

The Impact of Food Production, Agricultural Value Added, and Economic Growth on the Ecological Footprint in D8 Countries

D8 Ülkelerinde Gıda Üretimi, Tarımsal Katma Değer ve Ekonomik Büyümenin Ekolojik Ayak İzi Üzerindeki Etkisi

Abstract: This study examines the impact of the food production index, agricultural value added and GDP per capita on the ecological footprint in the D8 countries (Bangladesh, Indonesia, Iran, Malaysia, Egypt, Nigeria, Pakistan and Türkiye) during the period 1990–2022. The study utilised a panel data approach; following descriptive statistics and tests for multicollinearity, the analysis process included the Breusch-Pagan LM and Pesaran LMadj tests for cross-sectional dependence, the Pesaran CADF unit root test for stationarity, the Delta test for homogeneity, and the Westerlund cointegration test to assess the presence of a long-run relationship. Long-run coefficients were analysed using the DOLSMG estimator, whilst causality relationships were examined using the Dumitrescu-Hurlin panel causality test. The findings indicate that, across the panel, the food production index, agricultural value added and GDP per capita increase the ecological footprint in a positive and statistically significant manner. Country-specific results, however, reveal that these relationships are not homogeneous and may manifest in different directions in some countries. Furthermore, bidirectional causality was identified between the ecological footprint and all variables. These results indicate that food production, agricultural value creation and economic growth in the D8 countries increase environmental pressure. Therefore,

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policymakers must support production and growth targets with policies focused on high resource efficiency, environmental friendliness and sustainable development.

Keywords: Ecological footprint, food production index, agricultural value added, economic growth, D8 countries

JEL Classification: Q57, Q18, O13, O47, C33

Öz: Bu çalışma, 1990-2022 döneminde D8 ülkelerinde (Bangladeş, Endonezya, İran, Malezya, Mısır, Nijerya, Pakistan ve Türkiye) gıda üretim endeksi, tarımsal katma değer ve kişi başına düşen GSYH'nin ekolojik ayak izi üzerindeki etkisini incelemektedir. Çalışmada panel veri yaklaşımı kullanılmıştır. Tanımlayıcı istatistikler ve çoklu doğrusal bağlantı testlerinin ardından analiz sürecinde yatay kesit bağımlılığını sınamak amacıyla Breusch-Pagan LM ve Pesaran LMadj testleri, durağanlığı belirlemek için Pesaran CADF birim kök testi, homojenliği değerlendirmek için Delta testi ve uzun dönemli ilişkinin varlığını incelemek amacıyla Westerlund eşbütünleşme testi uygulanmıştır. Uzun dönem katsayıları DOLSMG tahmincisi ile analiz edilirken, nedensellik ilişkileri Dumitrescu-Hurlin panel nedensellik testi ile incelenmiştir. Bulgular, panel genelinde gıda üretim endeksi, tarımsal katma değer ve kişi başına düşen GSYH'nin ekolojik ayak izini pozitif ve istatistiksel olarak anlamlı biçimde artırdığını göstermektedir. Bununla birlikte, ülke bazlı sonuçlar bu ilişkilerin homojen olmadığını ve bazı ülkelerde farklı yönlerde ortaya çıkabildiğini ortaya koymaktadır. Ayrıca, ekolojik ayak izi ile tüm değişkenler arasında çift yönlü nedensellik ilişkisi tespit edilmiştir. Ülke düzeyindeki farklılıklar, panel sonuçlarının her ülke için aynı biçimde yorumlanmaması gerektiğini ve ülkelere özgü koşulların önemini göstermektedir. Bu sonuçlar, D8 ülkelerinde gıda üretimi, tarımsal değer yaratımı ve ekonomik büyümenin çevresel baskıyı artırdığını göstermektedir. Bu nedenle politika yapımcıların üretim ve büyüme hedeflerini yüksek kaynak verimliliği, çevre dostu üretim ve sürdürülebilir kalkınma odaklı politikalarla desteklemesi gerekmektedir.

Anahtar Kelimeler: Ekolojik ayak izi, gıda üretim endeksi, tarımsal katma değer, ekonomik büyüme, D8 ülkeleri

JEL Sınıflandırması: Q57, Q18, O13, O47, C33

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Introduction

Environmental degradation, food security, agricultural transformation and sustainable economic growth have become central issues for developing economies seeking to reconcile these with environmental sustainability. In this context, the ecological footprint provides a broader measure of environmental pressure than emissions-based indicators, as it encompasses both the biological resources required to sustain production and consumption activities and the ecological capacity needed to absorb the associated waste. Accordingly, it offers a suitable framework for assessing the environmental impacts of increases in agricultural production and income. This issue is particularly important for the Developing Eight (D8) countries (Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan and Türkiye). These economies are characterised by significant agricultural activity, rising food demand, demographic pressures and growth-oriented development strategies. Across the group, agriculture retains its importance in terms of employment, rural livelihoods, food supply and value creation. At the same time, the expansion of food production and agricultural value added may intensify land use, water abstraction, fertiliser and pesticide use, energy consumption and pressure on natural resources. Economic growth may further exacerbate these pressures through higher levels of production, consumption, industrial activity and energy demand.

The existing literature has comprehensively examined the environmental consequences of agricultural activity and economic growth. However, the evidence remains fragmented in three respects. Firstly, although food production, agricultural value added and economic growth represent interlinked channels through which agricultural transformation and development may influence environmental pressure, they are often assessed in isolation. Secondly, whilst much of the literature relies on carbon emissions or other narrow indicators, the ecological footprint provides a more comprehensive assessment of resource demand and ecological pressure. Thirdly, evidence for the D8 countries remains limited, even though these countries' development trajectories combine food security concerns, agricultural dependence, demographic expansion and environmental vulnerability. In this context, this study investigates the long-term effects of the food production index, agricultural value added and GDP per capita on the ecological footprint in the D8 countries over the period 1990-2022. By considering these variables together, the study distinguishes the environmental impacts of agricultural production expansion, agricultural value added and income growth within a common empirical framework. The analysis also takes into account cross-sectional dependence and slope heterogeneity, enabling the identification of both panel-level and country-specific relationships.

