BER BUSINESS AND ECONOMICS RESEARCH JOURNAL
www.berjournal.com ISSN: 2619-9491

Business and Economics Research Journal Vol. 17, No.1, 2026 pp. 1-13 doi: 10.20409/berj.2026.484

Natural Resource Rents, Geopolitical Risk, and Environmental Pollution: Evidence from Türkiye

Fatma Kızılkaya [1], **Oktay Kızılkaya** [2], **Faruk Mike** [3]

Abstract: *Türkiye's strategic geographical position and growth trajectory significantly shape its natural resource rents, environmental sustainability, and policy orientation. The primary objective of this study is to examine the long-run relationship between natural resource rents, geopolitical risk, and environmental degradation—proxied by the ecological footprint—in Türkiye over the period 1985–2021. To this end, the study employs the Fourier-based RALS-ADL cointegration approach, which allows for structural breaks and nonlinear adjustments in the data. The empirical results confirm the existence of a long-run equilibrium relationship among the variables. Natural resource rents, economic growth, and energy consumption exert positive and statistically significant effects on the ecological footprint, whereas geopolitical risk has a negative and significant impact. The positive effect of natural resource rents on the ecological footprint can be attributed to intensified resource extraction and energy-intensive production, whereas the negative impact of geopolitical risk likely reflects contractions in economic activity and investment under heightened uncertainty, thereby reducing environmental pressure. The main contribution of this study is to account for multiple and unknown structural changes and to provide more robust long-term inferences using the Fourier-based RALS-ADL methodology. Overall, the evidence emphasizes the necessity of a holistic policy framework that simultaneously considers natural resource management, geopolitical dynamics, economic expansion, and energy consumption in order to achieve environmental sustainability in Türkiye.*

Keywords: Natural Resource Rents, Geopolitical Risk, Ecological Footprint, Environmental Sustainability, RALS Fourier ADL Cointegration

JEL: F64, P28, C32

Received : 06 October 2025
Revised : 09 December 2025
Accepted : 31 December 2025

Type : Research

1. Introduction

Environmental pollution, which constitutes a major obstacle to the achievement of the sustainable development goals (SDGs), has become one of the most critical global challenges of the twenty-first century. Its root cause lies in human activities that surpass the planet's ecological regeneration capacity. The excessive exploitation of natural resources, dependence on fossil fuel–based energy, unplanned urbanization, and accelerated industrialization have all contributed to the intensification of environmental degradation. Coupled with the impacts of climate change, these factors exacerbate extreme weather events, reduce agricultural productivity, and heighten ecological vulnerabilities, thereby threatening the achievement of

Cite this article as: Kızıkaya, F., Kızılkaya, O., & Mike, F. (2026). Natural resource rents, geopolitical risk, and environmental pollution: Evidence from Türkiye. *Business and Economics Research Journal, 17*(1), 1-13. http://dx.doi.org/10.20409/berj.2026.484

[1] Assoc. Prof., PhD., Malatya Turgut Özal University, Faculty of Health Sciences, Department of Emergency Aid and Disaster Management, Malatya, Türkiye, fatma.kizilkaya@ozal.edu.tr (Corresponding Author)
[2] Prof., PhD., Malatya Turgut Özal University, Faculty of Social Sciences and Humanities, Department of International Trade and Finance, Malatya, Türkiye, oktay.kizilkaya@ozal.edu.tr
[3] Assoc. Prof., PhD., Osmaniye Korkut Ata University, Bahçe Vocational School, Department of Banking and Finance, Osmaniye, Türkiye, farukmike@osmaniye.edu.tr

sustainable development objectives (Intergovernmental Panel on Climate Change, 2014). The negative repercussions of climate change are particularly severe for developing countries, which typically exhibit lower adaptive capacity and greater vulnerability compared to advanced economies (Jahanger et al., 2022).

