Bölüm 7

Determinants of the Ecological Footprint and the Pollution Haven Hypothesis: A Nonlinear Time Series Analysis for Türkiye

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Abstract

This study was conducted to identify the key factors influencing the ecological footprint (environmental degradation) in Türkiye and to test the validity of the Pollution Haven Hypothesis. The analysis employs annual data for the period 1970-2024, examining the effects of foreign direct investment (FDI), economic growth, and energy consumption on environmental pressure using nonlinear time-series methods.

The results first show that the series has nonlinear properties. The nonlinear unit root and cointegration tests devised by Hepsağ (2021a, 2021b) were used. The results show that all variables are integrated in the same order, I(1), and that there is a symmetric but nonlinear long-run connection between them. The results indicate that the Pollution Haven Hypothesis is valid for Türkiye. In other words, Türkiye appears to be an attractive destination for polluting foreign investments due to its relatively lenient environmental standards. This situation is inconsistent with the country's sustainable development objectives.

1. Introduction

Ecological deterioration is considered one of the factors that significantly affect the quality of an individual's life and the sustainability of economic growth. Recently, the large accumulation of greenhouse gas emissions in the atmosphere elevates ecological degradation to a high level of concern in both developed and developing countries. It is notable that the industrialization process, which occurs through the utilization of non-renewable energy in the majority of countries, harms ecological degradation in these countries

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and negatively impacts economic progress (Ata, Eryer and Muhammed, 2025:79).

Since the onset of the Industrial Revolution, the intensive use of fossil fuels has significantly accelerated environmental degradation. Growing awareness of sustainability challenges has encouraged the establishment of international initiatives such as the Kyoto Protocol and the Paris Climate Agreement, both designed to improve environmental quality and mitigate global ecological risks. These multilateral agreements have been instrumental in enhancing environmental awareness and promoting coordinated global actions toward long-term ecological balance.

A combination of factors, including rising sea levels linked to global warming, evaporation of water bodies, glacier melting, high-intensity winds caused by temperature and pressure differentials, overexploitation of natural resources, deforestation, and the continuous rise in energy consumption driven by economic expansion, has collectively intensified environmental deterioration (Çoban & Özkan, 2022: 482).

FDI is widely acknowledged as an essential mechanism for fostering economic development. Within the framework of the Kyoto Protocol, special attention is given to the trade and environmental policies of developing nations. As globalization accelerates and capital mobility expands, the inflow of FDI to emerging economies has contributed to growth through technology transfer and productivity gains. However, while FDI supports economic progress, its environmental implications remain a subject of ongoing academic debate.

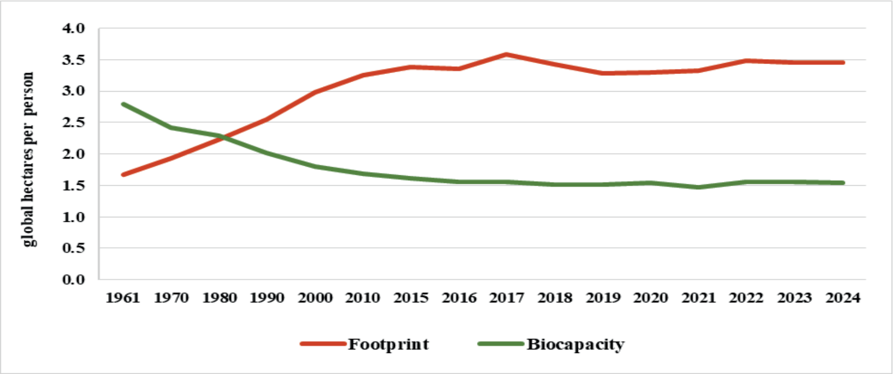
The environmental consequences of FDI are primarily discussed through two opposing perspectives. The first, known as the *Pollution Haven Hypothesis* (PHH), posits that FDI intensifies environmental degradation. Because developed economies enforce stricter environmental regulations, developing countries gain a competitive advantage in attracting foreign investment by maintaining more lenient standards. Consequently, production tends to shift toward countries with less stringent environmental frameworks, as rigorous regulations elevate production costs and undermine competitiveness (Bommer, 1999: 342). Likewise, Gill et al. (2018: 167) suggest that developed nations relocate industrial activities to developing economies to avoid the high costs associated with environmental compliance, effectively transferring ecological burdens to host countries.

In contrast, the *Pollution Halo Hypothesis* (PHH) asserts that FDI can alleviate environmental degradation by facilitating the diffusion of cleaner and more advanced technologies. Investments originating from developed countries often transfer eco-friendly innovations and management practices to developing economies (Zhang & Zhou, 2016: 944; Eskeland & Harrison, 2003). Through such technological spillovers, multinational corporations can reduce carbon dioxide emissions and improve local environmental performance. Thus, rather than becoming pollution havens, host economies may experience enhanced environmental quality. Given that FDI inflows to Türkiye are heavily concentrated in environmentally sensitive sectors- such as heavy manufacturing, chemicals, automotive sub-industries, and textiles- it is particularly important to empirically examine whether the pollution haven hypothesis applies in Türkiye's case.

Another major factor influencing environmental degradation is energy consumption. Fossil fuel-based energy use, in particular, remains one of the most significant contributors to ecological pressure. In Türkiye, the high dependency on coal and natural gas- combined with the limited role of renewable sources- highlights the importance of analysing how energy consumption interacts with environmental degradation.