This study contributes to the literature in three respects. Firstly, it integrates food production, agricultural value added and economic growth for the D8 countries into a single ecological footprint model. Secondly, it employs second-generation panel procedures and provides both panel-level and country-specific long-run estimates while accounting for cross-sectional dependence and slope heterogeneity. Thirdly, it provides policy-relevant evidence on whether agricultural and growth-oriented development models in the D8 countries are compatible with environmental sustainability. The findings are expected to inform policies aimed at improving food production and generating agricultural value-added whilst reducing ecological pressure.

1. Theoretical Framework

Today, environmental degradation is one of the key issues at the heart of discussions on economic and social development. In particular, the increase in production volumes, the intensification of natural resource use, the rise in energy demand and the expansion of pressure on land are making environmental sustainability increasingly fragile. Consequently, it has become essential to assess economic indicators affecting environmental quality not only in terms of growth performance but also in terms of their ecological consequences (Aydin et al., 2023). In this context, the ecological footprint emerges as a key indicator, as it evaluates environmental pressure not only through emissions but also through the total burden of human activities on biological capacity. Whilst carbon emissions often reflect only atmospheric degradation, the ecological footprint offers a broader environmental framework by taking into account production, consumption, land use and demand for natural resources collectively. Consequently, in studies seeking to explain environmental quality, turning to more comprehensive indicators such as the ecological footprint enables a more accurate assessment of the total pressure that economic activities exert on nature (Georgescu & Kinnunen, 2025).

Agricultural production and economic growth are among the most significant sources of this environmental pressure. On the one hand, food production and agricultural value added are indispensable for economic growth, employment, food security and rural well-being, particularly in developing countries (Wu et al., 2022). On the other hand, these processes can have adverse effects on environmental quality through increased land use, intensive irrigation, consumption of chemical fertilisers and pesticides, energy use and the exploitation of natural resources. Similarly, economic growth can increase ecological pressure by expanding energy demand, industrial activities and natural resource use, whilst boosting production capacity, income levels and consumption (Jie et al., 2023). The theoretical relationship between the food production index and ecological pressure is essentially based on the environmental cost of increased production. Although an increase in food production may initially appear positive in terms of agricultural success and food supply, this growth often requires greater water use, more intensive soil tillage, higher consumption of fertilisers and chemical inputs, and a larger production area (Tariq et al., 2023). If the technological structure of the production system is not environmentally friendly, growth in food production can directly lead to environmental degradation. Therefore, the relationship between the food production index and environmental quality must be understood not merely through the logic of 'more production', but in terms of the resource mix and environmental costs involved in achieving this production (Zhang et al., 2021). Indeed, some studies demonstrate that increases in food production raise greenhouse gas emissions and environmental degradation; others, however, indicate that this negative impact can be mitigated through institutional quality, eco-innovation and more efficient production processes (Ashraf et al., 2024; Wang & Mohammad Shah, 2023). Within this theoretical framework, the food production index is viewed as one of the key variables that could exert a positive, i.e., environmentally pressuring, effect on the ecological footprint.

The relationship between agricultural value added and environmental quality, however, is underpinned by a more complex theoretical framework. Agricultural value added reflects the economic contribution and production capacity of the agricultural sector. However, the nature of this contribution is decisive in terms of environmental outcomes (Raihan, 2023).

If an increase in agricultural value added is achieved through more intensive energy use, fossil fuel-dependent mechanisation, reliance on chemical inputs and the overexploitation of natural resources, this increase undermines environmental quality (Usman et al., 2022). Conversely, if the increase in agricultural value added is supported by the use of more efficient technologies, sustainable production methods, biomass capacity and resource efficiency, it yields results that reduce environmental pressure (Do & Hoang, 2024). Therefore, the environmental impact of agricultural value added is not, in theory, one-sided. On the one hand, there is production intensification and resource pressure; on the other, there is the channel of productivity and sustainability (Raihan & Tuspekova, 2022; Khurshid et al., 2022). This suggests that the impact of agricultural value added on the ecological footprint may vary depending on a country's agricultural structure and production techniques.

The theoretical relationship between GDP per capita and the ecological footprint is also one of the key areas of debate in the literature on environmental economics. Economic growth leads to increased prosperity by boosting production, income, consumption and the volume of investment (Nengsih et al., 2023). However, it also increases environmental pressure by expanding energy use, industrialisation, transport and demand for natural resources. Particularly in the early stages of growth, weak environmental regulations, the polluting nature of production technologies and an energy supply reliant on fossil fuels mean that increases in per capita income often result in higher ecological costs (Kirikkaleli et al., 2023). At the same time, as income levels rise, environmental awareness increases, investment in clean technologies strengthens, and stricter environmental policies are implemented. Consequently, the relationship between economic growth and environmental quality is characterised not by a linear relationship but by a phased and structurally dependent nature (Aydin et al., 2023; Guney et al., 2025). Examining the impact of GDP per capita on the ecological footprint is therefore important not only for understanding the environmental costs of growth but also for assessing its sustainability (Georgescu & Kinnunen, 2025).

When considered as a whole, this theoretical framework reveals that all three independent variables possess strong channels through which they can exert pressure on the ecological footprint. Consequently, variables such as the food production index, agricultural value added and GDP per capita should be regarded not merely as indicators of economic performance, but also as structural determinants of environmental pressure.

