Black Sea Journal of Agriculture

doi: 10.47115/bsagriculture.1963380

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 9 - Issue 4 : 591-602 / July 2026

THE EFFECTS OF ENVIRONMENTAL TAXES, SUSTAINABLE DEVELOPMENT, AND ENVIRONMENTAL PROTECTION EXPENDITURES ON THE ECOLOGICAL FOOTPRINT: PANEL DATA EVIDENCE FROM EUROPEAN UNION COUNTRIES

Yasin SÖĞÜT[1]*, Ahmet BAĞCI[2], Mohammad QUDRATULLAH[1]

[1]Kastamonu University, Faculty of Political Sciences, Department of Economics, 37150, Kastamonu, Türkiye
[2]Ministry of Agriculture and Forestry, Deputy Minister, 06800, Ankara, Türkiye

Abstract: This study examines the effects of environmental taxes, sustainable development level, and environmental protection expenditures on the ecological footprint in European Union countries. The analysis is conducted using a balanced panel dataset covering 24 countries over the period 1995-2021. The ecological footprint is used as the dependent variable, while environmental taxes, the Sustainable Development Index, and environmental protection expenditures are included as explanatory variables. The empirical procedure includes descriptive statistics, the VIF test, cross-sectional dependence tests, the Fisher-ADF panel unit root test, panel model selection tests, heteroskedasticity and autocorrelation diagnostics, Park-Kmenta FGLS and Beck-Katz PCSE estimations, the Delta homogeneity test, and the Dumitrescu-Hurlin panel causality test. The findings reveal that environmental taxes have a positive and statistically significant effect on the ecological footprint. In contrast, the Sustainable Development Index and environmental protection expenditures have negative and statistically significant effects, indicating that improvements in sustainable development performance and environmental protection spending contribute to reducing ecological pressure. The causality results also suggest dynamic interactions between the ecological footprint and the explanatory variables. Based on these findings, environmental taxes should be designed not merely as revenue-generating instruments but as policy tools that effectively transform environmental behavior, while environmental protection expenditures should be allocated in a more targeted and performance-oriented manner.

Keywords: Ecological footprint, Environmental taxes, Environmental protection expenditures, Sustainable development, Panel data analysis

***Corresponding author:** Kastamonu University, Faculty of Political Sciences, Department of Economics, 37150, Kastamonu, Türkiye
E mail: yasinsogut34@gmail.com (Y. SÖĞÜT)
Yasin SÖĞÜT https://orcid.org/0000-0001-7274-0591
Ahmet BAĞCI https://orcid.org/0000-0002-2029-6641
Mohammad QUDRATULLAH https://orcid.org/0009-0002-8430-3967

Received: June 03, 2026
Accepted: June 20, 2026
Published: July 15, 2026

Cite as: Söğüt, Y., Bağcı, A., & Qudratullah, M. (2026). The effects of environmental taxes, sustainable development, and environmental protection expenditures on the ecological footprint: panel data evidence from European Union countries. *Black Sea Journal of Agriculture*, 9(4), 591-602.

1. Introduction

In environmental sustainability studies, the increasing negative impacts on the environment caused by economic factors such as growing population, rapid industrialization, and urbanization are cited as an important topic of discussion (Şenel and Kalaycı, 2025). On the other hand, the increasing energy demand and production volume accompanying industrialization led to environmental pollution and consequently an increase in the ecological footprint in the long term. However, the literature suggests that this increase in production positively impacts economic growth and supports raising the welfare level of society. Therefore, it is stated that countries, after reaching a certain income level, encourage the transition to new technologies for a clean environment, increase environmental awareness, and promote environmental improvement (Ünal and Aktuğ, 2022). Balanced and efficient use of natural resources is one of the important points that form the basis of environmental sustainability. Unconscious behaviors such as misuse of land and excessive water consumption damage water and soil quality, directly negatively affecting the quality of life of future generations (Çelikay, 2024). The sustainability of natural life is possible through the efficient use of essential natural resources, and reducing the resulting waste requires only a certain amount of water and land (Özsöy and Dinç, 2016).

According to the 2019 Eurostat report, European Union countries have made significant progress toward achieving the sustainable development goals. However, these countries are still grappling with issues such as deteriorating urban air quality, inadequate waste management practices, and increasingly declining residential areas (Bilgin and Yıldırım, 2023). Since the 1980s, European Union countries have begun developing various policies related to environmental protection and the sustainable use of natural resources. Consequently, serious regulations have been implemented across Europe to limit environmental threats and prevent the deterioration of environmental quality (Çokgezen, 2007). Because environmental problems have a global impact, the EU is taking serious steps in this area. Therefore, the EU's work on the environment demonstrates that the Union is a pioneer and takes on significant responsibilities in this field (Aydın and Çamur, 2017).

As a part of nature, humans meet their essential needs by utilizing natural resources to sustain their lives. However, the amount of waste generated because of the pressure exerted on nature and the consumption of natural resources is often overlooked. The total impact on the environment resulting from these production and consumption activities is expressed by the Ecological Footprint (Tosunoğlu, 2014). Developed by Wackrenagel and Reel (1996) to measure the damage humans inflict on nature, the Ecological Footprint concept is used as a prominent tool to measure the total productive area that individuals or societies can recover from nature by consuming resources and consequently producing waste (Kılınç, 2021). Various determinants exist for measuring environmental degradation. However, while carbon emissions were generally used in previous studies, the ecological footprint indicator has recently begun to be used instead due to its broader and more comprehensive nature. Factors such as agriculture, fishing, and forestry constitute the main elements of the ecological footprint (Kapçak, 2024).

