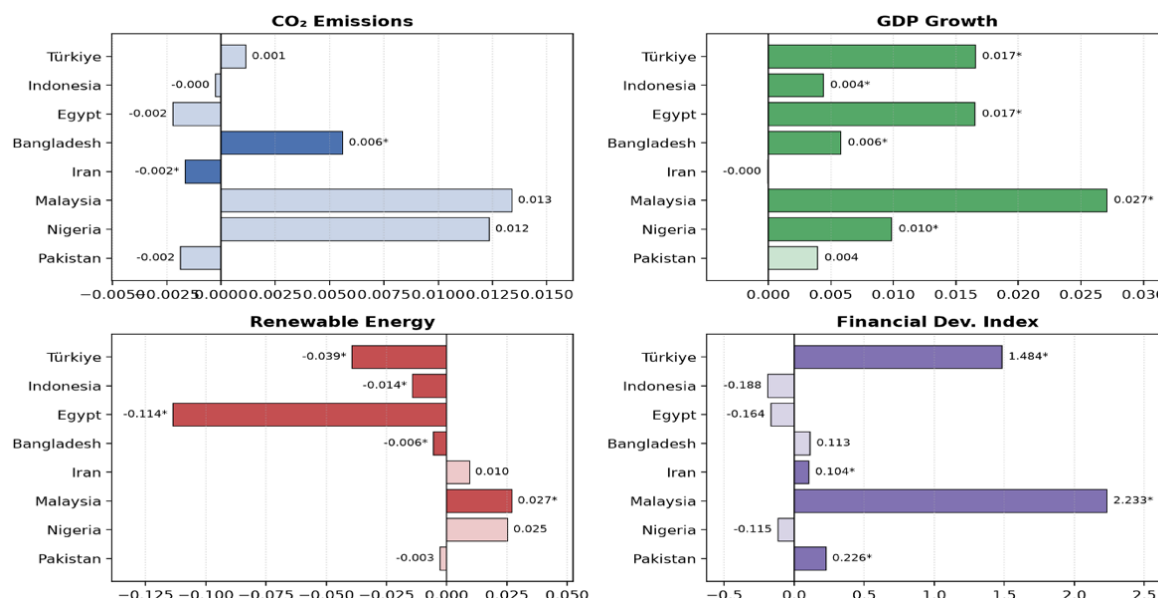


Figure 2. Enlarged, per-indicator coefficient estimates by D-8 country (significant coefficients marked with *).

A statistically significant relationship was found between the ecological footprint and carbon dioxide emissions, GDP growth, and renewable energy consumption in Bangladesh. CO₂ emissions from industrialization and energy production, along with GDP growth, appear to increase the ecological footprint. The high R-squared value (97%) for the overall model in Bangladesh indicates a very strong explanatory power. As with other countries, renewable energy consumption was found to be a factor that reduces the ecological footprint. In Iran, statistically significant relationship exists between the ecological footprint and carbon dioxide emissions and the financial development index. However, the relationship between carbon dioxide emissions and the ecological footprint was negative, contrary to expectations. The financial development index, on the other hand, has a positive relationship, increasing the ecological footprint.

In terms of GDP growth, a significant relationship was found between the ecological footprint and both GDP growth and the financial development index in Malaysia. Both variables had a positive relationship with the ecological footprint, indicating that they increased it. The financial development index appears to have a strong effect. Therefore, directing financial resources towards renewable energy investments could help mitigate the ecological footprint. A statistically significant relationship was found between the ecological footprint, GDP growth, and renewable energy consumption in Nigeria. However, unlike in other countries, renewable energy consumption has a positive relationship with the ecological footprint in Nigeria. This may have resulted from the increase in renewable energy costs, infrastructural and developmental costs for renewable energy development, the large span for the completion of such projects, the loss of trees due to development projects like river barrages for hydroelectric energy development, and the rate of substitution. Lastly, in Pakistan, the financial development index shows a relationship with the ecological footprint, and this is positive and significant, but it also shows a low R-squared value (23%), as it suggests that some other factors not covered in the study influence it, such as increased usage of fossil fuels, usage of chemical fertilizers, and loss of forest for urban or infrastructure development, etc.