2. Literature Review

Studies in the literature examining the relationship between environmental quality and economic and agricultural indicators demonstrate that this relationship is neither unidirectional nor homogeneous, but can vary depending on the environmental indicator used, the country sample, the production structure and the econometric method. Within this framework, the effects of the three key explanatory variables associated with the ecological footprint, the dependent variable of the present study, namely the food production index, agricultural value added and GDP per capita, on environmental quality present a broad yet fragmented picture in the literature. In particular, whilst food production and agricultural activities are considered necessary for food security and growth, they can also accelerate environmental degradation through natural resource use, energy consumption, fertilisation, irrigation and land pressure. Consequently, an

increasing number of studies in the literature are assessing the relationship between agricultural production indicators and environmental quality not merely in terms of production growth, but within the context of sustainability and ecological carrying capacity.

2.1. Food Production Index and Environmental Quality

A significant proportion of studies examining the relationship between the food production index and environmental quality present findings suggesting that increases in production lead to greater environmental pressure. Tariq et al. (2023), using panel FMOLS and the Dumitrescu-Hurlin causality test on a sample of major economies comprising the US, China, Japan, Russia, Germany and Australia for the period 1990-2020, demonstrated that an increase in the food production index leads to higher food-system greenhouse gas emissions. Furthermore, the study identified a one-way causality from the food production index to greenhouse gas emissions; this result suggests that the expansion of food production may be a factor fuelling environmental degradation. Similarly, in their analysis covering the period 1990-2021 for Pakistan, Ashraf et al. (2024) utilised ARDL and FMOLS methods to determine that food production increases environmental degradation, whilst institutional quality mitigates this negative effect. This finding demonstrates that the environmental consequences of food production depend not only on production volume but also on governance and institutional capacity.

However, whilst some studies examine the relationship between food production and environmental quality through more indirect channels, they clearly highlight the environmental cost dimension. More recent evidence from Nigeria also supports the view that food-production expansion can intensify ecological pressure. Using data for the 1981-2020 period, Obekpa et al. (2025) found that food production activities and the nonlinear expansion of food production increase the total ecological footprint as well as several of its components, including built-up land, cropland, and forest-product footprints. The study further shows that population growth reinforces ecological pressure, highlighting the environmental risks associated with food-security strategies that rely on resource-intensive agricultural expansion. These findings suggest that improving food security requires not only higher output but also production practices that reduce pressure on ecological resources. Zhang et al. (2021) jointly assessed food production efficiency and environmental sustainability for the top 10 countries in global agricultural production using entropy-weighted, SBM-DEA, Malmquist, OLS and Tobit methods. In particular, the inclusion of CO₂ emissions, deforestation, irrigation and fertiliser use as environmental pollution indicators in the model highlighted the tension between high food production efficiency and environmental pollution. Similarly, Mrówczyńska-Kamińska et al. (2021), in the panel regression model they developed for 14 major food-producing countries, examined the greenhouse gas emission intensity of food production systems and demonstrated that per capita income, population density, agricultural land area, the share of livestock production, and per capita energy use increase emission intensity. In contrast, Kibria et al. (2023), offering a more indirect yet complementary perspective, found in their analysis of South Asia using FMOLS, DOLS and robust least squares methods that the food production index increased cereal production, but that agricultural CO₂ emissions reduced cereal production in the long term. This result indicates a clear tension between the goal of increasing food production and environmental sustainability. On the other hand, in their

study using the PLS-SEM method in the Chinese food industry, Wang and Mohammad Shah (2023) demonstrated that product, process and organisational eco-innovation improve food production quality and that environmental awareness plays a mediating role in this relationship. Although this study does not measure environmental quality directly using ecological footprint or emission indicators, it makes a complementary contribution to the literature by demonstrating that environmentally sensitive production practices can yield positive outcomes in food production processes. Overall, studies centred on the food production index indicate that increased production can, in many cases, heighten environmental pressure; however, institutional quality, eco-innovation and more efficient production techniques can help to limit this pressure.

2.2. Agricultural Value Added and Environmental Quality

The relationship between agricultural value added and environmental quality, however, yields more clearly conflicting results in the literature. Whilst one group of studies argues that agricultural value added increases environmental degradation, another group of studies arrives at opposite conclusions under sustainable agricultural practices, more efficient production structures, or different environmental quality indicators. For example, Usman et al. (2022), using FMOLS and the Dumitrescu-Hurlin causality test for South Asian countries over the 1995-2017 period, demonstrated that agricultural value added increases CO₂ emissions and exacerbates environmental degradation. Similarly, in their study covering the period 1990-2019 for Brazil, Raihan and Tuspekova (2022) utilised ARDL, DOLS, FMOLS and CCR methods and found that an increase in agricultural value added led to higher CO₂ emissions. The study attributes this result to the increased use of fossil fuels, fertilisers and pesticides aimed at boosting agricultural productivity. Similarly, Do and Hoang (2024), using ARDL and Granger causality tests on a Vietnamese sample, demonstrated that agricultural value added reduces the load capacity factor, thereby weakening environmental quality. This finding suggests that agricultural activities may have detrimental effects not only in terms of carbon emissions but also in relation to broader environmental sustainability indicators. Recent evidence further supports the environmentally pressuring role of agricultural value creation. Using data for the five most populous Asian countries over the 1975-2020 period, Ali and Xiangyu (2025) employed the MG, AMG, and CCEMG estimators and found that agricultural value added significantly increases both the ecological footprint and carbon emissions. The study also identified bidirectional causality between agricultural value added and the ecological footprint, indicating that agricultural expansion and ecological pressure may reinforce each other over time. These findings suggest that, unless agricultural value creation is supported by cleaner energy use and sustainable production practices, it is likely to intensify environmental degradation.