Environmental protection expenditures refer to financial spending aimed at preventing or eliminating environmental pollution arising from production processes or the consumption of goods and services (Broniewicz, 2011). Implemented to support sustainable development policies, environmental protection expenditures represent the use of financial resources allocated to ensure the sustainability of natural resources and improve environmental quality. In this context, environmental protection expenditures encompass various practices financed by public and private institutions. Environmental protection expenditures include direct and indirect expenditures. Investments in renewable energy sources, securing forest areas, and projects preventing environmental degradation are considered direct expenditures, while financial measures aimed at reducing environmental pollution, such as incentives and taxation, are considered indirect expenditures (Söğüt, 2024). The main objectives of public environmental protection expenditures are to support the sustainable or efficient use of natural resources and to ensure environmental protection. Furthermore, these expenditures have both positive and negative effects on economic growth. On the one hand, in the short term, it positively affects economic recovery in terms of total government spending and causes growth, while on the other hand, it can negatively affect the economy by increasing the costs of some manufacturing sectors (Krajewski, 2016).

Sustainable development was first brought to the international agenda in 1987 by the United Nations World Commission on Environment and Development with the report known as the Brundtland Report, entitled "Our Common Future" (Berigel and Eroğlu, 2025). This concept, which has become widely used in recent years alongside the concept of the environment, is defined as meeting our present needs by efficiently using resources without harming the needs of future generations (Glasby, 2002). In today's world, the understanding of sustainability is central to almost all modern societies. Accordingly, states, social structures, and individuals are guided by the fundamental principles of sustainability, considering long-term impacts. The concept of sustainability is examined through three complementary fundamental dimensions: environmental, economic, and social. Considering these dimensions together distinguishes sustainability from classical environmental policies, aiming for long-term balance (Bozoğlu and Ciğerim, 2022). The concept of Sustainable Development does not only address economic growth but also includes environmental and social dimensions. Therefore, measuring development solely by gross domestic product is insufficient, and environmental sustainability indicators are needed to address this inadequacy. In this context, the ecological footprint plays an important role in evaluating sustainability by measuring the impacts of human activities on nature, the use of biologically productive areas, and the area needed to dispose of waste generated from consumption (Özsoy and Dinç, 2016). The Sustainable Development Goals, adopted by the United Nations General Assembly in 2015, aim to solve the major economic, social, and environmental problems facing humanity. The Sustainable Development Goals contain important objectives for the future of humanity. They cover many areas such as combating poverty, ensuring food security, equitable and inclusive education, gender equality, and employment (Coşkun, 2024). Among the Sustainable Development Goals, SDG-7 emphasizes the need for cheaper, cleaner, and more accessible energy. In this context, increasing energy efficiency and reducing carbon emissions by 2030 are among the main objectives (Zakari et al., 2022). Climate change is directly included as one of the fundamental issues within the scope of sustainable development goals due to its environmental, economic and social impacts. Worldwide, agriculture and land use account for approximately one-quarter of greenhouse gas emissions. Therefore, a significant reduction in greenhouse gas emissions in food systems is necessary to achieve the global warming target. In this context, achieving SDG-13 requires the development of climate change adaptive and emission-reducing policies in food systems (Campbell et al. 2018).

The main motivation of this study is to examine, within a holistic framework, the impact of fiscal and institutional policy instruments affecting environmental sustainability in European Union countries on the ecological footprint. In the literature, environmental taxes, environmental protection expenditures, and sustainable development indicators are mostly considered separately; however, the effects of these variables on the ecological footprint produce variable results depending on country groups, periods, and methodologies. Therefore, this study aims to comparatively reveal the role of environmental policy instruments in reducing ecological pressure by evaluating environmental taxes, the sustainable development index, and environmental protection expenditures within the same model. Given the leading position of European Union countries in environmental policies, the findings obtained from these countries provide a meaningful basis for evaluating both the effectiveness of environmental fiscal policies and the importance of policy design aligned with sustainable development goals. In this respect, the study aims to provide empirical evidence for ecological footprint-based environmental sustainability discussions and to contribute to the development of more targeted environmental policies for policymakers.

1.1. Literature Review

This section examines empirical studies investigating the relationship between ecological footprint and environmental taxes, environmental protection expenditures, and sustainable development indicators. To facilitate a more systematic evaluation of the literature, studies have been classified along three main axes. First, research examining the relationship between environmental taxes and ecological footprint; second, studies addressing the impact of environmental protection expenditures on environmental quality and ecological footprint; and finally, studies evaluating the relationship between sustainable development indicators and ecological footprint. This classification, consistent with the variable nature of the study, allows for a comparative assessment of the existing findings.

Table 1 examines studies on environmental taxes and ecological footprint. Therefore, it is understood that no common clear conclusion has been reached regarding the impact of environmental taxes on ecological footprint. Rafique et al. (2022), Javed et al. (2023), Chen et al. (2022), and Kartal (2024) reveal that environmental taxes have a direct or indirect mitigating effect on ecological footprint. In contrast, Bişgin (2025) and Teletar and Birinci (2022) state that there is no relationship between the two variables. The results indicate that the impact of environmental taxes can vary depending on country conditions or developed policies.

Table 2 presents studies on Environmental Protection Expenditures and Ecological Footprint. The literature shows differing results regarding the impact of environmental protection expenditures on ecological footprint. While Çağlar and Yavuz (2023) state that environmental protection expenditures do not affect environmental quality, Barrell et al. (2021) reveal that these expenditures effectively improve environmental quality. Some other studies (Murshed et al., 2021; Fang et al., 2023; Yılmaz, 2025) indicate that increased environmental expenditures have a negative impact on environmental effects.

Table 1. Environmental taxes and ecological footprint

Author	Country	Period	Method	Result
Rafique et al. (2022)	OECD	1996-2016	ARDL	There is a negative relationship between environmental taxes and ecological footprint in both the long and short term.
Kartal (2024)	EU5	1995-2021	Quantile	The study shows that environmental taxes have a non-linear effect on ecological footprint.
Bişgin (2025)	Türkiye	1994-2022	Fourier cointegration	Study have shown no correlation between ecological footprint and environmental taxes.
Javed et al. (2023)	Italy	1994-2019	DYARDL, ARDL	Environmental taxes, renewable energy, and technological innovation together have a mitigating effect on the ecological footprint.
Chen et al. (2022)	OECD and non-OECD	1990-2015	CS-ARDL	Environmental taxes indirectly reduce the ecological footprint.
Teletar and Birinci (2022)	Türkiye	1994-2019	Nonlinear time series analysis	Environmental taxes have no long-term impact on ecological footprint and CO_2 emissions.