Environmental degradation compromises not only ecological systems but also the long-term sustainability of economic development. Although developing economies increasingly seek to adopt environmentally responsible growth strategies, they often face the dual challenge of sustaining rapid economic expansion while limiting ecological damage. In the case of Türkiye, national priorities such as fostering economic growth, alleviating poverty, expanding infrastructure, and enhancing living standards are frequently accompanied by growing energy demand, which places significant pressure on soil, water, and air quality. Thus, reconciling the trade-off between economic growth and environmental sustainability has emerged as a central policy concern.

Against this backdrop, understanding the roles of geopolitical risk and natural resource rents in shaping environmental outcomes is essential for advancing global sustainability targets (Chen et al., 2023; Zhang et al., 2023). In developing economies such as Türkiye, maintaining a balance between natural resource rents, energy consumption, and environmental sustainability constitutes a central challenge for both economic growth and environmental policy. Türkiye's geostrategic location adds a distinctive dimension to this nexus, particularly through its implications for energy security and natural resource management (Kızılkaya et al., 2024; Yilanci et al., 2025). At the same time, Türkiye has demonstrated its commitment to environmental protection and global cooperation by ratifying several international agreements, including the Kyoto Protocol, the Paris Agreement, the Montreal Protocol, the Rotterdam Convention, and the CITES Convention (Ministry of Foreign Affairs of the Republic of Türkiye, 2025; Ministry of Environment, Urbanization and Climate Change, 2025). Therefore, a comprehensive examination of the environmental consequences of natural resource revenues and geopolitical risks is of critical importance for the effective formulation and implementation of sustainable development policies.

Despite the growing body of literature examining the environmental effects of natural resource rents and geopolitical risk, several important gaps remain. First, most existing studies focus either on cross-country samples or advanced economies, while country-specific evidence for developing economies—particularly Türkiye—remains limited. Second, prior research predominantly relies on carbon (CO_2) emissions as a proxy for environmental degradation, which captures only a partial dimension of environmental pressure and overlooks broader ecological impacts. Third, the role of geopolitical risk in shaping environmental outcomes has received relatively limited attention in the context of resource-dependent economies characterized by strategic geopolitical positions. Finally, existing studies largely employ conventional econometric techniques that may fail to account for multiple structural breaks and nonlinear adjustments inherent in long historical time series. These limitations are particularly relevant for Türkiye, given its resource-dependent growth dynamics, increasing energy demand, and heightened exposure to geopolitical tensions arising from its strategic geographical location.

Motivated by these gaps, the primary objective of study is to examine the long-run relationships among natural resource rents, geopolitical risk, and environmental degradation in Türkiye by employing annual data for the period 1985–2021 through the Fourier-based RALS-ADL methodology. To investigate these issues, this study employs the geopolitical risk index—which captures uncertainty associated with conflicts, terrorism, and political instability—and the ecological footprint, a multidimensional indicator that provides a broader measure of environmental pressure compared to conventional CO_2 emissions. In addition, natural resource rents are incorporated to capture the economic returns derived from resource exploitation.

The most significant contribution of this study lies in being the first empirical investigation to analyze the long-run relationship among natural resource rents, geopolitical risk, and environmental degradation in Türkiye by employing the Fourier-based RALS-ADL methodology. The choice of the Fourier-based RALS-ADL cointegration approach is motivated by the presence of potential structural breaks and nonlinear adjustments in Türkiye's macroeconomic and environmental dynamics over the related period. This methodology allows for the approximation of multiple and unknown structural shifts through smooth Fourier functions without imposing prior assumptions on their number or timing, while the RALS augmentation improves test power and efficiency under non-normal error distributions (Lee et al., 2015). Accordingly, this study contributes to the literature by providing the first country-specific empirical evidence for Türkiye on the long-run nexus between natural resource rents, geopolitical risk, and environmental degradation using the Fourier-based RALS-ADL framework, thereby ensuring more robust and reliable long-run inference.