Conversely, there are also findings in the literature indicating that agricultural value added can improve environmental quality. In his study covering the period 1984-2020 for Vietnam, Raihan (2023) used ARDL and VECM methods, as well as DOLS, FMOLS and CCR estimators, to demonstrate that an increase in agricultural value added reduces CO₂ emissions in both the short and long term. The author attributes this result to more efficient agricultural practices, biomass carbon sequestration capacity and sustainable agricultural policies. Similarly, in their ARDL and NARDL-based studies covering the 1990-2022 period for Bangladesh, Amin and Rahman (2024) found that the long-run effect of agriculture was

not significant in the linear model; however, in the asymmetric model, they demonstrated that agricultural expansion reduced carbon emissions in both the short and long term. In the same context, Khurshid et al. (2022) found, using the NARDL approach on a Pakistani sample, that positive shocks in agricultural production increased CO₂ emissions, whilst negative shocks reduced them, thereby highlighting the asymmetric nature of the relationship. It is therefore understood that the relationship between agricultural value added and environmental quality does not possess a linear or universal structure; rather, it can vary depending on the country's structure, the energy and input composition of production, the environmental indicator used, and the econometric method employed.

2.3. Economic Growth and Environmental Quality

Although the relationship between GDP per capita or economic growth and environmental quality is similarly debated in the literature, the general trend suggests that growth increases environmental pressure. In their panel data analysis for Indonesia, Nengsih et al. (2023) demonstrated that GDP has a negative and significant effect on environmental quality, meaning that economic growth reduces environmental quality. Similarly, in their study covering the period 1990-2019 in Portugal, Kirikkaleli et al. (2023) used the NARDL approach to demonstrate that positive shocks in economic growth increase CO₂ emissions; DOLS, CCR and FMOLS estimators also confirmed this result. Furthermore, Guney et al. (2025), in their analysis covering 24 European Union countries, demonstrated using CCE and AMG estimators that economic growth exerts a negative impact on load capacity and increases environmental pressure. These findings indicate that economic growth can undermine environmental quality, particularly in production structures that are energy-intensive, fossil fuel-dependent and reliant on resource consumption. Recent country-specific evidence also confirms the environmentally adverse effect of economic growth. Using annual data for South Korea over the 1990–2022 period, Damak and Eweade (2026) applied the ARDL approach and robustness estimators, including FMOLS, DOLS, and CCR, to examine the effects of economic growth, the rule of law, renewable energy use, and petroleum exports on the ecological footprint. Their findings show that GDP growth increases the ecological footprint in the long run, whereas renewable energy use and the rule of law reduce ecological pressure. This evidence indicates that the environmental cost of economic growth can be mitigated when growth is accompanied by stronger institutions and a cleaner energy transition.

However, there are also studies showing that the relationship between economic growth and environmental quality is not linear and can vary depending on certain thresholds. In their study covering 20 European Union countries, Aydin et al. (2023) used CS-ARDL and CS-DL estimators and demonstrated that the relationship between economic growth and the ecological footprint varies by country, thereby showing that the Environmental Kuznets Curve hypothesis holds true only in some countries. More specifically, Georgescu and Kinnunen (2025), using the MT-NARDL model they developed for Finland, examined economic growth under low, medium and high regimes; they found that low growth increases environmental pressure, medium-level growth provides temporary improvement, and the high-growth regime reduces the ecological footprint. This result suggests that the relationship between economic growth and the environment may have a phased, regime-sensitive and non-linear structure. Consequently, whilst the literature generally indicates that the economic growth variable leads to increased environmental

degradation, it is understood that this effect may weaken, or even reverse, in certain countries and at specific stages of development.

Overall, the existing literature indicates that food production, agricultural value added, and economic growth can intensify environmental pressure, although the magnitude and direction of these effects vary across countries according to agricultural production structures, energy dependence, technological capacity, and institutional conditions. Nevertheless, the literature remains fragmented in two important respects. First, the food production index, agricultural value added, and economic growth are generally examined separately, despite representing interconnected dimensions of agricultural transformation and development. Second, much of the empirical evidence relies on carbon emissions or country-specific analyses, while studies jointly assessing these three variables through the ecological footprint remain limited, particularly for the D8 countries. Accordingly, the present study is positioned at the intersection of the agriculture–environment and growth–environment literatures. It jointly examines the effects of food production, agricultural value added, and GDP per capita on the ecological footprint within a single empirical framework for the D8 countries. By employing panel procedures that account for cross-sectional dependence and slope heterogeneity and by reporting both panel-level and country-specific long-run estimates, the study goes beyond a common-coefficient interpretation of the agriculture–environment nexus. It therefore contributes evidence on whether food production expansion, agricultural value creation, and income growth generate common or country-specific ecological pressures across developing economies with distinct agricultural and development structures.

3. Data and Methodology

3.1. Data

This study examines the impact of the food production index, agricultural value added and GDP per capita on the ecological footprint in the D8 countries (Bangladesh, Indonesia, Iran, Malaysia, Egypt, Nigeria, Pakistan and Türkiye) for the period 1990–2022. The study period begins in 1990 because this year represents the earliest point at which consistent annual data for the ecological footprint and the explanatory variables are jointly available for all D8 countries. The period ends in 2022 because it is the most recent year for which comparable and complete data were available across all variables and countries at the time of data collection. In addition, the 1990–2022 period captures major structural changes in the D8 economies, including agricultural transformation, population growth, increasing food demand, trade integration, and growth-oriented development policies. The variables used in the study and the databases from which they were obtained are presented in Table 1; the ecological footprint variable was sourced from the Global Footprint Network, whilst the food production index, agricultural value added and GDP per capita variables were obtained from the World Bank database.

Table 1

Descriptions of the variables

Variables	Abbreviation	Description	Source
Ecological Footprint	efp	Ecological footprint of consumption (gha per person)	Global Footprint Network (2026)

Food production index	fpi	Food production index (2014–2016=100)	
Agricultural value added	ava	Agriculture, forestry, and fishing, value added (constant LCU)	World Bank (2026)
GDP per capita	gdp	GDP per capita (constant 2015 US\$)	

Note. Agricultural value added is measured in constant local currency units. Its coefficient is interpreted as a within-country elasticity; absolute levels are not compared across countries.