Table 2. Environmental protection expenditures and ecological footprint

Author	Country	Period	Method	Result
Çağlar and Yavuz (2023)	EU Countries	1995-2018	CS-ARDL	Environmental protection expenditures have no impact on environmental quality.
Barrell et al. (2021)	EU Countries	2005-2015	data envelopment analysis methodology	Environmental expenditures are not effectively improving environmental quality.
Murshed et al. (2021)	South Asia Countries	1990-2014	CD, panel cointegration and regression analysis considering slope heterogeneity and structural breaks.	Environmental regulations reduce the ecological footprint in the long term.
Yılmaz (2025)	117 Countries	2000-2003	Panel data set	As environmental spending increases, greenhouse gas emissions decrease.
Fang et al. (2023)	China	2010-2019	Spatial Durbin Model (SDM)	Environmental expenditures reduce environmental impacts.

Table 3. Sustainable development index and ecological footprint

Author	Country	Period	Method	Result
Li et al. (2022)	China	2006-2018	Panel data analysis	It varies by region
Shut'ko et al. (2020)	Kuzbass (Russia)	2013-2017	Decoupling analysis	As sustainable development increases, the ecological footprint decreases
Ahmed et al. (2022)	G7 Countries	1985-2017	Granger causality test	As SDG increases, the ecological footprint decreases
Moran et al. (2008)	Multinational	1995-2003	Inter-country comparative analysis	Increasing SDG does not always reduce the ecological footprint

Table 3 discusses studies on the relationship between the Sustainable Development Index and the Ecological Footprint. The studies generally suggest that the Sustainable Development Index has a mitigating effect on the ecological footprint. Shut'ko et al. (2020) and Ahmed et al. (2022) stated that an increase in the sustainability level of countries reduces environmental degradation. Li et al. (2022) explained that this can vary from region to region. Moran et al. (2008) stated that an increase in sustainable development does not always have a mitigating effect on the ecological footprint. Therefore, these differing results indicate that sustainable development can vary depending on the policies implemented by countries or the specific conditions of those countries.

A careful examination of the existing literature reveals not only mixed empirical findings but also several important research gaps. First, most studies investigate environmental taxes, environmental protection expenditures, or sustainable development indicators separately, implicitly assuming that these policy instruments operate independently. However, from a theoretical perspective, environmental sustainability outcomes are shaped by the interaction of fiscal instruments, public environmental investments, and broader sustainable development policies. Therefore, analyzing these factors in isolation may provide only a partial understanding of the determinants of ecological pressure. Second, empirical studies simultaneously incorporating environmental taxes, environmental protection expenditures, and sustainable development performance within a unified analytical framework remain highly limited. As a result, the relative effectiveness of these policy instruments in reducing ecological footprint is still not fully understood. Third, despite the European Union being one of the world's leading regions in implementing environmental taxation, sustainability strategies, and environmental protection programs, evidence evaluating the combined effectiveness of these instruments remains scarce. This study addresses these theoretical, empirical, and contextual gaps by examining the impacts of environmental taxes, environmental protection expenditures, and the Sustainable Development Index on ecological footprint within a single model for European Union countries. In doing so, it provides a more comprehensive framework for understanding how different environmental policy instruments jointly influence ecological sustainability outcomes.

2. Materials and Methods

2.1. Data Set and Variables

The dataset used in this study was designed to allow for the assessment of the relationship between ecological footprint and environmental policy instruments and the level of sustainable development. The selection of ecological footprint as the dependent variable offers the opportunity to evaluate environmental degradation not only through carbon emissions but also within a broader framework encompassing the use of natural resources and the pressure on biological capacity. The selection of environmental taxes, the sustainable development index, and environmental protection expenditures as explanatory variables reflects the study's aim to analyze environmental policy capacity, sustainable development performance, and publicly funded environmental protection efforts together. Through these variables, the study aims to comparatively examine the impact of environmental fiscal instruments, the level of development, and environmentally focused expenditures on the ecological footprint.The sample covers 24 European Union member states over the period 1995-2021. Although the European Union currently consists of 27 member countries, Czechia, Estonia, and Greece were excluded from the analysis due to incomplete observations for one or more variables throughout the study period. To ensure consistency and comparability across countries and years, a balanced panel dataset was employed. The study period was determined by the availability of continuous and comparable data for all variables, particularly the Sustainable Development Index and Environmental Protection Expenditures. The year 1995 was selected as the starting point because it represents the earliest year for which the required data series could be jointly obtained for the majority of countries, while 2021 was chosen as the endpoint due to data availability constraints at the time of data collection. The selected period also enables the analysis to capture the long-term evolution of environmental taxation policies, environmental protection expenditures, and sustainable development performance within the European Union.

2.2. Model

This study analyzes the impact of environmental taxes, sustainable development levels, and environmental protection expenditures on ecological footprint using a panel data method. The panel data approach allows for the examination of differences between countries and changes over time within the same model by considering both cross-sectional and time dimensions. The basic model estimated in this study is as given in Equation 1:

$$EFP_{it}=\alpha_i+\beta_1 ET_{it}+\beta_2 SDI_{it}+\beta_3 EPE_{it}+\varepsilon_{it} \quad (1)$$

In the model, EFP represents the ecological footprint, ET represents environmental taxes, SDI represents the sustainable development index, and EPE represents environmental protection expenditures. i represents the cross-sectional unit, t the time dimension, αi the unit effects, and ε_{it} the error term.

2.3. Preliminary Analyses

In the empirical analysis process, descriptive statistics were first examined to reveal the basic distribution characteristics of the variables. Then, the VIF test (Işık Taçyıldız, 2025) was applied to determine whether there was a multicollinearity problem among the independent variables. Low VIF values indicate that there is no multicollinearity among the independent variables that would distort the estimation results.