The CCE-MG estimator (Pesaran, 2006) was carried out by augmenting each country regression with cross-sectional averages of the dependent and explanatory variables. Augmenting each country regression by cross-sectional means for each of the dependent and explanatory variables, the mean results show that only GDP growth retains a marginally significant panel-wide positive effect, with a coefficient of 0.008 and $p = 0.075$, whereas carbon dioxide emissions, renewable energy consumption, and financial development are, on average, without significant results.

This is to be expected following the varying individual country effects, reinforcing the selection of the panel SUR model for each country with specific effects.

Table 11. CCE Mean Group (CCE-MG) Robustness Estimates

Variable	Coefficient	Std. err.	t	p-value
CO ₂ Emissions	0.0038	0.0026	1.45	0.192
GDP Growth	0.0084	0.0040	2.09	0.075
Renewable Energy Consumption	-0.0177	0.0197	-0.90	0.399
Financial Development Index	0.0456	0.1930	0.24	0.820

5. Discussion

However, in an attempt to obtain more insights into the relationship between economic and environmental indicators and the ecological footprint, country-specific analysis was performed for D-8 countries. Country-specific analysis revealed diverse but informative trends on the impact of environmental and economic activity on ecological footprints for countries in this bloc. Among others, carbon dioxide, as arguably the most damaging environmental characteristic, was found to be statistically insignificant for most D-8 countries, with only Bangladesh and Iran demonstrating statistically significant positive and negative correlations with ecological footprints, respectively. Moreover, the relationship between CO₂ and ecological footprints might not always follow the expected results based on recent literature on emissions and environmental footprints in developing economies, since, as Ehigiamusoe et al. (2023) argue, carbon dioxide represents a part of atmospheric emissions, while ecological footprints embrace different environmental impacts in terms of ecological resource use. Therefore, the result may show divergence between these elements.

Along the same lines, Destek and Manga (2021) and Konya (2022) argue that, when it comes to the comparison of the co-integration of carbon dioxide emissions with environmental degradation, the overall and more general ecological footprint index displays more consistent results in comparison with carbon dioxide. In other words, according to Rustemoglu (2021), the trends of carbon dioxide emissions have become decoupled from the trends of ecological footprint, so a higher CO₂ level would underestimate ecological stress. In this regard, Bangladesh shows a positive and statistically significant result of carbon dioxide emissions on ecological footprints in terms of the positive effect of increasing CO₂ on increasing the ecological footprint. However, for Iran, carbon dioxide has a statistically significant negative effect on the ecological footprint. In fact, this outcome is somewhat contrary to the typical theoretical expectation. However, as suggested by Konya (2022) in the context of the EKC hypothesis, rising income implies a negative effect on per capita CO₂ emissions. Hence, this counterintuitive relation may occur due to rising income and a turn by the Government of Iran towards renewable energy sources to mitigate pollution (Almutairi et al., 2022; Maroufi & Hajilary, 2022; Zahedi et al., 2022).

Economic growth positively affects the ecological footprint in all of the D-8 countries, apart from Pakistan and Iran. In general, increased economic activity increases emissions, which leads to the increased utilization of fossil fuels, as well as more waste and increased demand for resources (Khezri et al., 2023; Onakposeha et al., 2025). However, the positive effects of the increase in per capita GDP on the ecological footprint, as noticed by Onakposeha et al. (2025) and Akyol Ozcan (2024), can, to a certain extent, be limited by environmental policies and measures taken for energy efficiency, as suggested by Nathaniel and Adedoyin (2021). Hence, these varying results across the countries confirm that not all growth causes increased ecological footprints. The example of Pakistan and Iran in the previous section and the example of regional policy, e.g., Zheng et al. (2025), explain the variations across the countries. However, regional policy should be considered in terms of the choice of policy to promote economic growth.

In Pakistan, Malaysia, and Iran, renewable energy consumption does not have an effect on the ecological footprint. While, in all of the other D-8 countries apart from Nigeria, it has a negative and statistically significant impact, which supports prior literature stating that the greater, the share of renewables in the economy, the greater the reduction in the environmental footprint through reduced dependence on fossil fuels (Koseoglu et al., 2022; Raghutla & Kolati, 2023). The relationship of the positive impact of people's social well-being with the ecological footprint, and by extension, of GDP, and therefore social well-being, with the ecological footprint in an econometric sense, is shown by Wu et al. (2021). The ecological footprint should, however, not only be viewed from the perspective of environmental costs. It means a compromise between the well-being that humans provide to each other, the well-being of society, and the well-being provided to future generations (Onakposeha et al., 2025), so we can make the

best policy choice. However, these countries have structural limitations, such as the underdevelopment of their renewable infrastructure (Dogan et al., 2019; Xue et al., 2021), and in Nigeria's case (Ansari et al., 2021), we witness an even more drastic scenario in terms of the positive effect on its environmental footprint.