Since the early 1980s, Türkiye has regarded FDI as a strategic means of acquiring technology, financing growth, and improving productivity. According to UNCTAD, cumulative FDI inflows to Türkiye over the past two decades have exceeded 180 billion USD. However, this surge in investment has coincided with substantial environmental changes. Figure 1 presents a comparative overview of Türkiye's biological capacity and ecological footprint (gha per capita) between 1961 and 2024.

Figure 1. Ecological Footprint and Biocapacity in Türkiye (1961-2024)



Source: Global Footprint Network.

As shown in Figure 1, the gap between Türkiye's ecological footprint and biocapacity has widened considerably since the 1980s, reflecting a deepening ecological deficit and worsening environmental conditions. Between 1980 and 2024, the country's ecological footprint expanded by roughly 60%. Despite the accompanying economic growth, the persistent rise in environmental degradation poses a serious challenge to sustainable development.

Preventing environmental deterioration is critical for safeguarding the quality of life of future generations. Türkiye ranks among the countries most vulnerable to climate change. Because of its geographical position, climatic diversity, and socioeconomic structure, the nation faces significant exposure to climate risks. Therefore, enhancing resilience and adaptive capacity has become a key priority within Türkiye's environmental policy agenda (World Bank, 2022: 8). Moreover, as Türkiye's primary trading partners are EU member states, the environmental commitments adopted under the European Green Deal and other global climate frameworks will directly influence Türkiye's trade competitiveness and FDI attractiveness. Consequently, Türkiye's active participation in international climate accords and its compliance with related commitments will be decisive in shaping future economic prospects. Nonetheless, the country's heavy dependence on fossil fuels- accounting for about 81% of total energy consumption (World Bank, 2025c)- remains a major obstacle to achieving environmental sustainability. Increasing the share of renewable energy sources is thus essential for mitigating ecological degradation and supporting sustainable growth.

Most previous studies exploring the effects of FDI, economic growth, and energy use on environmental outcomes have primarily focused on carbon dioxide emissions as a proxy for environmental degradation. Yet the ecological footprint, which offers a more holistic assessment of environmental sustainability, has received relatively limited empirical attention. Furthermore, much of the existing literature relies on linear models that fail to capture potential asymmetries between short- and long-run dynamics.

In this light, the primary goal of this study is to investigate the variables impacting Türkiye's ecological footprint from 1970 to 2024, as well as to analyse the validity of the pollution haven hypothesis. By employing nonlinear time-series techniques, the study examines how FDI, economic growth, and energy consumption jointly influence environmental pressure. The paper aims to provide a comprehensive and dynamic understanding of the structural challenges Türkiye faces in reconciling economic development with environmental sustainability. The study continues with the literature review, subsequently presenting the econometric analysis and findings, and concludes with the final section.

2. Literature Review

For decades, research on environmental sustainability predominantly relied on one-dimensional indicators such as carbon emissions. However, such measures fail to capture the multidimensional nature of environmental pressures. To address this limitation, the concept of the ecological footprint was developed, providing a broader and more comprehensive framework for assessing ecological degradation (Wackernagel & Rees, 1996).

The ecological footprint represents an inclusive metric that accounts for the use of biologically productive land and water resources necessary to sustain human activities. It encompasses several subcomponents, including cropland, the carbon footprint, fishing grounds, forests, grazing land, and built-up areas. In this respect, the ecological footprint offers a more holistic evaluation of environmental sustainability compared to indicators that only focus on carbon emissions.

Accordingly, this study employs the ecological footprint as a proxy for environmental quality to examine how FDI, economic growth, and energy consumption influence environmental degradation in Türkiye. The following section summarizes key empirical studies investigating these relationships, as presented in Table 1.

Table 1. Overview of Studies on FDI, Energy Consumption, Growth and the Ecological Footprint

Ecological Footprint/ FDI- GDP- Energy Consumption				
Author(s)	**Year**	**Data Set**	**Method**	**Relationship**
Solarin and Al-Mulali	2018	20 Developed and Developing Countries (1982-2013)	Panel Data Analysis	When all countries are analyzed together, FDI does not significantly affect environmental indicators. At the individual country level, however, FDI, GDP, and urbanization increase pollution in developing nations but reduce it in advanced economies.
Destek and Okumuş	2019	10 Newly Industrialized Countries (1982-2013)	Panel Data Analysis	Energy consumption exerts a positive effect on the ecological footprint, whereas the relationship between FDI and the ecological footprint exhibits an inverted U-shaped pattern.