2.4. Cross-Sectional Dependence and Unit Root Test

In panel data analysis, the presence of cross-sectional dependence indicates that countries are affected by common shocks or reciprocal interactions. Therefore, in this study, cross-sectional dependence was tested using LM, adjusted LM, LM CD, and variable-based Pesaran et al. (2008) CD tests. Considering cross-sectional dependence is important for determining the unit root and estimation methods to be used.

The stationarity properties of the series were analyzed using the Fisher-ADF panel unit root test. In this test, the null hypothesis is that the series contains a unit root (Lee and Chang, 2008). Thus, it was determined whether the variables were stationary at their level values, and the aim was to reduce the risk of spurious regression in the estimation process.

Table 4. Variable definitions and data sources

Variables	Symbol	Description / Measurement	Expected Impact	Data Source
Ecological Footprint	EFP	Ecological footprint per capita in global hectares	Dependent Variable	Global Footprint Network
Environmental Taxes	ET	Environmental taxes / Share of GDP	±	OECD
Sustainable Development Index	SDI	Index indicating the level of sustainable development	–	SDI Database
Environmental Protection Expenditures	EPE	Environmental protection expenditures / Share of GDP	–	IMF

2.5. Panel Model Selection

To determine the appropriate structure of the panel model, F-tests and LR-tests were applied for unit and time effects. These tests indicate whether panel models that consider unit and/or time effects are necessary instead of the classical pooled model. The Hausman test was used to choose between fixed effects and random effects models. In the Hausman test, the null hypothesis is that the random effects model is appropriate (Schreiber, 2008).

2.6. Diagnostic Tests and Prediction Methods

To identify problems related to the error structure of the model, heteroskedasticity and autocorrelation tests were applied. Since the presence of problems such as heteroskedasticity, autocorrelation, and cross-sectional dependence can reduce the reliability of standard errors obtained from classical estimators, robust estimation methods were used in the study. In this context, Park-Kmenta FGLS and Beck-Katz PCSE estimators were used. The Park-Kmenta FGLS method takes into account heteroskedasticity, cross-sectional correlation, and panel-specific AR(1) autocorrelation structure. The Beck-Katz PCSE estimator, on the other hand, produces panel-corrected standard errors in the presence of inter-panel correlation and autocorrelation (Vancauteren and Weiserbs, 2011).

2.7. Homogeneity and Causality Analysis

To determine whether the slope coefficients are homogeneous among the cross-sectional units, the Delta homogeneity test was applied. This test is important for evaluating whether the relationships between variables differ among the countries comprising the panel (Qingxiang et al., 2008). Finally, to examine the dynamic directional relationships between the variables, the Dumitrescu-Hurlin panel Granger causality test was used. This test is preferred in panel data studies because it allows for heterogeneous causal relationships among the units comprising the panel (Magoti et al., 2020).

3. Results

This section presents preliminary analyses of the variables used in the study, cross-sectional dependence and unit root tests, panel model selection tests, diagnostic tests, estimation results, homogeneity, and causality findings, respectively.

3.1. Preliminary Analysis Results

Table 5 presents descriptive statistics for the variables. The fact that the number of observations for all variables is 648 indicates a balanced structure in the panel dataset. The mean value of the EFP variable is 5.638142, while the minimum and maximum values are 2.452750 and 17.94167, respectively. This indicates that there are significant differences in ecological footprint between countries and periods in the sample. The mean value of the ET variable is 2.695377, and its standard deviation is 0.729756. The fact that the SDI variable ranges between 0.103 and 0.820 reveals that the level of sustainable development varies within the sample. The mean value of the EPE variable is 0.694783, showing that environmental protection expenditures differ across countries and years.

Table 6 presents the VIF results calculated to evaluate the multicollinearity problem among the independent variables. According to the findings, the VIF value of the EPE and SDI variables is 1.01, and the VIF value of the ET variable is 1.00. The average VIF value of 1.01 indicates that there is no multicollinearity problem among the independent variables in the model. This result suggests that the coefficient estimates in the regression analysis are not severely distorted due to multicollinearity.

Table 5. Descriptive statistics

Variable	Observation	Mean	Standart Deviation	Minimum	Maximum
EFP	648	5.638142	2.444588	2.452750	17.94167
ET	648	2.695377	0.729756	0.814310	5.356861
SDI	648	0.574597	0.184262	0.103000	0.820000
EPE	648	0.694783	0.362709	0.030294	1.914624

Table 6. Results of the multicollinearity test

Variable	VIF	1/VIF
EPE	1.01	0.987410
SDI	1.01	0.990502
ET	1.00	0.996375
Mean VIF	1.01	

3.2. Cross-Sectional Dependence and Unit Root Test Results

Table 7 presents the results of the cross-sectional dependence tests. First, the LM, corrected LM, and LMCD tests, applied to the error terms, yielded test statistics of 546.900, 27.760, and 13.960, respectively. All p-values were found to be statistically significant at the 0.01 significance level. This finding indicates that the null hypothesis of cross-sectional independence across the model is rejected, and that cross-sectional dependence exists among the units comprising the panel.

Variable-based Pesaran CD test results similarly indicate cross-sectional dependence. CD test statistics for the variables EFP, ET, SDI, and EPE were calculated as 18.002, 7.165, 32.779, and 4.239, respectively; p-values were found to be 0.000 for all variables.

Therefore, the null hypothesis of cross-sectional independence is rejected for each variable. This result shows that there is interdependence among the countries in the panel due to common shocks, economic-political interactions, or similarities in environmental policies. Therefore, the study needs to use second-generation panel data methods that take cross-sectional dependence into account.

The Fisher-ADF panel unit root test results indicate that the variables are generally stationary at their level values. Since the null hypothesis of the test is the presence of a unit root, the significant test statistics indicate that the series are stationary. Although some statistics yielded different results for the SDI variable, the majority of the findings support level stationarity. Therefore, it was deemed appropriate to use the variables at their level values in the analysis.