The remainder of the paper is organized as follows. Section 2 reviews the theoretical linkages between the study variables and the ecological footprint. Section 3 reviews the studies in the literature. Section 4 outlines the dataset, model specification, and methodology. Section 5 presents and interprets the empirical findings. Section 6 concludes with a summary of the key results and discusses policy implications.

2. Theoretical Framework

2.1. Geopolitical Risks vs. Ecological Footprint

Geopolitical risk refers to the uncertainty and instability arising from conflicts, wars, terrorism, and diplomatic tensions in international relations. These risks affect not only political stability but also market dynamics, investment behavior, and environmental sustainability through mechanisms such as wars, terrorist attacks, economic crises, and political uncertainties (Antonakakis et al., 2017; Caldara & Iacoviello, 2022). For instance, events such as the Mumbai attacks, the U.S.–China trade war, the COVID-19 pandemic, and the Russia–Ukraine war have significantly disrupted global oil and commodity markets, exacerbating economic volatility (Chen et al., 2023). As a result, businesses, investors, and central banks increasingly consider geopolitical risks when formulating economic growth strategies.

Türkiye represents a particularly important case in this context due to its strategic location at the intersection of Asia and Europe, proximity to the Middle East and the Caucasus—regions with vast oil and natural gas reserves—and its position within the Mediterranean basin, a hub of global maritime trade routes. The country also controls critical straits and possesses substantial mineral deposits, water resources, and biodiversity. However, its geography exposes it to heightened geopolitical tensions and border-related security threats. Ongoing instability in neighboring Syria and Iraq, migration crises, and the presence of terrorist organizations such as the PKK and ISIS create persistent security challenges. In addition, the growing influence of Russia and the strategic maneuvers of Iran further shape Türkiye's geopolitical environment. Competition over access to energy resources, particularly Black Sea reserves and Middle Eastern energy corridors, underscores the centrality of energy security in the country's geopolitical risk profile. These dynamics inevitably influence Türkiye's economic policies, decision-making processes, and development strategies (Kızılkaya et al., 2024; Yilanci et al., 2025).

From an environmental perspective, geopolitical risks have both mitigating and progressive effects (Anser et al., 2021a). On the one hand, risks may reduce economic growth and energy demand by disrupting industrial activity, which in turn lowers greenhouse gas emissions and temporarily alleviates environmental pressures. On the other hand, heightened uncertainty can hinder investment in renewable energy, innovation, and green technologies, thereby exacerbating environmental degradation. Wang et al. (2022) classify these impacts under three main channels: (i) the consumption effect, whereby geopolitical tensions alter consumer spending patterns with environmental consequences; (ii) the investment effect, where firms reduce or delay long-term investments, particularly in environmentally friendly technologies; and (iii) the mitigating effect, in which industrial slowdowns lead to temporary reductions in emissions.

Building on these arguments, geopolitical risks are expected to influence the ecological footprint through multiple and potentially opposing channels. Heightened geopolitical tensions may suppress economic activity and energy demand in the short run, thereby temporarily alleviating environmental pressure. However, persistent geopolitical uncertainty can delay investments in renewable energy, weaken environmental governance, and reinforce dependence on fossil fuels, leading to higher ecological pressure in the long run. For countries characterized by strategic geopolitical exposure and energy security concerns, such as Türkiye, these dynamics are particularly pronounced. Consequently, the overall environmental impact of geopolitical risk depends on the relative dominance of contractionary effects versus longer-term structural mechanisms, rendering the net effect an empirical issue.

In the case of Türkiye, the relationship between geopolitical risk and environmental sustainability is examined through the ecological footprint framework. Based on the theoretical ambiguity outlined above, the following hypothesis is proposed:

H_1: Geopolitical risk has a statistically significant effect on the ecological footprint in Türkiye.

A positive coefficient of geopolitical risk would indicate that heightened geopolitical tensions expand the ecological footprint by intensifying environmental pressure, thereby deteriorating environmental sustainability. Conversely, a negative coefficient would suggest that geopolitical risk reduces the ecological footprint, reflecting a contractionary effect on economic activity and energy demand that temporarily alleviates environmental pressure.