The effect of financial development on the ecological footprint varies among the D-8 countries, with a significant and positive relationship found in Iran, Malaysia, Pakistan, and Türkiye, implying that a higher degree of financial depth leads to enhanced borrowing capacity for intensive activities, resulting in environmental damage. It may be caused because financial sector development contributes to environmental damage by extending the availability of credit to sectors engaged in intensive production and energy consumption (Gokmenoglu et al., 2021; Onakposeha et al., 2025). Nevertheless, this relationship did not prove to be statistically significant in Bangladesh, Egypt, Indonesia, and Nigeria. These results may arise from, among other things, the quality of the institutional framework and financial systems, as well as differences in stages of development, thus suggesting the need for environmentally conscious financial planning (Baloch et al., 2019; Dada et al., 2022; Ehigiamusoe et al., 2023).

6. Conclusion

In this paper, we aim to examine environmental sustainability with respect to the impact of economic growth, carbon emissions, the consumption of renewable energy, and financial development for the Developing Eight (D-8) countries of Türkiye, Iran, Pakistan, Bangladesh, Indonesia, Malaysia, Egypt, and Nigeria in the context of the ecological footprint by considering panel data from 1990 to 2021. Using multiple diagnostic tests, such as the Swamy S test for the heterogeneity of slopes and the Breusch-Pagan LM test for cross-sectional dependence, and then applying the Seemingly Unrelated Regression (SUR) model for each equation with a separate estimate while allowing contemporaneous correlations across the equations gave us more flexibility. This will enable us to provide information on how each variable is related to the ecological footprint within country-level specificity and time horizons.

According to the analysis, economic growth and financial development for almost all the selected D-8 countries, except Iran and Pakistan for GDP, have positive and significant effects on the ecological footprint. Similar effects were recorded for financial development, which had the widest spatial spreading among the surveyed group, affecting in particular and to a great extent Pakistan's footprint. We already know that the growth of economic activity and the activities that it leads to would lead to increased environmental pollution with higher energy demand and waste production (Kaya, 2020). Conversely, the usage of renewable energy resources has a negative significant influence in most selected countries, with the exception of Pakistan, Iran, and Malaysia, where these impacts were insignificant. On the other hand, in Nigeria, the variable had a positive impact, which can be due to structural deficiencies in the production mix, inefficiency, or negative effects in the total ecological footprint related to environmental conditions caused by the implementation of renewable energy sources. An unexpected relation between CO₂ emissions and the ecological footprint was observed in the D-8 countries, with the exceptions of Bangladesh and Iran. The relation for Iran has a negative direction, while a significant and positive relation was estimated for Bangladesh, as this is also the case for its industrial production of energy.

The findings have several policy implications for the studied countries. First, the findings indicate that a government must focus on the environmental implications of economic growth and financial development. Therefore, the promotion of green investment as part of economic activity will contribute to more environmentally sustainable financial development and GDP. Second, policies related to the promotion of renewable energy, although widely beneficial, must also take account of context specificity for maximizing the positive environmental externalities. Thus, governments need to take into account special measures to facilitate renewable energy integration and develop adequate infrastructure to fully tap into the potential positive environmental gains of renewable energy. Third, the focus on CO₂ emissions alone is not sufficient for assessing environmental quality, and we have to consider the ecological footprint as a tool that shows a broader picture of global impacts.

Despite our use of the SUR model and broad database, this study has some limitations. First, we included only four key control variables that influenced the relationship between economic development and the environment. Factors such as population growth, technological progress, urban growth, trade, and the quality of institutions could strongly alter the relation between economic activity and environmental damage; therefore, the inclusion of interaction effects in our models and the use of nonlinearities in future studies are warranted. Second, future research should explore sector-based decomposition of financial development or GDP to demonstrate which of them causes

greater environmental degradation to the economy. In addition, the index of Governance Quality and indexes of Environmental Regulations and Green Innovation could provide a strong basis for constructing a framework on the basis of which policymakers can frame sustainable development policies for the countries being studied.