Table 7. Cross-sectional dependence test results

Test / Variable	Test Stat	P-value	Mean joint T	Mean ρ	Mean |ρ|
LM	546.900	0.000	—	—	—
LM adj*	27.760	0.000	—	—	—
LM CD*	13.960	0.000	—	—	—
EFP	18.002	0.000	27.00	0.21	0.42
ET	7.165	0.000	27.00	0.08	0.38
SDI	32.779	0.000	27.00	0.38	0.47
EPE	4.239	0.000	27.00	0.05	0.38

Note: In LM, LM adj*, and LM CD* tests, the null hypothesis is that there is no cross-sectional dependence. In variable-based CD tests, the null hypothesis is cross-sectional independence. * Indicates a two-sided test result.

Table 8. Fisher-ADF panel unit root test results

Variable	Inverse chi-squared P	Inverse normal Z	Inverse logit t L*	Modified inv. chi-squared Pm	Result
EFP	67.3290**	-1.6932**	-1.7919**	1.9728**	I(0)
ET	83.8780***	-2.7043***	-2.8549***	3.6618***	I(0)
SDI	89.8766***	-0.4030	-1.5749*	4.2740***	I(0)*
EPE	165.2419***	-5.3563***	-8.0474***	11.9660***	I(0)

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

3.3. Panel Model Selection and Diagnostic Test Results

Table 9 presents the results of the F, LR, and Hausman tests regarding panel model selection. The F test results show that both unit effects and time effects are statistically significant. Similarly, the LR test results support the existence of both unit and time effects. These findings indicate that a model considering the panel data structure should be used instead of the classical pooled model. Since the null hypothesis could not be rejected in the Hausman test result, the test finding points to the suitability of the random effects model. However, due to the positive descriptiveness warning in the Hausman test output, the final model choice was evaluated together with other diagnostic tests.

Table 10 presents the diagnostic test results regarding the model's error structure. All p-values being 0.0000 in the heteroskedasticity tests indicates that the constant variance assumption is rejected and that the model has a heteroskedasticity problem. Furthermore, the Modified Bhargava et al. Durbin-Watson and Baltagi-Wu LBI statistics remaining well below 2 suggest the presence of positive autocorrelation in the error terms. These findings necessitate the use of estimation methods resistant to heteroskedasticity and autocorrelation in the final estimation phase.

3.4. Estimation Results

Table 11 presents the Park-Kmenta FGLS estimation results. According to the estimation results, the effect of the ET variable on EFP is positive and statistically significant at the 1% level. In contrast, the effects of the SDI and EPE variables on EFP were found to be negative and statistically significant at the 1% level. These findings show that the independent variables have significant effects on EFP, even when considering heteroskedasticity, cross-sectional correlation and panel-specific AR(1) autocorrelation structure.

Table 12 presents the Beck-Katz PCSE estimation results. According to the findings, the effect of the ET variable on EFP is positive and statistically significant. In contrast, the effects of the SDI and EPE variables on EFP were found to be negative and statistically significant. These results show that the independent variables have significant effects on EFP, even when considering inter-panel correlation and panel-specific AR(1) autocorrelation.

Table 9. Test results regarding panel model selection

Test	Impact/Model Preference	Basic Hypothesis	Test Stat	P-value	Decision
F Test	Unit impact / Crossid	There are no unit effects.	F(23, 621) = 152.25	0.0000	H_0 reject
F Testi	Time impact / Year	There are no time effects.	F(26, 618) = 1.83	0.0075	H_0 reject
LR Testi	Unit impact / Crossid	There are no unit effects.	chibar^2(01) = 1070.19	0.000	H_0 reject
LR Testi	Time impact / Year	There are no time effects.	chibar^2(01) = 4.51	0.017	H_0 reject
Hausman Testi	Fixed / Random Effect Preference	The random effects model is suitable.	$\chi^2(3) = 0.09$	0.9933	H_0 is not reject

Table 10. Results of heteroskedasticity and autocorrelation tests

Test	Test Stat	df	p-value	Result
W0	10.5646776	df(23, 624)	0.0000	There is heteroskedasticity
W50	8.6637627	df(23, 624)	0.0000	There is heteroskedasticity
W10	10.3339813	df(23, 624)	0.0000	There is heteroskedasticity
Modified Bhargava et al. Durbin-Watson	0.528105	-	-	There is autocorrelation
Baltagi-Wu LBI	0.67181072	-	-	There is autocorrelation

Table 11. Park-Kmenta FGLS estimation results

Variable	Coefficient	Std. Error	z-stat
ET	0.0745695***	0.0112377	6.64
SDI	-5.008205***	0.1342451	-37.31
EPE	-0.2503959***	0.0214120	-11.69
Sabit	8.181286***	0.1139003	71.83

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

Table 12. Beck-Katz PCSE forecast results

Variable	Coefficient	Panel Corrected Std. Error	z-stat
ET	0.1695782**	0.077510	2.19
SDI	-5.328883***	0.667499	-7.98
EPE	-0.3081812**	0.1360394	-2.27
Sabit	8.135726***	0.559235	14.55

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

Table 13. Homogeneity test results

Test	Test Stat	p-value	Result
Delta	20.963	0.000	Homogeneity is rejected.
Corrected Delta	23.223	0.000	Homogeneity is rejected.

3.5. Results on Homogeneity and Causality

Table 13 presents the results of the homogeneity test. The p-values of 0.000 for both the Delta and corrected Delta test statistics indicate that the null hypothesis, which states that the slope coefficients are homogeneous, is rejected. This result suggests that the coefficients in the model may differ among the units comprising the panel. Therefore, it should be considered that the relationships between variables may show heterogeneity across countries.

Table 14 presents the results of the Dumitrescu-Hurlin panel Granger causality test. The findings indicate a bidirectional causal relationship between ET and EFP, and between SDI and EFP. Regarding the relationship between EPE and EFP, a strong causality from EFP to EPE was detected, while the relationship from EPE to EFP was supported at the 10% significance level. Overall, the results reveal a dynamic interaction between ecological footprint and the explanatory variables included in the model.

4. Discussion

The findings show that environmental taxes, the level of sustainable development, and environmental protection expenditures have statistically significant effects on the ecological footprint. The consistency of the signs and significance levels of the variables in both the Park-Kmenta FGLS and Beck-Katz PCSE estimation results indicates that the findings remain valid under robust estimation methods. The positive effect of environmental taxes on the ecological footprint suggests that these taxes, in their current form, do not function as expected in reducing environmental pressure.