3.2. Methodology

A model similar to Equation (1) has been developed to examine the impact of the food production index, agricultural value added and per capita GDP on the ecological footprint.

$$\ln efp_{it} = \beta_0 + \beta_1 \ln fpi_{it} + \beta_2 \ln ava_{it} + \beta_3 \ln gdp_{it} + \varepsilon_{it} \quad (1)$$

In Model (1), the ecological footprint, denoted by $\ln efp$, is the dependent variable. The variables denoted by $\ln fpi$, $\ln ava$ and $\ln gdp$, representing the food production index, agricultural value added and GDP per capita respectively, are the independent variables; logarithms have been taken of all variables. The model investigates the extent to which increases in the food production index, agricultural value added and GDP per capita contribute to an increase in the ecological footprint, and it is expected that the coefficients for all variables will be positive and significant. In this study, the panel data method was employed to examine the effect of the food production index, agricultural value added and GDP per capita on the ecological footprint; the analyses began with descriptive statistics and tests for multicollinearity. The methodological strategy was designed to accommodate the main characteristics of the D8 panel, namely the possibility of common shocks across countries and heterogeneous long-run responses. Given that D8 countries are exposed to shared global developments, including food-price shocks, energy-market fluctuations, climate-related risks, and international economic conditions, assuming cross-sectional independence could lead to biased or inefficient inferences. Therefore, cross-sectional dependence was examined using the Breusch and Pagan (1980) LM and Pesaran et al. (2008) bias-adjusted LM tests. These tests are appropriate for panels with a relatively small cross-sectional dimension and a longer time dimension, as in the present study. After identifying cross-sectional dependence, the Pesaran (2007) CADF unit root test was employed. The main advantage of the CADF test is that it controls for unobserved common factors and cross-sectional dependence by augmenting standard unit root regressions with cross-sectional averages. It therefore provides more reliable stationarity results than first-generation unit root tests when countries are affected by common shocks. To verify the robustness of the CADF results, the Breitung and Das (2005) panel unit root test was also employed. This test provides a complementary second-generation assessment of stationarity by accounting for cross-sectional dependence through a common-factor structure.

Slope homogeneity was subsequently assessed using the Pesaran and Yamagata (2008) Delta test. This test is important because it determines whether the long-run effects of food production, agricultural value added, and economic growth can reasonably be assumed to be identical across D8 countries. Rejecting slope homogeneity justifies the use of estimators that allow country-specific coefficients and avoids potentially misleading conclusions based on a single common slope parameter. The Westerlund (2007) bootstrap cointegration

test was then used to test for a long-run relationship among the variables. This method was selected because it is based on an error-correction framework, permits heterogeneity across countries, and, through bootstrap critical values, addresses cross-sectional dependence. It is therefore particularly suitable for evaluating long-run relationships in heterogeneous panels such as the D8 sample. Following confirmation of cointegration, long-run coefficients were estimated using the Dynamic Ordinary Least Squares Mean Group (DOLSMG) estimator (Pedroni, 2001). DOLSMG was preferred because it estimates separate country-level long-run relationships and then obtains panel-average effects, thereby allowing the coefficients to differ across countries. In addition, the inclusion of leads and lags of first-differenced regressors helps reduce potential endogeneity and serial-correlation bias in cointegrated relationships. This feature is particularly valuable because the environmental effects of food production, agricultural value added, and income growth may evolve gradually and differ substantially across D8 economies.

Finally, the Dumitrescu and Hurlin (2012) panel causality test was applied to investigate the direction of causal relationships. Its main advantage is that it allows causal effects to vary across countries rather than imposing a homogeneous causality structure on the entire panel. Accordingly, it provides a more flexible assessment of the feedback relationships between ecological pressure, agricultural activity, and economic growth. For consistency across the empirical analysis, a lag length of one was used in all tests requiring lag specification. This choice is appropriate for the annual data structure and helps preserve degrees of freedom given the relatively limited time dimension of the panel.

4. Empirical Results

This section presents the empirical findings in the same sequence as the methodological procedure. First, descriptive statistics and multicollinearity diagnostics are reported. Second, the results of the cross-sectional dependence, unit root, and slope homogeneity tests are presented to establish the appropriate econometric framework. Third, the Westerlund bootstrap cointegration results are reported to assess the existence of a long-run relationship among the variables. Finally, the DOLSMG long-run coefficient estimates and Dumitrescu-Hurlin causality results are discussed at both the panel and country levels.

Table 2

Descriptive statistics and VIF

Variables	Obs	Mean	Std. Dev.	Min	Max	VIF
lnepf	264	0.396	0.689	-1.102	1.514	—
lnfpi	264	4.344	0.276	3.667	4.859	1.28
lnava	264	29.524	3.843	24.798	36.603	1.11
lngdp	264	7.920	0.806	6.160	9.566	1.30

Table 2 reports 264 observations. The mean values of lnepf, lnfpi and lngdp are 0.396, 4.344 and 7.920, respectively. Agricultural value added is measured in constant local currency units, so the pooled descriptive statistics for lnava combine different currencies and do not provide a basis for comparing countries. Its coefficients are interpreted as within-country

elasticities. The VIF values for $\ln fpi$, $\ln ava$ and $\ln gdp$ are 1.28, 1.11 and 1.30, respectively. All values are below 5, indicating no multicollinearity problem

Table 3

Cross-Sectional Dependence

Cross Section Dependence	Statistics	P-value
LM	47.95	0.0108
LM _{adj}	7.014	0.0000

Table 3 indicates that there is cross-sectional dependence in the model according to the LM and LM_{adj} tests. Following the identification of cross-sectional dependence in the model, the Pesaran (2007) CADF unit root test, a second-generation unit root test, was conducted.

Table 4

CADF test results

Variables	I(0)	I(1)
$\ln efp$	-1.952 (0.302)	-4.170 (0.000)***
$\ln fpi$	-1.999 (0.255)	-3.964 (0.000)***
$\ln ava$	-1.493 (0.806)	-3.970 (0.000)***
$\ln gdp$	-2.045 (0.213)	-2.728 (0.002)***

Note. *** $p < .01$.