Zafar et al.,	2019	USA (1970-2019)	ARDL	Economic growth and energy use exert negative effects on the ecological footprint, while FDI, natural resource abundance, and human capital contribute to mitigating environmental degradation.
Balsalobre-Lorente et al.,	2019	MINT Countries (1990-2013)	FMOLS and DOLS	FDI contributes to reducing the ecological footprint, validating the Pollution Halo Hypothesis.
Doytch	2020	117 Countries (1984-2011)	Panel Data Analysis	The Pollution Halo Hypothesis is validated for high-income countries.
Chowdhury et al.,	2021	92 Countries (2001-2016)	Panel Quantile Regression Analysis	FDI raises the ecological footprint, rejecting the Pollution Halo Hypothesis. Economic growth negatively affects environmental quality.
Muhammad et al.,	2021	BRIC Countries, 145 Developing Countries, 31 Developed Countries, 176 Global Countries (1991-2018)	Panel Data Analysis	FDI exacerbates environmental degradation in BRICS and developing countries, whereas it alleviates such pressures in developed economies, thereby confirming the Pollution Halo Hypothesis for advanced nations.
Çoban and Özkan	2022	Türkiye (1970-2020)	ARDL	Both FDI and energy consumption worsen environmental quality, supporting the Pollution Haven Hypothesis.
Karaduman	2022	11 Newly Industrialized Country (1975-2017)	Panel Data Analysis	GDP per capita positively affects the ecological footprint, while the Pollution Halo Hypothesis is validated in these economies.
Kızılgöl and Öndes	2022	31 OECD Countries (1995-2017)	Panel Data Analysis and Causality Analysis	Urbanization, renewable energy consumption, and FDI exert significant influences on the ecological footprint. Moreover, unidirectional causality is found to run from FDI, urbanization, and renewable energy use toward the ecological footprint..
Mishra and Dash	2022	5 South Asian Countries (1971-2019)	ARDL	Economic growth and globalization have long-term positive effects on the carbon footprint.
Murshed et al.,	2022	6 South Asian Countries (1995-2015)	Panel Data Analysis	Rising FDI inflows intensify the ecological footprint, supporting the Pollution Haven Hypothesis.
Özkan and Çoban	2022	Türkiye (1970-2018)	KRLS	FDI reduces the ecological footprint, while economic growth increases it, validating the Pollution Halo Hypothesis for Türkiye.

Avcı	2023	Türkiye (1984-2018)	Fourier Cointegration Test and Fourier Toda-Yamamoto Causality Test	FDI inflows expand the ecological footprint, whereas economic growth has no significant impact, supporting the Pollution Haven Hypothesis.
Duman	2023	BRICS-T Countries (1992-2018)	FMOLS-DMOLS	Trade openness, FDI, and income levels increase the ecological footprint, whereas renewable energy use and R&D expenditures help mitigate it.
Naqvi et al.,	2023	87 Middle-Income Countries (1990-2017)	Panel AMG and Causality Analysis	FDI expansion worsens environmental quality, confirming the Pollution Haven Hypothesis.
Saqib et al.,	2023	16 European Countries (1990-2020)	Panel Data Analysis	A negative association is observed between FDI and the ecological footprint, providing evidence in support of the Pollution Halo Hypothesis.
Barış	2024	19 Countries with High Levels of Foreign Direct Investment (1990-2021)	Panel ARDL	FDI, economic growth, and the ecological footprint are positively associated.
Padhan and Bhat	2024	46 Developing Countries (2010-2020)	GMM	FDI helps reduce carbon emissions, while economic growth and industrialization intensify the ecological footprint.
Atılgan and Dallı	2025	Türkiye (1989-2022)	ARDL	The expansion of FDI increases the ecological footprint, thereby validating the Pollution Haven Hypothesis for Türkiye.
Ata, Eryer and Abdulkarim	2025	Emerging Market Economies (1990-2022)	Panel Data Analysis	This study found that the ecological footprint in emerging market economies was stable. This finding indicates that there is convergence within these economies to achieve global sustainability.
Göger and Uçan	2025	Western European Countries (2000-2022)	Panel Data Analysis	FDI mitigates environmental pressure, while higher energy use exacerbates it, supporting the Pollution Halo Hypothesis.

3. Model, Data Set, Methodology, and Findings

This study explores how FDI, economic growth, and energy consumption influence the ecological footprint in Türkiye over the period 1970-2024, within the conceptual framework of the Pollution Haven Hypothesis. The ecological footprint serves as a proxy for environmental quality, and all variables are analyzed in their logarithmic forms. The variables, their units of measurement, and respective data sources are summarized in Table 2.

Table 2. Definition of Variables

Variables	Unit of Measurement	Abbreviation	Source
Ecological Footprint	Global hectares (gha)	EF	Global Footprint Network
Foreign Direct Investment	FDI net inflows (current US$)	FDI	World Bank
Economic Growth	Gross Domestic Product (constant 2015 US$)	GDP	World Bank
Energy Consumption	Exajoules	EC	Energy Institute
Functional Model **EF=f (FDI, GDP, EC)**			
Econometric Model $LNEF_t = \beta_0 + \beta_1 LNFDI_t + \beta_2 LNGDP_t + \beta_3 LNEC_t + \varepsilon_t$			

Annual data were utilized for the analysis, and all econometric procedures were conducted using Gauss and WinRATS software packages. A review of previous literature shows that most empirical tests of the Pollution Haven Hypothesis rely on linear modeling approaches, which often fail to reflect nonlinear patterns or structural shifts among variables. To address this limitation, the present study employs nonlinear econometric methods capable of jointly capturing structural breaks and nonlinear dynamics, thereby enhancing both analytical precision and interpretive depth.

3.1. Econometric Method

The analysis begins with a linearity test to determine whether the series exhibit linear or nonlinear characteristics. After identifying the nature of the series, stationarity was examined using both the Augmented Dickey Fuller (ADF) test and the nonlinear Hepsağ (2021a) unit root test, which explicitly accounts for smooth structural changes. Subsequently, the Hepsağ (2021b) nonlinear cointegration test was applied to assess long-run relationships among the variables. The results indicated a significant presence of nonlinearity in the data, prompting further investigation into potential structural breaks.