This result shows that the mere implementation of environmental taxes is insufficient; the tax design, the way tax revenues are used, and the capacity to transform environmental behaviors are crucial. In this respect, the finding differs from studies such as Rafique et al. (2022), Javed et al. (2023), Chen et al. (2022), and Kartal (2024), which indicate that environmental taxes have mitigating effects on the ecological footprint. In contrast, it offers a framework more consistent with the findings highlighted by Bişgin (2025) and Telatar and Birinci (2022), which show that the impact of environmental taxes can vary depending on country conditions and policy design.

Table 14. Dumitrescu-Hurlin panel causality test results

Causality Aspect	Lag	W-bar	Z-bar	P-value	Z-bar tilde	P-value	Result
ET → EFP	7	14.7913	10.2012	0.0000	0.7762	0.4376	It exists according to the Z-bar.
EFP → ET	7	17.3292	13.5241	0.0000	1.4067	0.1595	It exists according to the Z-bar.
SDI → EFP	7	17.3780	13.5879	0.0000	1.4188	0.1560	It exists according to the Z-bar.
EFP → SDI	7	14.4161	9.7099	0.0000	0.6830	0.4946	It exists according to the Z-bar.
EPE → EFP	1	1.4902	1.6980	0.0895	1.1609	0.2457	According to Z-bar, it's at a level of 10%.
EFP → EPE	7	10.6604	4.7926	0.0000	-0.2500	0.8026	It exists according to the Z-bar.

The negative impact of the sustainable development index on the ecological footprint indicates that improvements in sustainable development performance work to reduce environmental pressure. This result is consistent with Shut'ko et al. (2020) and Ahmed et al. (2022), who stated that an increase in the level of sustainable development can limit environmental degradation. However, considering the country and regional differences highlighted by Moran et al. (2008) and Li et al. (2022), it can be said that the effect of sustainable development in reducing the ecological footprint is not an automatic process; it is shaped by economic, institutional, and environmental policy capacity. The fact that environmental protection expenditures have a negative and significant coefficient reveals that these expenditures function as a tool for reducing the ecological footprint. This finding is consistent with Murshed et al. (2021), Fang et al. (2023), and Yılmaz (2025), who showed that environmental expenditures and regulations can reduce environmental pressure. This differs from the studies by Çağlar and Yavuz (2023) and Barrell et al. (2021), which indicate that environmental protection expenditures have limited or no effect on environmental quality. Overall, the findings show that in European Union countries, the key to reducing the ecological footprint is not only the availability of financial instruments, but also whether these instruments are designed in a way that is consistent with sustainable development goals, effective, and focused on environmental outcomes.

5. Conclusion

This study examines the impact of environmental taxes, sustainable development level, and environmental protection expenditures on ecological footprint in a sample of European Union countries for the period 1995-2021 using panel data. Ecological footprint was used as the dependent variable, while environmental taxes, the sustainable development index, and environmental protection expenditures were used as explanatory variables. In the empirical analysis process, descriptive statistics and VIF results for the variables were evaluated first, followed by cross-sectional dependence, Fisher-ADF panel unit root test, panel model selection tests, heteroskedasticity, and autocorrelation tests. In the final estimation phase, Park-Kmenta FGLS and Beck-Katz PCSE estimators were used; furthermore, the analysis was extended with the Delta homogeneity test and the Dumitrescu-Hurlin panel causality test.

The findings show that environmental taxes, the level of sustainable development, and environmental protection expenditures have statistically significant effects on the ecological footprint. The Park-Kmenta FGLS and Beck-Katz PCSE estimation results reveal that environmental taxes have a positive and significant effect on the ecological footprint. This finding indicates that environmental taxes, in their current form, are not sufficiently effective in reducing environmental pressure; on the contrary, they may not produce the expected environmental impact depending on their implementation, scope, or the use of the revenues. In contrast, the negative and significant coefficients for the sustainable development index and environmental protection expenditures show that improvements in sustainable development performance and environmental protection expenditures have a mitigating effect on the ecological footprint. The causality test results reveal dynamic relationships between the ecological footprint and environmental taxes, the level of sustainable development, and environmental protection expenditures. In light of these findings, environmental taxes in European Union countries need to be redesigned not only to generate public revenue but also to transform environmental behavior. Increasing tax rates alone may not be sufficient. The key is to structure the tax system in a way that deters polluting activities, encourages clean production technologies, and guides companies towards low-carbon production processes. Furthermore, instead of the revenue from environmental taxes being lost within the general budget, directing it towards areas such as environmental protection investments, renewable energy projects, energy efficiency practices, and green technology support will increase environmental effectiveness.

Considering the ecological footprint reduction effect of environmental protection expenditures, both the quantity and the quality and scope of these expenditures are important. Public resources should be directed particularly to areas that produce direct environmental results, such as waste management, water and soil conservation, biodiversity conservation, clean energy infrastructure, and environmental restoration projects. To increase the effectiveness of expenditures, performance-based monitoring mechanisms should be developed, and the tangible impacts of expenditures on the ecological footprint should be regularly assessed. The ecological footprint reduction effect of the sustainable development index shows that environmental policies should not be limited solely to fiscal instruments. Economic growth, social welfare, and environmental protection goals should be considered together; sustainable development policies should be designed in an integrated manner with energy, industry, transport, agriculture, and urbanization policies. In this context, the green transition process in EU countries should be considered not only as an environmental policy but also as a development policy.