To summarize, the environmental path in the D-8 economies depends more on the interaction between economic growth, financial development, and the consumption pattern of energy sources and technology for each national context, rather than on one factor alone. Policies for these countries should differ; whereas a green fiscal reform focusing on financial allocation and capital markets could direct Türkiye and Malaysia away from the ecological damage driven by both growth and finance, an upscaling and modernization of renewable energy production, along with energy efficiency in the other countries, could move the Indonesian, Egyptian, and Bangladeshi economies towards cleaner paths and help to avoid additional environmental harms coming from additional utilization of energy, for example, in Nigeria. Next steps would be to include indicators on Governance Quality, Environmental Regulation Index, and Green Innovation Index, as well as formal EKC and threshold dynamics analysis.

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Appendices

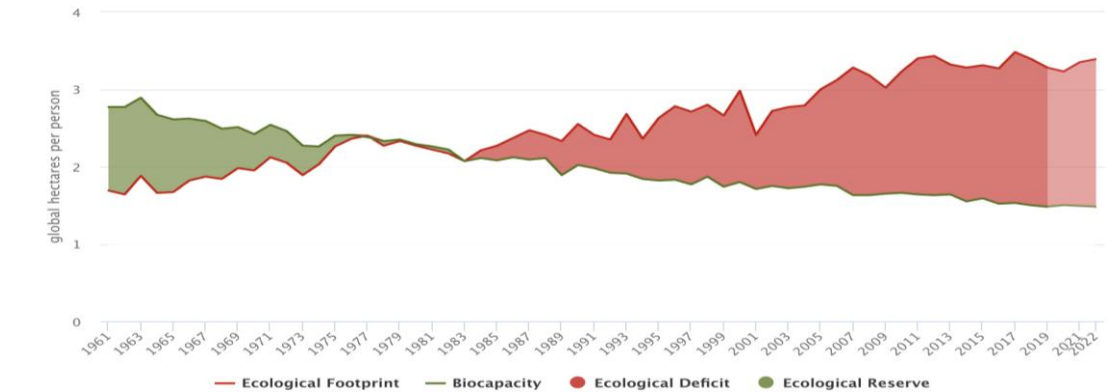


Figure A1. Türkiye's Ecological Footprint

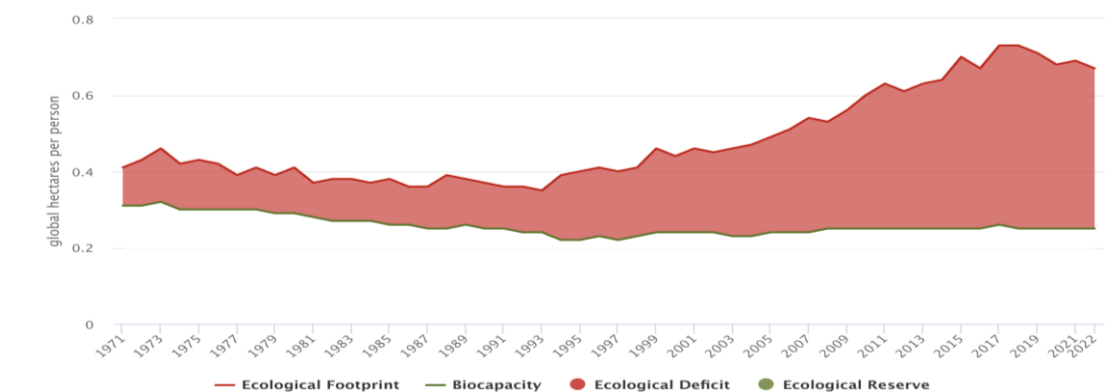


Figure A2. Bangladesh's Ecological Footprint

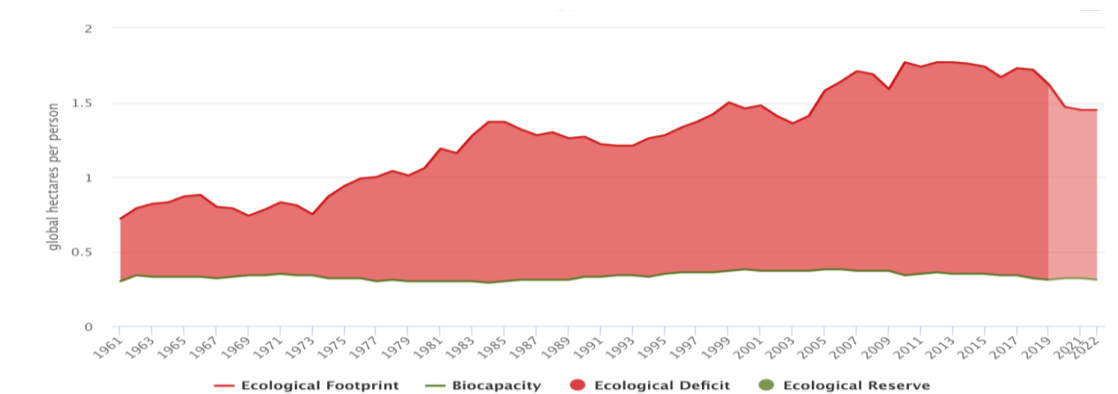


Figure A3. Egypt's Ecological Footprint

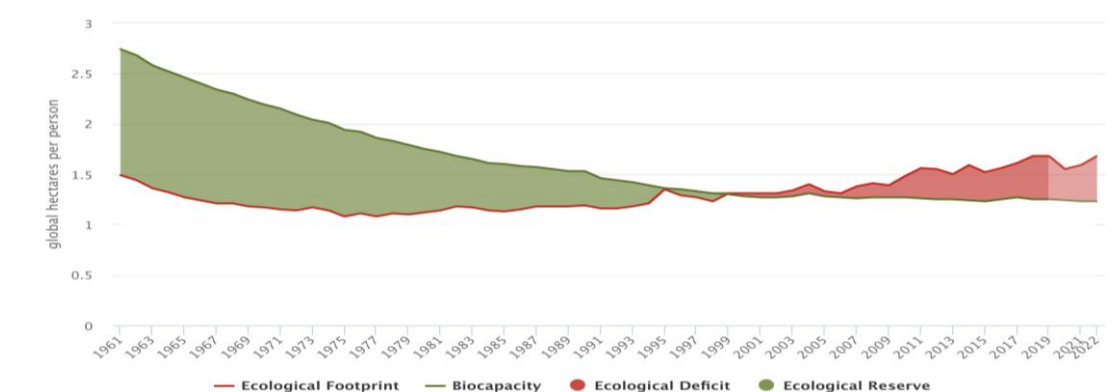


Figure A4: Indonesia's Ecological Footprint

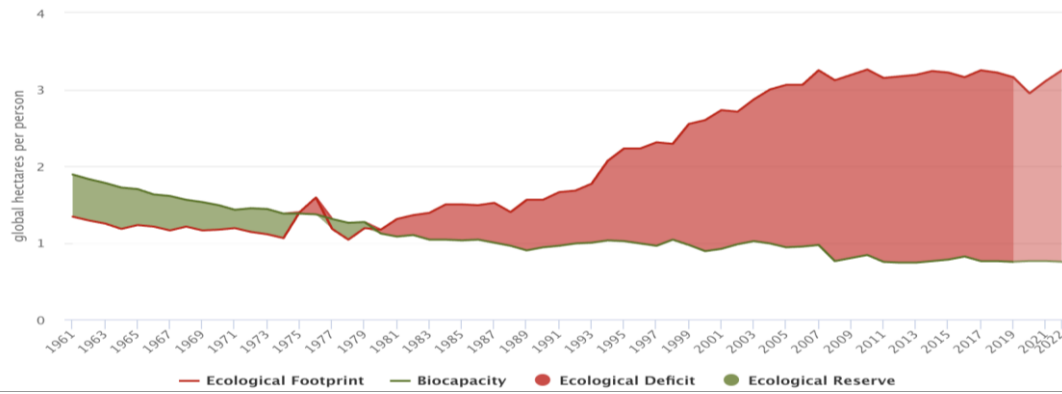


Figure A5: Iran's Ecological Footprint