3.2. Linearity Tests

Disregarding the linearity properties of the data may lead to biased or misleading inferences. Among the prominent tests for detecting nonlinearity are those introduced by McLeod and Li (1983), Brock et al. (1987), and Cao and Tsay (1992). In this study, the nonlinear tests developed by Harvey and Leybourne (2007) and Harvey, Leybourne, and Xiao (2008) were employed. The Harvey and Leybourne (2007) test accommodates both I(0) and I(1) processes simultaneously. The hypotheses are formulated as follows:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-1}^2 + \beta_3 y_{t-1}^3 + \beta_4 \Delta y_{t-1} + \beta_5 \left(\Delta y_{t-1}\right)^2 + \beta_6 \left(\Delta y_{t-1}\right)^3 + \varepsilon_t \qquad (1)$$

The hypotheses used to test for nonlinearity in this model are as follows:

$$H_0 : \beta_2 = \beta_3 = \beta_5 = \beta_6 = 0$$

$$H_1 : \beta_2 \neq \beta_3 \neq \beta_5 \neq \beta_6 \neq 0$$

These hypotheses are tested using the X_4^2 critical value.

Harvey, Leybourne, and Xiao (2008), on the other hand, examined linearity separately according to whether the series are I(0) or I(1). Accordingly, two different Wald test statistics were computed: one for stationary series in levels and another for stationary series in first differences. The first test regression considers the I(0) process of the series (Harvey et al., 2008):

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-1}^2 + \beta_3 y_{t-1}^3 + \sum_{j=1}^{p} \beta_4 \Delta y_{t-1} + \varepsilon_t \qquad (2)$$

In this case, the null hypothesis is $H_0 : \beta_2 = \beta_3 = 0 \left(W_0\right)$. The second test regression considers the I(1) process of the series:

$$\Delta y_t = \lambda_1 \Delta y_{t-1} + \lambda_2 \left(\Delta y_{t-1}\right)^2 + \lambda_3 \left(\Delta y_{t-1}\right)^3 + \sum_{j=2}^{p} \lambda_{4,j} \Delta y_{t-j} + \varepsilon_t \qquad (3)$$

For this equation, the null hypothesis is $H_0 : \lambda_2 = \lambda_3 = 0 \left(W_1\right)$ which is tested using the X_2^2 critical value. The linearity properties of the series included in the analysis were examined using the Harvey and Leybourne (2007) and Harvey et al. (2008) tests, and the results obtained are presented in Table 3.

Table 3. Linearity Test Results

Variable	**Harvey (2008) Test Statistic (W_λ)**	**Harvey (2007) Test Statistic (W^*)**
EF	10.23**	11.10**
FDI	7.76**	9.50**
GDP	27.06**	13.26**
EC	8.23**	12.15**

Note: , $X^2_{2(0,05)} = 5.99$, $X^2_{4(0,05)} = 9.48$. ** indicates nonlinearity at the 5% significance level.

Since all test statistics exceed their corresponding chi-square critical values, the null hypothesis of linearity is rejected. Hence, the variables exhibit nonlinear behaviour, confirming the necessity of applying nonlinear time-series methods in subsequent stages of analysis.

3.3. Unit Root Analysis

The nonlinear ESTAR unit root test with smooth structural breaks developed by Hepsağ (2021a) is designed to account for both smooth structural changes and nonlinear dynamics. The test models structural breaks using a logistic smooth transition function (LSTAR), while the nonlinear dynamics are captured within an ESTAR framework. The procedure includes three alternative models: *Model A*, which allows for a break in the intercept; *Model B*, which incorporates a break in the intercept under a deterministic trend; and *Model C*, which accounts for breaks in both the intercept and the trend (Hepsağ, 2021a: 626). The test statistic is derived using a Wald-type testing procedure. The hypotheses of the test are formulated as follows:

H_0 : The series contains a unit root.

H_1 : The series are ESTAR stationary under smooth structural breaks.

If the computed statistic falls below the relevant critical value, the null hypothesis of a unit root cannot be rejected. Conversely, when it exceeds the critical threshold, the series is deemed ESTAR stationary with smooth structural breaks.

In this research, the smooth-transition ESTAR test proposed by Hepsağ (2021a) was applied. The resulting statistics and estimated break dates are reported in Table 4. However, the Hepsağ (2021a) method cannot be applied to the first differences of the series, as differencing eliminates deterministic components such as the constant and trend, thereby rendering the smooth transition mechanism inapplicable. For this reason, the conventional ADF unit root test was employed for the first-differenced series. The results of both tests are presented below.

Table 4. Unit Root Test Results

	$\tau_{SN\alpha\beta}$		ADF	
Variables	**Level**	**Break Date**	**Level**	**First Difference**
EF	12.21	1995	-1.124 (0.699)	-8.188*** (0.000)
FDI	6.272	1974	-3.169 (0.101)	-10.17*** (0.000)
GDP	5.340	1999	-2.592 (0.285)	-2.464** (0.014)
EC	9.032	1998	-2.800 (0.203)	-2.593** (0.010)

Note: Model C was used as the baseline in the analysis, and τ_{SN} denotes the Smooth Nonlinear tau statistic. The critical value of 12.404 at the 5% significance level for T=55 was obtained from Table 1 $\tau_{SN\alpha\beta}$ in Hepsağ (2021a: 628). ** and *** indicate stationarity at the 5% and 10% significance levels, respectively.