In conclusion, the study shows that environmental protection expenditures and sustainable development performance play a significant role in reducing the ecological footprint in European Union countries, while the environmental effectiveness of environmental taxes depends on the tax design and revenue utilization method. Therefore, it is important for policymakers to restructure environmental fiscal instruments in a way that is consistent with sustainable development goals and results oriented. Further studies conducting more detailed analyses considering different country groups, sectoral indicators, or sub-components of environmental taxes could provide more comprehensive evidence on the effectiveness of environmental policy instruments.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	Y.S.	A.B.	M.Q.
C	34	33	33
D	34	33	33
S	34	33	33
DCP	60		40
DAI	100		
L		50	50
W	33	34	33
CR	33	34	33
SR	100		

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

References

Ahmed, Z., Ahmad, M., Rjoub, H., Kalugina, O. A., & Hussain, N. (2022). Economic growth, renewable energy consumption, and ecological footprint: Exploring the role of environmental regulations and democracy in sustainable development. *Sustainable Development, 30*(4), 595-605. https://doi.org/10.1002/sd.2251

Aydın, A. H., & Çamur, Ö. (2017). Avrupa Birliği çevre politikaları ve çevre eylem programları üzerine bir inceleme. *Bingöl Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 7*(13), 21-44.

Barrell, A., Dobrzanski, P., Bobowski, S., Siuda, K., & Chmielowiec, S. (2021). Efficiency of environmental protection expenditures in EU countries. *Energies, 14*(24), 8443. https://doi.org/10.3390/en14248443

Berigel, S., & Eroğlu, İ. (2025). N-11 ülkelerinde ekonomik karmaşıklık ve bm sürdürülebilir kalkınma endeksi ilişkisi: Dumıtrescu-Hurlın panel nedensellik analizi. *Uluslararası Sosyal ve Ekonomik Çalışmalar Dergisi, 6*(1), 40-56. https://doi.org/10.62001/gsijses.1624922

Bilgin, E., & Yildirim, Z. (2023). Çevre vergisi ile ekolojik ayak izi arasındaki ilişki: Türkiye ve seçili AB üye ülkeleri üzerine ampirik bir inceleme. *Maliye Araştırmaları-6, 2023*, 71.

Bişgin, A. (2025). Türkiye'de Çevre Vergileri Ekolojik Ayak İzini Azaltmada Etkin mi? Fourier Yaklaşımı. *MANAS Sosyal Araştırmalar Dergisi, 14*(4), 1557-1569. https://doi.org/10.33206/mjss.1504481

Bozoğlu, O., & Ciğerim, E. (2022). Sürdürülebilirlik, sürdürülebilir kalkinma ve sürdürülebilir üniversiteler. *Socrates Journal of Interdisciplinary Social Researches, 8*(18), 146-158. https://doi.org/10.51293/socrates.273

Broniewicz, E. (2011). Environmental protection expenditure in European Union. *Environmental Management in Practice, 21*(36), 2-28.

Çağlar, A. E., & Yavuz, E. (2023). The role of environmental protection expenditures and renewable energy consumption in the context of ecological challenges: Insights from the European Union with the novel panel econometric approach. *Journal of Environmental Management, 331*, 117317. https://doi.org/10.1016/j.jenvman.2023.117317

Campbell, B. M., Hansen, J., Rioux, J., Stirling, C. M., & Twomlow, S. (2018). Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems. *Current Opinion in Environmental Sustainability, 34*, 13-20. https://doi.org/10.1016/j.cosust.2018.06.005

Çelikay, F. (2024). *Doğal kaynaklarin verimli kullanimi ve gelecek nesiller için sürdürülebilir bir dünya inşasi üzerine*. Eskişehir Osmangazi Üniversitesi, Tasarruf Ekonomisi ve Sürdürülebilirlik Uygulama ve Araştırma Merkezi.

Chen, M., Jiandong, W., & Saleem, H. (2022). The role of environmental taxes and stringent environmental policies in attaining the environmental quality: Evidence from OECD and non-OECD countries. *Frontiers in Environmental Science, 10*, 972354. https://doi.org/10.3389/fenvs.2022.972354

Çokgezen, J. (2007). Avrupa Birliği çevre politikası ve Türkiye. *Marmara Üniversitesi İktisadi ve İdari Bilimler Dergisi, 23*(2), 91-115. https://izlik.org/JA82MC92DD

Coşkun, S. (2024). Sürdürülebilir kalkınma hedefleri, neoliberalizm ve çalışma hayatı: Türkiye, OECD ülkeleri ve dünya üzerine bir inceleme. *Akademik İncelemeler Dergisi, 19*(2), 289-312. https://doi.org/10.17550/akademikincelemeler.1400985

Fang, G., Yang, K., Chen, G., Ren, X., & Taghizadeh-Hesary, F. (2023). Exploring the effectiveness of fiscal decentralization in environmental expenditure based on the CO2 ecological footprint in urban China. *Humanities and Social Sciences Communications, 10*(1), 1-14. https://doi.org/10.1057/s41599-023-02227-3

Glasby, G. P. (2002). Sustainable development: The need for a new paradigm. *Environment, Development and Sustainability, 4*(4), 333-345. https://doi.org/10.1023/A:1024138010770

Global Footprint Network. (2026). *Global Footprint Network data platform*. Retrieved May 4, 2026, from https://data.footprintnetwork.org/

International Monetary Fund. (2026). *Climate data*. Retrieved May 4, 2026, from https://climatedata.imf.org/datasets/d22a6decd9b147fd904 0f793082b219b_0/explore

Işık Taçyıldız, S. Ş. (2025). Prediction of albumen height based on egg quality traitsby principal components regression. *Black Sea Journal of Statistics, 1*(2), 41–46. https://doi.org/10.5281/zenodo.18234774

Javed, A., Rapposelli, A., Khan, F., & Javed, A. (2023). The impact of green technology innovation, environmental taxes, and renewable energy consumption on ecological footprint in Italy: Fresh evidence from novel dynamic ARDL simulations. *Technological Forecasting and Social Change, 191*, 122534. https://doi.org/10.1016/j.techfore.2023.122534

Kapçak, S. (2024). Döngüsel ekonomi bileşenlerinin ekolojik ayak izi üzerindeki etkisi: Panel veri analizi. *Uluslararası Ekonomi İşletme ve Politika Dergisi, 8*(1), 124-138. https://doi.org/10.29216/ueip.1425770

Kartal, M. T. (2024). Quantile-based effect of energy, transport, and total environmental tax on ecological footprint in EU5 countries. *Environmental Science and Pollution Research, 31*(13), 20033-20047. https://doi.org/10.1007/s11356-024-32214-3

Kılınç, E. C. (2021). Ekolojik ayak izi-enerji ar-ge harcamaları ilişkisi: OECD ülkeleri örneği. *Ömer Halisdemir Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 14*(2), 527-541. https://doi.org/10.25287/ohuiibf.723064

Krajewski, P. (2016). The impact of public environmental protection expenditure on economic growth. *Problemy Ekorozwoju, 11*(2), 99-104.