According to the results of the CADF unit root test in Table 4, all variables are stationary at the first difference (I(1)) level at the 1% significance level. Since all variables are stationary at the I(1) level, it is possible to investigate whether there is cointegration among the variables.

Table 5

Breitung and Das (2005) panel unit root test results

Variables	I(0)	I(1)
$\ln efp$	0.8491 (0.8021)	- 6.4221 (0.0000)***
$\ln fpi$	4.7469 (1.0000)	-7.6488 (0.0000)***
$\ln ava$	4.9870 (1.0000)	- 9.2836 (0.0000)***
$\ln gdp$	5.9309 (1.0000)	- 5.1279 (0.0000)***

Note. *** $p < .01$.

To verify the robustness of the CADF unit root test results, the Breitung and Das (2005) panel unit root test was additionally employed. This second-generation test is suitable for panels affected by cross-sectional dependence and provides a complementary assessment of the order of integration. As reported in Table 5, none of the variables is stationary at levels. However, all variables become stationary after first differencing at the 1% significance level. The Breitung and Das (2005) results therefore confirm the CADF findings and indicate that all variables are integrated of order one, I(1). However, prior to conducting the cointegration test, a Delta homogeneity test was performed to determine the homogeneity of the slope coefficients and to identify whether the cointegration relationship should be tested using a first-generation or second-generation panel

cointegration test (Pesaran & Yamagata, 2008). The results of the Delta test are presented in Table 6.

Table 6

Delta test results

Delta test	Test statistics	P value
Δ	16.585	0.000
Δ_{adj}	18.005	0.000

As shown in Table 6, the slope coefficients are heterogeneous according to the Delta test results. In this context, the second-generation panel cointegration test, the Westerlund (2007) panel cointegration test, was applied to address cross-sectional dependence and heterogeneity in the study, and the results are presented in Table 7.

Table 7

Westerlund (2007) panel cointegration test

Statistic	Value	Z-value	Robust P-value
Gt	-2.152	-1.223	0.055
Ga	-7.343	0.212	0.070
Pt	-5.055	-1.015	0.107
Pa	-6.355	-0.934	0.050

Note. Bootstrap p-values were obtained using 100 replications, with 1 lags and 1 leads. The Gt and Ga statistics support cointegration at the 10% significance level.

Given the cross-sectional dependence in the model, the bootstrap p-values are considered. Since the slope coefficients are heterogeneous, the interpretation focuses on the Gt and Ga statistics. Their robust p-values are 0.055 and 0.070, respectively, supporting cointegration at the 10% significance level but not at the 5% level. The evidence of a long-run relationship is therefore weak, and the long-run estimates should be interpreted with this qualification. Long-run coefficients were estimated using the Dynamic Ordinary Least Squares Mean Group (DOLSMG) estimator (Pedroni, 2001). The results are presented in Table 8.

Table 8

DOLSMG long-run estimates

Countries	lnfpi: Beta	lnfpi: t-stat	lnava: Beta	lnava: t-stat	lngdp: Beta	lngdp: t-stat
Bangladesh	0.03523	0.1742	1.571	3.478***	0.8654	8.103***
Indonesia	-0.4089	-2.216**	0.7786	3.687***	0.411	2.54**
Iran	0.7118	1.834*	-1.025	-3.06***	-0.3592	-0.7939
Malaysia	-0.3141	-1.397	0.6618	8.732***	0.3464	1.205
Egypt	0.5164	2.928***	-0.6439	-0.83	0.1185	0.3074
Nigeria	1.412	2.785***	-0.4086	-8.072***	1.132	4.059***
Pakistan	0.7821	5.851***	0.03703	0.4769	1.471	13.02***
Türkiye	-0.4074	-2.309**	0.209	2.345**	0.1905	1.946*
Model	0.2909	2.704*	0.1475	2.389	0.5219	10.74*

Note. * $p < .10$. ** $p < .05$. *** $p < .01$.

Table 8 reports the DOLSMG long-run coefficient estimates. The model-level coefficients represent the average long-run effects across the D8 panel, whereas the country-level coefficients capture heterogeneous long-run responses for each country. According to the DOLSMG estimation results reported in Table 8, there is a significant and positive relationship between the food production index and the ecological footprint for the panel as a whole. An increase in the food production index leads to an increase in the ecological footprint. At the country level, the effect of the food production index on the ecological footprint is negative and significant in Indonesia and Türkiye; positive and significant in Iran, Egypt, Nigeria, and Pakistan; and insignificant in Bangladesh and Malaysia. Thus, an increase in the food production index reduces the ecological footprint in Indonesia and Türkiye, increases it in Iran, Egypt, Nigeria, and Pakistan, and has no effect in Bangladesh and Malaysia. On the other hand, for the panel as a whole, there is a positive and significant relationship between agricultural value added and the ecological footprint. An increase in agricultural value added increases the ecological footprint. At the country level, the effect of agricultural value added on the ecological footprint is positive and significant in Bangladesh, Indonesia, Malaysia, and Türkiye, while it is negative and significant in Iran and Nigeria, and insignificant in Egypt and Pakistan. Accordingly, an increase in agricultural value added increases the ecological footprint in Bangladesh, Indonesia, Malaysia, and Türkiye; reduces it in Iran and Nigeria; and has no effect in Egypt and Pakistan. When the relationship between economic growth and the ecological footprint is examined for the panel as a whole, a positive and significant relationship is observed. At the country level, the effect of economic growth on the ecological footprint is positive and significant in Bangladesh, Indonesia, Nigeria, Pakistan, and Türkiye, whereas it is insignificant in Iran, Malaysia, and Egypt. Therefore, an increase in economic growth raises the ecological footprint in Bangladesh, Indonesia, Nigeria, Pakistan, and Türkiye, while it has no effect in Iran, Malaysia, and Egypt.