The findings show that all series are non-stationary in levels but become stationary after initial differencing, meaning that the variables are integrated of order one, I(1). The smooth structural break dates identified through the unit root test reflect significant cyclical transformations in the Turkish economy. Following the 1974 Cyprus Peace Operation, the imposition of international embargoes severely restricted foreign capital inflows. In the early 1990s, the acceleration of industrialization and the implementation of the Customs Union in 1995 led to an expansion in Türkiye's import and export volumes, accompanied by increases in energy consumption, carbon emissions, and overall environmental pressure. Moreover, the 1998 Russian and Asian financial crises adversely affected Türkiye's foreign trade and energy supply, causing notable fluctuations in energy consumption. The 1999 Marmara Earthquake and the subsequent 2000-2001 economic crisis created severe macroeconomic imbalances in the national economy, thereby intensifying structural disruptions.

3.4. Cointegration Test and Long-Run Results

The nonlinear cointegration approach proposed by Hepsağ (2021b) is built on the premise that short-run positive and negative shocks may exert asymmetric influences on the adjustment process toward long-run equilibrium. This assumption implies that the underlying relationship among variables may follow an asymmetric exponential smooth transition autoregressive (AESTAR) pattern.

The testing procedure unfolds in two main stages. In the first stage, the long-run equilibrium among the variables is estimated via the OLS method using level data, and the residuals are obtained. In the second stage, these residuals are modeled through an AESTAR process, which can be expressed as:

$$\Delta y_t = G_t(\theta_1, u_{t-1})\{S_t(\theta_2, u_{t-1})\gamma_1 + (1 - S_t(\theta_2, u_{t-1}))\gamma_2\}u_{t-1} + \psi' \Delta x_t + \sum_{i=1}^{p} \omega' \Delta z_{t-i} + \varepsilon_t \qquad (4)$$

Here,

$$\Delta x_t = \sum_{i=1}^{p} \Gamma_i' \, \Delta z_{t-i} + \eta_t$$

represents the ESTAR process

$$G_t(\theta_1, u_{t-1}) = 1 - exp\,(-\theta_1(u_{t-1}^2)), \theta_1 \geq 0,$$

while the LSTAR process is expressed as

$$S_t(\theta_2, u_{t-1}) = [1 + \exp\,(-\theta_2(u_{t-1}))]^{-1}, \theta_2 \geq 0$$

is defined in this way. In this model, since θ_2, γ_1, and γ_2 are not identified under H_0, the existence of a cointegration relationship cannot be directly tested. Therefore, to obtain the F_{ANEC} test statistic, a first-order Taylor expansion is performed, and the resulting regression model is expressed as follows (Özçelik, 2022: 392):

$$\Delta y_t = \phi_1 \hat{u}_{t-1}^3 + \phi_2 \hat{u}_{t-1}^4 + \psi' \Delta x_t + \sum_{i=1}^{p} \omega'_i \Delta z_{t-i} + v_t \qquad (5)$$

The hypotheses of the test can be summarized as follows:

H_0: $\phi_1 = \phi_2 = 0$ (No cointegration among the series)

$H_1 : \phi_1 \neq \phi_2 \neq 0$ (Presence of symmetric or asymmetric ESTAR cointegration among the series)

If the computed statistic is smaller than the corresponding critical value, the null hypothesis of no cointegration cannot be rejected. Conversely, when the statistic exceeds the threshold, the existence of symmetric or asymmetric cointegration is confirmed. In such cases, the coefficient ϕ_1 must be negative to ensure convergence toward equilibrium (Hepsağ, 2021b: 403). Once the existence of cointegration is verified, a follow-up test is conducted to determine whether the relationship exhibits symmetry or asymmetry, using the hypotheses:

$$H_0 : \phi_2 = 0 \text{(symmetric cointegration)}$$

$$H_1 : \phi_2 \neq 0 \text{(asymmetric cointegration)}$$

If the calculated F-statistic exceeds the standard critical values, an asymmetric ESTAR cointegration relationship is inferred. The Hepsağ (2021b) test can be applied under three alternative data specifications:

1. **Case 1 (Raw Data):** No constant or trend term,
2. **Case 2 (Demeaned Data):** Includes a constant,
3. **Case 3 (Detrended Data):** Includes both constant and trend.

The empirical outcomes obtained from the nonlinear cointegration test are summarized in Table 5.

Table 5. Nonlinear Cointegration Test Results

Model	$F_{ANEC,t}$	**Cointegration Relationship**	**F-test**	**Type of Cointegration** |
EF=f (FDI, GDP, EC)	8.769**	There is cointegration	1.458 (0233)	Symmetric ESTAR
	$F_{ANEG,t}$			
EF=f (FDI, GDP, EC)	12.27**	There is cointegration	2.751 (0.103)	Symmetric ESTAR

Note: The $F_{ANEC,t}$ and $F_{ANEG,t}$ statistic, developed by Hepsağ (2021b), refers to the Asymmetric Nonlinear Error Correction test statistic. The subscript *t* indicates that the model with a trend component is considered. The symbol ** denotes the existence of a cointegration relationship at the 5% significance level. The critical values, 8.660 and 9.798, are obtained from Table 1 in Hepsağ (2021b: 404).

According to the results, a nonlinear long-run relationship exists among the variables, validating the presence of cointegration. The follow-up symmetry test indicates that short-run positive and negative shocks have similar effects on the long-run adjustment process. Hence, the long-run relationship among EF, FDI, GDP, and EC is identified as symmetric but nonlinear.