Lee, C. C., & Chang, C. P. (2008). New evidence on the convergence of per capita carbon dioxide emissions from panel seemingly unrelated regressions augmented Dickey–Fuller tests. *Energy, 33*(9), 1468-1475. https://doi.org/10.1016/j.energy.2008.05.002

Li, X., Xiao, L., Tian, C., Zhu, B., & Chevallier, J. (2022). Impacts of the ecological footprint on sustainable development: Evidence from China. *Journal of Cleaner Production, 352*, 131472. https://doi.org/10.1016/j.jclepro.2022.131472

Magoti, E., Mabula, S., & Ngong'ho, S. B. (2020). Triple deficit hypothesis: A panel ARDL and Dumitrescu-Hurlin panel causality for East African countries. *African Journal of Economic Review, 8*(1), 144-161.

Moran, D. D., Wackernagel, M., Kitzes, J. A., Goldfinger, S. H., & Boutaud, A. (2008). Measuring sustainable development—Nation by nation. *Ecological Economics, 64*(3), 470-474. https://doi.org/10.1016/j.ecolecon.2007.08.017

Murshed, M., Rahman, M. A., Alam, M. S., Ahmad, P., & Dagar, V. (2021). The nexus between environmental regulations, economic growth, and environmental sustainability: linking environmental patents to ecological footprint reduction in South Asia. *Environmental Science and Pollution Research, 28*(36), 49967-49988. https://doi.org/10.1007/s11356-021-13381-z

OECD. (2026). *Environmental tax*. Retrieved May 5, 2026, from https://www.oecd.org/en/data/indicators/environmental-tax.html

Özsoy, C. E., & Dinç, A. (2016). Sürdürülebilir kalkınma ve ekolojik ayak izi. *Finans Politik ve Ekonomik Yorumlar, 619*, 35-55. https://izlik.org/JA67HR53DH

Pesaran, M.H., A. Ullah and T. Yamagata (2008). A bias adjusted LM test of error cross section independence. *The Econometrics Journal, 11*(1), 105-127. https://doi.org/10.1111/j.1368-423X.2007.00227.x

Qingxiang, L., Zhihong, J., Qun, H., & Yong, Y. (2008). The experimental detecting and adjusting of the precipitation data homogeneity in the Yangtze Delta. *Journal of Applied Meteorological Science, 19*(2), 219-226.

Rafique, M. Z., Fareed, Z., Ferraz, D., Ikram, M., & Huang, S. (2022). Exploring the heterogenous impacts of environmental taxes on environmental footprints: An empirical assessment from developed economies. *Energy, 238*, 121753. https://doi.org/10.1016/j.energy.2021.121753

Schreiber, S. (2008). The Hausman test statistic can be negative even asymptotically. *Journal of Economics and Statistics, 228*(4), 394-405.

Şenel, K., & Kalaycı, C. (2025). Türkiye'de çevre vergileri, ekonomik büyüme, sürdürülebilir kalkınma ile ekolojik ayak izi ilişkisi: ARDL yaklaşımı. Cumhuriyet Üniversitesi İktisadi ve İdari Bilimler Dergisi, 26(3), 584-600. https://doi.org/10.37880/cumuiibf.1673259

Shut'ko, L., Samorodova, L., & Ivanov, A. (2020). Ecological footprint and decoupling in the sustainable development of a region. In *E3S Web of Conferences* (Vol. 174, p. 04058).

Söğüt, Y. (2024). *Yeşil bütçelemeye yönelik çevresel araçların yük kapasitesi eğrisi çerçevesinde incelenmesi: Avrupa Birliği ülkelerinden kanıtlar = Examining environmental instruments for green budgeting within the framework of the load capacity curve: Evidence from European Union countries* (Unpublished doctoral dissertation). Sakarya Üniversitesi, Sosyal Bilimler Enstitüsü, Maliye Anabilim Dalı.

Sustainable Development Index. (2026). *Sustainable Development Index*. Retrieved May 5, 2026, from https://www.sustainabledevelopmentindex.org/

Telatar, O. M., & Birinci, N. (2022). The effects of environmental tax on Ecological Footprint and Carbon dioxide emissions: a nonlinear cointegration analysis on Turkey. *Environmental Science and Pollution Research, 29*(29), 44335-44347. https://doi.org/10.1007/s11356-022-18740-y

Tosunoğlu, B. (2014). Sürdürülebilir küresel refah göstergesi olarak ekolojik ayak izi. *Hak İş Uluslararası Emek ve Toplum Dergisi, 3*(5), 132-149. https://izlik.org/JA74UP96WG

Ünal, H., & Aktuğ, M. (2022). Çevresel Kuznets eğrisi hipotezi kapsamında Türkiye'de çevre kalitesinin değerlendirilmesi. *İnsan ve Toplum, 12*(1), 113-136. https://izlik.org/JA86JR79GM

Vancauteren, M., & Weiserbs, D. (2011). Intra-European trade of manufacturing goods: An extension of the gravity model. *International Econometric Review, 3*(1), 1-24. https://izlik.org/JA56YL92GD

Yılmaz, S. (2025). The impact of environmental protection expenditures on reducing greenhouse gas emissions. Sustainability, 17(7), 3192. https://doi.org/10.3390/su17073192

Zakari, A., Khan, I., Tan, D., Alvarado, R., & Dagar, V. (2022). Energy efficiency and sustainable development goals (SDGs). *Energy, 239*, 122365. https://doi.org/10.1016/j.energy.2021.122365