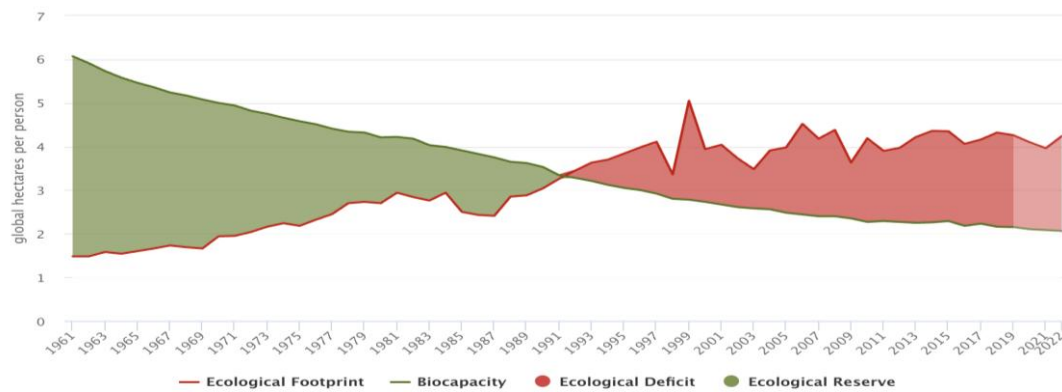


Figure A6: Malaysia's Ecological Footprint

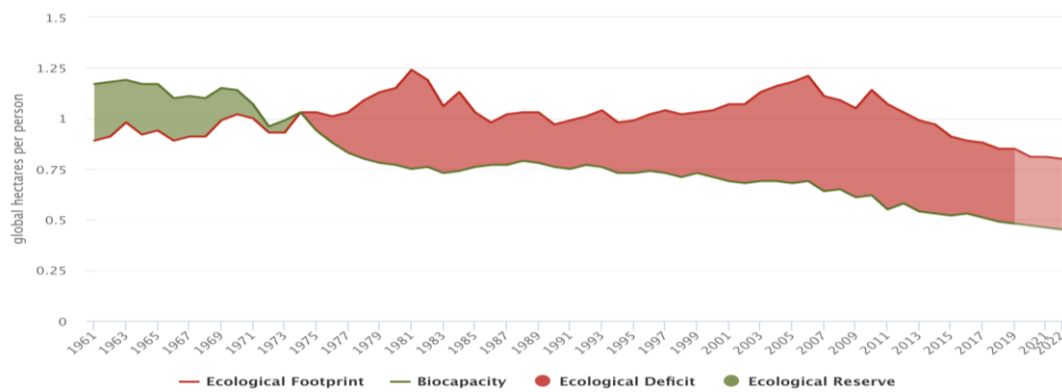


Figure A7: Nigeria's Ecological Footprint

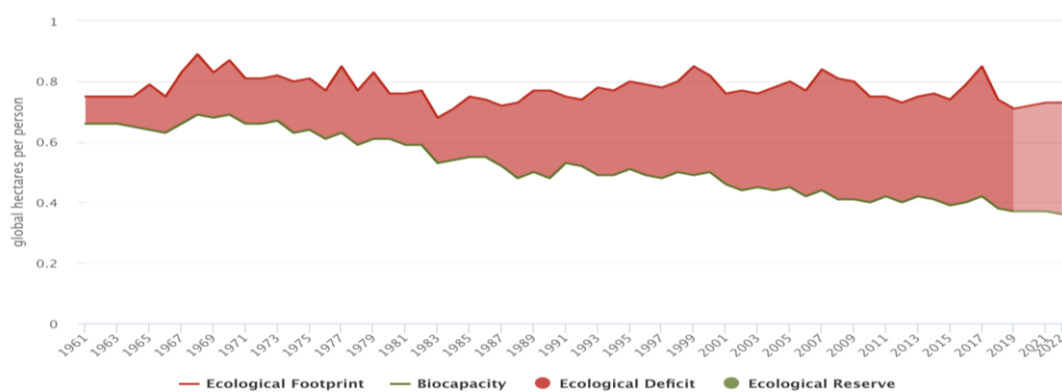


Figure A8: Pakistan's Ecological Footprint

ETHICAL AND SCIENTIFIC PRINCIPLES STATEMENT OF RESPONSIBILITY

The authors declare that ethical rules and scientific citation principles were complied with throughout the preparation process of this study.

STATEMENT OF RESEARCHERS' CONTRIBUTION RATE TO THE ARTICLE

The authors declare that they have contributed equally to the article.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

FINANCIAL DISCLOSURE

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