Long-Run Estimation Results

After establishing cointegration, the long-run parameters were estimated using the nonlinear Following the cointegration test, the long-run analysis was conducted using the nonlinear least squares method, and the results are presented in Table 6.

Table 6. Long-Run Coefficient Estimates

	Bağımlı Değişken: *EF*	
Independent Variables	**Coefficient**	**p-values**
FDI	0.019	0.013**
GDP	0.222	0.050*
EC	0.387	0.000***
Diagnostic Tests		
Breusch-Godfrey	2.162	0.407
Heteroskedasticity	0.958	0.987
Ramsey	0.643	0.426
Jarque-Bera	2.367	0.306

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

According to the results of the nonlinear cointegration test developed by Hepsağ (2021b), a symmetric long-run cointegration relationship is identified among the series. Based on the long-run coefficient estimates presented in Table 6, FDI, economic growth, and energy consumption positively affect the ecological footprint. The empirical estimates demonstrate that a 1% increase in FDI results in a 0.019% rise in the ecological footprint, whereas a 1% expansion in economic growth elevates it by 0.222%. Moreover, a 1% increase in energy consumption leads to a 0.387% escalation in environmental pressure. Collectively, these findings highlight energy consumption as the dominant long-run determinant of environmental degradation in Türkiye. Furthermore, the positive contribution of FDI to environmental deterioration substantiates the validity of the pollution haven hypothesis in the Türkiye context.

The long-run results are consistent with Türkiye's economic and environmental dynamics. As a developing country, Türkiye is an economy striving to attract investment. However, incoming investments are predominantly concentrated in energy-intensive and environmentally polluting industries such as heavy manufacturing, chemical production, automotive sub-industries, and textiles, rather than in environmentally friendly and high-technology sectors. This situation exacerbates ecological degradation and provides further support for the pollution haven hypothesis.

Similarly, since Türkiye's growth model relies heavily on industrial and energy-intensive sectors, it is an expected outcome that economic growth increases environmental pressure. The dominant share of fossil fuels, particularly coal and natural gas, in Türkiye's energy consumption explains why energy use emerges as the strongest determinant of the ecological footprint. Although investments in renewable energy have been increasing, their share in total energy supply remains limited. Therefore, the findings clearly reveal the nature of the effects of Türkiye's current energy and growth structure on its ecological footprint.

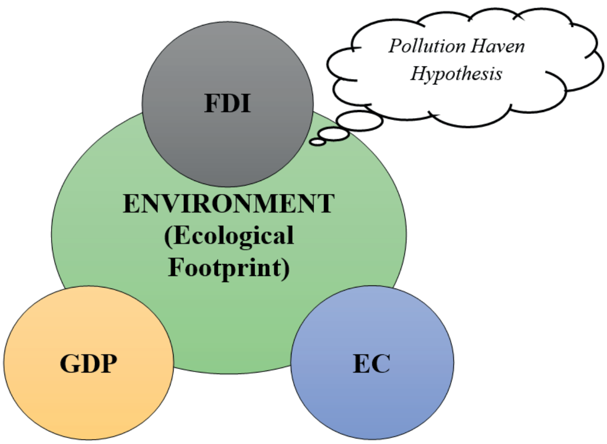


Figure 2: Summary of the Findings

4. Conclusions and Policy Recommendations

The primary aim of this study is to examine the effects of FDI, economic growth, and energy consumption on the ecological footprint in Türkiye for the period 1970- 2024. In this context, unit root and cointegration tests based on nonlinear time series analysis were employed to investigate the environmental effects of FDI in Türkiye. According to Hepsağ (2021a) and conventional unit root tests, the series are stationary at their first differences, indicating that they are integrated of order one, I(1). Moreover, the nonlinear cointegration test proposed by Hepsağ (2021b) reveals that all variables in the model move together in the long run, confirming their integration at the I(1) level.

The results indicate that FDI, economic growth, and particularly energy consumption exert increasing effects on the ecological footprint in Türkiye. This finding confirms the validity of the pollution haven hypothesis for the Turkish case. Although FDI plays a significant role in the economic growth of a developing country like Türkiye, the accompanying environmental degradation poses a substantial risk. This situation underlines the importance of Turkey tightening its environmental rules and striking a balance between economic development and environmental protection in order to accomplish its long-term sustainable development goals.

The findings of this study provide valuable insights for developing countries such as Türkiye. FDI holds great importance for developing economies that aim to achieve industrialization and economic growth. However, the lack of environmentally friendly policies in these countries may lead to an increase in their ecological footprint as a result of such investments. The results of the study offer guidance for reducing the ecological footprint, particularly if developing countries adopt stricter environmental regulations. Within this framework, the following policy recommendations can be proposed:

- **Green investment incentives:** Governments may introduce tax reductions, simplified licensing procedures, and financial support for firms adopting eco-friendly technologies to steer FDI toward sustainable and low-carbon production.
- **Renewable and circular economy focus:** Encouraging investments in renewable energy, energy efficiency, and circular production models will help reduce the ecological footprint.
- **Transition to renewables:** Türkiye should accelerate its shift from fossil-fuel-based energy systems toward solar, wind, and geothermal alternatives to mitigate environmental degradation.
- **Sustainable growth strategy:** Economic growth policies should be harmonized with environmental sustainability goals to minimize ecological pressures arising from industrial expansion.
- **Regulatory mechanisms:** Tools such as carbon taxes, emission caps, and green certification systems can be employed to curb pollution-intensive production.
- **Public participation and awareness:** Enhancing environmental literacy and involving non-governmental organizations in

environmental decision-making processes will improve policy effectiveness.