After establishing the existence of a cointegration relationship in the study, the Dumitrescu–Hurlin Panel Causality Test was employed to examine the causal relationships among the variables, and the results are presented in Table 9.

Table 9

Dumitrescu-Hurlin Panel Causality Test Results

Direction of Causality	$Z_{(N,T)}$ statistic	P value
$\ln fpi \rightarrow \ln efp$	6.3299	0.0000
$\ln efp \rightarrow \ln fpi$	12.5392	0.0000
$\ln ava \rightarrow \ln efp$	9.3385	0.0000
$\ln efp \rightarrow \ln ava$	4.1642	0.0000
$\ln gdp \rightarrow \ln efp$	7.0212	0.0000
$\ln efp \rightarrow \ln gdp$	4.5329	0.0000

Note. The lag order is 1.

The Dumitrescu–Hurlin panel causality results in Table 9 show bidirectional Granger causality between the ecological footprint and each explanatory variable. Food production, agricultural value added and GDP per capita Granger-cause the ecological footprint, while

the ecological footprint also Granger-causes each of these variables. These findings indicate feedback between environmental pressure and agricultural and economic activity in D8 countries.

4.1. Discussion

This study examines the effects of the food production index, agricultural value added, and GDP per capita on the ecological footprint in D8 countries over the period 1990-2022. The panel results indicate that all three variables increase the ecological footprint. This finding reveals that the expansion of food production, growth in the agricultural sector, and rising income levels intensify environmental pressure in the D8 group of countries. These results suggest that the prevailing development structure in these countries still operates through resource-intensive production patterns and growth dynamics that generate ecological costs. Overall, the findings are largely consistent with the literature emphasising that, unless supported by efficiency gains, technological transformation, or stronger environmental governance, agricultural expansion and economic growth tend to worsen environmental quality.

One of the main findings of the study is that the food production index has a positive and significant effect on the ecological footprint for the panel as a whole. This finding indicates that increases in food production are often accompanied by greater use of land, water, fertilisers, and energy, thereby increasing environmental pressure. This result is consistent with the findings of Tariq et al. (2023), who reported that food production increases food-system greenhouse gas emissions, and Ashraf et al. (2024), who found that food production contributes to environmental degradation in Pakistan. Although these studies use emissions-based indicators and country-specific settings, the present results extend their conclusions by showing that food production also increases the broader ecological footprint across the D8 panel. It is also in line with the findings of Zhang et al. (2021), who identified a tension between food production efficiency and environmental sustainability. Therefore, the findings for D8 countries support the view that increases in food production, backed by more intensive use of land, water, fertilisers, and energy, raise ecological pressure. However, the negative coefficients obtained for Indonesia and Türkiye indicate that this relationship does not operate in the same way across all countries. In this respect, the country-specific results suggest that the environmental cost of food production may be reduced under more efficient or environmentally sensitive production structures, which is also consistent with the general implications reported by Wang and Mohammad Shah (2023).

Agricultural value added has a positive and statistically significant effect on the ecological footprint for the panel as a whole. This finding is consistent with Usman et al. (2022), who showed that agricultural value added increases carbon emissions in South Asia, and Raihan and Tuspekova (2022), who reported a similar result for Brazil. It is also supported by the more recent evidence of Ali and Xiangyu (2025), who found that agricultural value added increases the ecological footprint in highly populated Asian countries. While the previous literature mainly focuses on individual countries or alternative regional samples, the present study extends this evidence to the D8 group and confirms that agricultural value creation is generally associated with higher ecological pressure. Likewise, it is supported by Do and Hoang (2024), who found that agricultural value added weakens environmental quality through the load capacity factor. Therefore, the panel findings confirm that value

creation in agriculture in D8 countries is associated more with environmental pressure than with ecological improvement. However, the negative and significant coefficients found for Iran and Nigeria indicate that the environmental effect of this variable may produce different outcomes depending on the agricultural structure of each country. In this sense, the country-specific heterogeneity does not contradict Raihan (2023), who found that agricultural value added reduces emissions in Vietnam. From a comparative perspective, it can be understood that the environmental effect of agricultural value added depends less on the size of the agricultural sector than on how this added value is generated.

The positive and statistically significant effect of GDP per capita on the ecological footprint for the panel as a whole indicates that economic growth remains one of the major sources of environmental pressure in D8 countries. This finding shows that rising income levels in these countries are still associated with higher consumption, greater energy use, production expansion, and increased demand for natural resources. This result is consistent with Nengsih et al. (2023), who found that GDP worsens environmental quality in Indonesia, Kirikkaleli et al. (2023), who reported that economic growth increases CO₂ emissions in Portugal, and Guney et al. (2025), who concluded that growth intensifies environmental pressure in European Union countries. It is also in line with Damak and Eweade (2026), who found that GDP growth increases the ecological footprint in South Korea. By focusing on the D8 countries, the present study extends this evidence to a group of developing economies where growth remains closely linked to resource use, production expansion, and rising consumption. However, the insignificant coefficients for Iran, Malaysia, and Egypt indicate that the growth–environment relationship does not operate with the same strength in all D8 countries. This is consistent with Aydin et al. (2023) and Georgescu and Kinnunen (2025), who argue that the environmental consequences of economic growth may vary depending on country-specific conditions, threshold effects, and growth regimes.

Finally, the existence of bidirectional causality between the ecological footprint and the three explanatory variables indicates that environmental pressure in D8 countries is not merely an outcome of production and growth, but also a mechanism that feeds back into these processes over time. Taken together, the findings show that the dominant pattern in D8 countries is consistent with the main strand of the literature. Increases in food production, agricultural expansion, and income growth generally intensify environmental pressure. However, country-specific differences also demonstrate that these effects are not fixed and may vary depending on structural, technological, and institutional conditions.