- **International collaboration:** Strengthening cooperation with global institutions can facilitate access to green financing mechanisms, including carbon markets, climate funds, and sustainable development grants.

In conclusion, ensuring environmental sustainability within Türkiye's economic growth process depends on redesigning foreign direct investment policies to prioritize environmentally conscious and green technology-oriented investments. The findings of this study indicate the necessity of developing new policy models that account for the nonlinear dynamics of the environment- economy relationship. In this context, the formulation of comprehensive environmental and economic policies will enable Türkiye to achieve its sustainable development goals while enhancing long-term welfare through the preservation of environmental quality.

References

Ata, A. Y., A. Eryer and M. Abdulkarim (2025). Ecological Footprint Convergence in Emerging Market Economies: Panel Data Analysis, *InTraders International Trade Academic Journal* 8(1), 74-91, e-ISSN: 2667-4408.

Atılgan, D. & Dallı, T. (2025). Türkiye'de kirlilik cenneti hipotezi geçerli mi? Ekolojik ayak izinden kanıtlar. *Gümüşhane Üniversitesi Sosyal Bilimler Dergisi*, 16(3), 1082-1095.

Avcı, G.M. (2023). Environmental impact of foreign direct investment in Turkey: Does the quality of institutions matter? Evidence from time series analysis using the Fourier extension. *Environmental Science and Pollution Research*. 30, 107841-107853. https://doi.org/10.1007/s11356-023-29964-x

Balsalobre-Lorente, D., Gokmenoglu, K.K., Taspinar, N. & Cantos-Cantos, J.M. (2019). An approach to the pollution haven and pollution halo hypotheses in MINT countries. *Environ Science and Pollution Research*, 26, 23010-23026. https://doi.org/10.1007/s11356-019-05446-x

Barış, S. (2024). Doğrudan yabancı yatırımlar ekolojik ayak izini artırıyor mu? Yüksek doğrudan yabancı yatırım alan ülkeler için bir analiz. *Journal of Academic Opinion*, 4(2), 52-63.

Bommer, R. (1999) Environmental policy and industrial competitiveness: The pollution-haven hypothesis reconsidered. *Review of International Economics*, 7(2), 342-355. https:// doi.org/10.1111/1467-9396.00168

Brock, W.A., Dechert, W.D. & Scheinkman, J.A. (1987). A Test for independence based on the correlation dimension. *University of Wisconsin DP*, No. 8702

Cao, C.Q. & Tsay, R.S. (1992). Non-linear time-series analysis of stock volatilities. *Journal of Applied Econometrics*, 7, 165-185. https://doi.org/10.1002/jae.3950070512

Chowdhury, M.A.F., Shanto, P.A., Ahmed, A. & Rumana, R.H. (2021). Does foreign direct investments impair the ecological footprint? New evidence from the panel quantile regression. *Environmental Science and Pollution Research*, 28, 14372-14385. https://doi.org/10.1007/s11356-020-11518-0

Çoban, M.N. & Özkan, O. (2022). Türkiye'de enerji tüketimi, ticari açıklık, co2 emisyonları ve kirlilik sığınağı hipotezi: Yeni dinamik ARDL simülasyonlarından kanıtlar. *Kırklareli Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 11(2), https://doi.org/10.53306/klujfeas.1147997

Destek, M.A. & Okumuş, I. (2019). Does Pollution Haven Hypothesis Hold in Newly Industrialized Countries? Evidence From Ecological Footprint. *Environ Sci Pollut Res*, 26, 23689-23695. 10.1007/s11356-019-05614-z

Doytch, N. (2020). The impact of foreign direct investment on the ecological footprints of nations. *Environmental and Sustainability Indicators*, 8, 100085. https://doi.org/10.1016/j.indic.2020.100085

Duman, E. (2023). Seçilmiş Ekonomik Değişkenlerin Ekolojik Ayak İzine Etkisinin analizi: BRICS-T Ülkeleri Örneği. *Sosyoekonomi*, 31(58), 277-288. https://doi.org/10.17233/sosyoekonomi.2023.04.14

Energy Institute (2025). *Energy consumption*. https://www.energyinst.org/statistical-review (accessed on: 11.10.2025).

Gill, F.L., Viswanathan, K.K. & Karim, M.Z.A. (2018). The critical review of the pollution haven hypothesis. *International Journal of Energy Economics and Policy*, 8(1), 167-174.

Global Footprint Network (2025). *Ecological Footprint*. https://data.footprintnetwork.org/#/ (accessed on: 11.10.2025).