Conclusion and Policy Implications

This study examined the effects of the food production index, agricultural value added, and GDP per capita on the ecological footprint in D8 countries over the period 1990-2022. D8 countries are of particular importance in discussions of environmental sustainability due to the weight of agricultural production in their economic structures, the pressures associated with food security, and their growth-oriented development objectives. The empirical findings reveal that, for the panel as a whole, the food production index, agricultural value added, and GDP per capita all have a positive and significant impact on the ecological footprint. In other words, increases in food production, expansion in agricultural value added, and rising income levels intensify environmental pressure in D8 countries. In addition, the causality results indicate the existence of bidirectional relationships between these variables and the ecological footprint. This finding suggests that environmental

pressure is not merely an outcome of production and growth, but also functions as a mechanism that feeds back into these processes.

The findings are broadly consistent with the existing literature showing that resource-intensive food production, agricultural value creation, and income growth can increase environmental pressure. The positive effect of the food production index supports studies indicating that agricultural output expansion is often accompanied by higher land, water, energy, and chemical-input use. Likewise, the positive effect of agricultural value added suggests that value creation in the agricultural sectors of D8 countries is still largely generated through resource-intensive production structures. The positive impact of GDP per capita further indicates that the scale effect of growth continues to dominate its technique and composition effects in these economies, where rising income remains closely associated with higher consumption, energy use, and demand for natural resources. By examining these relationships jointly for the D8 countries and employing the ecological footprint as a broad environmental indicator, the study extends previous evidence that has largely relied on single-country analyses or emissions-based measures.

However, the country-specific results show that this relationship does not operate in the same way across all countries. The fact that the food production index is negative in some countries and insignificant in others, and that agricultural value added and economic growth likewise produce different coefficients depending on the country, reveals that environmental pressure is not determined solely by the volume of production. Factors such as the technological structure of production, the energy mix, the level of agricultural modernisation, the efficiency of resource use, and institutional capacity appear to play a decisive role in this relationship. Therefore, rather than adopting a one-size-fits-all policy approach to explain environmental degradation in D8 countries, it would be more appropriate to develop a framework that takes country-specific structural differences into account. Although the common tendency at the panel level points to rising environmental pressure, the differences observed at the country level also suggest that more efficient and environmentally friendly forms of production are possible.

In light of these findings, the first policy priority should be to promote production models that reduce the environmental costs of increasing food production. In D8 countries, the goal of expanding food supply should not focus solely on raising output levels; it should also be supported by water-saving irrigation techniques, practices that preserve soil quality, methods that reduce dependence on chemical fertilisers, and production systems with high energy efficiency. Since increases in food production raise the ecological footprint, production policies need to be redesigned in a way that takes environmental impacts into account alongside productivity. In this context, it is important to encourage environmentally friendly agricultural technologies, steer producers toward sustainable practices, and establish support mechanisms that improve resource efficiency in agriculture.

Second, policies aimed at increasing agricultural value added should be designed with a focus on quality rather than quantity. The results of the study show that, in most cases, the economic value generated in the agricultural sector increases together with environmental pressure. Therefore, the objective of raising agricultural value added should be supported not by expansion based on greater input use, but by technology adoption, productivity gains, sustainable mechanisation, the use of renewable energy, and low-carbon production

chains. In particular, reducing dependence on fossil fuels in agriculture, expanding the use of biological and organic inputs, and evaluating waste within a circular economy framework can jointly promote both higher value added and environmental improvement. In other words, the success of agricultural development policies in D8 countries should be measured not only by the magnitude of value added, but also by the extent to which this value added is generated in an environmentally friendly manner.

Third, economic growth strategies need to be rebalanced in ways that reduce environmental pressure. The finding that increases in GDP per capita raise the ecological footprint indicates that growth in D8 countries still relies heavily on high energy use, natural resource consumption, and environmental costs. For this reason, it is not sufficient for growth policies to focus solely on output expansion. Stronger coordination should be established among industrial, energy, and agricultural policies, while clean production technologies, renewable energy investments, and energy efficiency practices should become integral components of growth strategies. In particular, in order to reduce the pressure of growth on the ecological footprint, public incentives should be directed toward environmentally friendly investments, environmental performance criteria should be integrated into investment policies, and a production structure aligned with sustainable development goals should be promoted.

Finally, the bidirectional causality relationships identified in the study indicate that environmental policies cannot be considered separately from economic and agricultural policies. Since increases in the ecological footprint may, over time, also affect production structures, agricultural productivity, and growth performance, environmental sustainability should be regarded not only as a protective objective but also as a fundamental condition for long-term economic resilience. For this reason, policymakers in D8 countries need to treat the environment not as a side effect of growth to be corrected later, but as an integral component of the development process itself. Overall, the study demonstrates that the production- and growth-centred structure in D8 countries places substantial pressure on the ecological footprint; however, this pressure can be reduced through more efficient, cleaner, and more sustainable policies. In this respect, the study provides important empirical evidence indicating that the relationship between agriculture, growth, and the environment in D8 countries needs to be reconsidered.

Limitations and Future Research

This study has several limitations that should be considered when interpreting the findings. First, the analysis is limited to the D8 countries and the 1990-2022 period; therefore, the results cannot be generalised automatically to other country groups or periods. Second, the ecological footprint is used as the sole indicator of environmental pressure and may not capture all dimensions of environmental degradation. Third, due to data availability constraints, the model focuses on food production, agricultural value added, and GDP per capita and does not explicitly incorporate other potentially relevant factors, such as renewable energy use, institutional quality, agricultural input intensity, technological innovation, trade openness, or environmental policy stringency. Future research may extend the analysis by incorporating these variables, applying alternative environmental indicators, and examining potential nonlinear or asymmetric relationships. Comparative analyses across different developing-country groups and country-specific time-series

studies may also provide more detailed evidence on the structural conditions under which food production and agricultural value creation can be decoupled from ecological pressure.

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