Göger, K. & Uçan, O. (2025). Batı Avrupa ülkelerinde doğrudan yabancı yatırımların ekolojik ayak izi üzerindeki etkisi: Panel veri analizi. *International Social Sciences Studies Journal*, 11(3), 478-493. https://doi.org/10.5281/zenodo.15062728

Harvey, D.I. & Leybourne, S.J. (2007). Testing for time series linearity. *Econometrics Journal*, 10, 149-165. https://doi.org/10.1111/j.1368-423X.2007.00203.x

Harvey, D.I., Leybourne, S.J. & Xiao, B. (2008). A powerful test for linearity when the order of integration is unknown. *Studies in Nonlinear Dynamics & Econometrics*, 12(3), 1-24. https://doi.org/10.2202/1558-3708.1582

Hepsağ, A. (2021a). A unit root test based on smooth transitions and non-linear adjustment. *Communications in Statistics- Simulation and Computation*, 50(3), 625-632. https://doi.org/10.1080/03610918.2018.1563154

Hepsağ, A. (2021b). Testing for cointegration in non-linear asymmetric smooth transition error correction models. *Communications in Statistics- Simulation and Computation*, 50(2), 400-412. https://doi.org/10.1080/03610918.2018.1559927

Karaduman, C. (2022). The effects of economic globalization and productivity on environmental quality: Evidence from newly industrialized countries. *Environmental Science and Pollution Research*, 29, 639- 652. https://doi.org/10.1007/s11356-021-15717-1

Kızılgöl, Ö. & Öndes, H. (2022). Factors affecting the ecological footprint: a Study on the OECD countries. *Science of the Total Environment*, 849, 157757. https://doi.org/10.1016/j.scitotenv.2022.157757

McLeod, A.I. & Li, W.K. (1983). Diagnostic checking ARMA time series models using squared- residual autocorrelations. *Journal of Time Series Analysis*, 4(4), 269-273.

Mishra, A. K. & Dash, A. K. (2022). Connecting the carbon ecological footprint, economic globalization, population density, financial sector development, and economic growth of five south asian countries. *Energy Research Letters*, 3(2). https://doi.org/10.46557/001c.32627

Muhammad, B., Khan, M. K., Khan, M. I. & Khan, S. (2021). Impact of foreign direct investment, natural resources, renewable energy consumption, and economic growth on environmental degradation: Evidence from BRICS, developing, developed and global countries. *Environmental Science and Pollution Research*, 28, 21789-21798. https://doi.org/10.1007/s11356-020-12084-1

Murshed, M., Nurmakhanova, M., Al-Tal, R., Mahmood, H., Elheddad, M. & Ahmed, R. (2022). Can intra-regional trade, renewable energy use, foreign direct investments, and economic growth mitigate ecological footprints in South Asia?. *Energy Sources, Part B: Economics, Planning, and Policy*, 17(1). https://doi.org/10.1080/15567249.2022.2038730

Naqvi, S.A.A., Hussain, M., Hussain, B., Shah, A.A.R., Nazir, J. & Usman, M. (2023). Environmental sustainability and biomass energy consumption through the lens of pollution Haven hypothesis and renewable energy-environmentalkuznets curve. *Renewable Energy,* 212, 621-631. https://doi.org/10.1016/j.renene.2023.04.127

Özçelik, O. (2022). Ekonomik ve siyasi belirsizliklerin Türkiye'nin dış ticarette ödeme şekli tercihlerine etkileri: Doğrusal olmayan asimetrik ESTAR koentegrasyon testi ile sınama. *BMIJ*,10(1), 380-398. https://doi.org/10.15295/bmij.v10i1.2023

Özkan, O. & Çoban, M.N. (2022). Türkiye'de kirlilik hale hipotezi ve ekonomik büyüme, ekonomik küreselleşme ve ekolojik ayak izi bağlantısı: KRLS'den kanıtlar. *Uluslararası Yönetim İktisat ve İşletme Dergisi*, 18(4), 1049-1068. http://dx.doi.org/10.17130/ijmeb.1143139.

Padhan, L. & Bhat, S. (2024). Pollution haven or pollution halo in the context of emerging economies: a two-step system GMM approach, *Environment, Development and Sustainability*. http://dx.doi.org/10.1007/s10668-024-05616-z

Saqib, N., Öztürk, I., Usman, M., Sharif, A. & Razzaq, A. (2023). Pollution Haven or Halo? How European countries leverage FDI, energy, and human capital to alleviate their ecological footprint. *Gondwana Research,* 116, 136-148. https://doi.org/10.1016/j.gr.2022.12.018

Solarin, S.A. & Al-Mulali, U. (2018). Influence of foreign direct investment on indicators of environmental degradation. *Environmental Science and Pollution Research*, 25, 24845-24859. https://doi.org/10.1007/s11356-018-2562-5

Wackernagel, M. & Rees, W. (1996). *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers.

World Bank (2022). Türkiye country climate and development report. CCDR Series. World Bank, Washington, DC https:// openknowledge world bank.org/entities/publication/01826a0c-059f-5a0c-91b7-2a6b8ec5de2f.

World Bank (2025a). *GDP (constant 2015 US$)*, https://data.worldbank.org/indicator/NY.GDP.MKTP.KD (accessed on: 10.10.2025)

World Bank (2025b). *Foreign direct investment, net inflows (BoP, current US$)*, https://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD (accessed on: 10.10.2025)

World Bank (2025c). *Fossil fuel energy consumption (% of total)*, https://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS (accessed on: 10.10.2025)

Zafar, M.W., Zaidi, S.A.H., Khan, N.R., Mirza, F.M., Hou, F. & Kirmani, S.A.A. (2019). The impact of natural resources, human capital, and foreign direct ınvestment on the ecological footprint: the case of the United States. *Resources Policy*, 63, 101428. https://doi.org/10.1016/j.resourpol.2019.101428

Zhang, C. & Zhou, X. (2016). Does foreign direct investment lead to lower CO_2 emissions? Evidence from a regional analysis in China. *Renewable and Sustainable Energy Reviews*, 58, 943-951.