2.2. Natural Resource Rents vs. Ecological Footprint

Natural resource rents represent the economic returns generated from the exploitation of a country's natural resources, including minerals, energy, forests, and water. In contrast, the ecological footprint measures the extent to which human activities place pressure on ecological systems by quantifying resource use and environmental impacts. The interaction between these two concepts is central to understanding the trade-offs between economic development and environmental sustainability. Although natural resource rents are often perceived as a driver of growth and development, the literature provides mixed evidence. Sachs and Warner (1995) argue that revenues from natural resources do not directly foster economic growth; instead, resource dependence frequently generates structural distortions that hinder long-term development. Moreover, the economic benefits of resource exploitation are accompanied by substantial environmental costs. Overexploitation and resource degradation can increase the ecological footprint, contributing to environmental decline, habitat loss, and a reduction in the ecological services on which societies depend (Wackernagel & Rees, 1998).

These dynamics are closely related to the natural resource curse hypothesis, which suggests that excessive reliance on natural resource rents may weaken institutional quality, discourage environmental regulation, and prioritize short-term economic gains over long-term ecological sustainability. Under such conditions, intensive extraction activities and energy-intensive production processes expand land use, emissions, and resource depletion, thereby increasing the ecological footprint. Empirical studies across different regions largely support this view, although the magnitude of the effect varies depending on structural characteristics and institutional settings (Ahmad et al., 2020; Jahanger et al., 2022; Zafar et al., 2019). Conversely, an alternative mechanism emphasizes the role of effective resource governance and strategic reinvestment of resource revenues. When natural resource rents are directed toward renewable energy development, technological innovation, biodiversity conservation, and pollution control, they may enhance resource efficiency and mitigate environmental pressure. In this context, institutional quality and policy choices play a decisive role in determining whether natural resource rents exacerbate or alleviate ecological degradation (Daly, 1996; Li et al., 2024).

Taken together, these opposing theoretical mechanisms imply that the environmental impact of natural resource rents is ambiguous a priori and depends on whether extraction-driven pressures or governance-driven mitigation channels dominate. Accordingly, natural resource rents are expected to play a decisive role in shaping the ecological footprint. Based on this theoretical ambiguity, the following hypothesis is proposed:

H_2: Natural resource rents have a statistically significant effect on the ecological footprint in Türkiye.

A positive coefficient of natural resource rents would indicate that higher resource revenues intensify extraction activities and energy-intensive production, thereby expanding the ecological footprint and exacerbating environmental pressure. Conversely, a negative coefficient would suggest that resource rents are effectively channelled into cleaner technologies, environmental protection, and sustainable resource management, leading to a reduction in ecological pressure.

3. Literature Review

A growing body of empirical research has explored the drivers of environmental sustainability, with particular emphasis on economic structures, institutional quality, and external uncertainties. Within this literature, natural resource rents and geopolitical risk have been identified as key determinants influencing environmental outcomes through multiple channels such as energy consumption patterns, investment decisions, and technological progress. Environmental sustainability is commonly measured using indicators including CO_2 emissions and ecological footprint, allowing researchers to capture both production- and consumption-based environmental pressures. However, the empirical findings remain inconclusive, reflecting substantial heterogeneity across countries, development levels, and econometric methodologies (Chu et al., 2023; Ulucak et al., 2020; Zafar et al., 2019). The literature reviews are summarized in Table 1.

The relationship between natural resource rents and environmental sustainability has been extensively examined, yet the evidence remains mixed. A dominant strand of the literature suggests that higher natural resource rents tend to deteriorate environmental sustainability by intensifying extraction activities and reinforcing fossil fuel–based production structures, particularly in emerging and developing economies (Ahmad et al., 2020; Jahanger et al., 2022; Shuayb et al., 2025; Zhou et al., 2024). These studies argue that resource abundance often leads to environmental degradation when revenues are not effectively channelled into clean technologies or renewable energy investments. In contrast, some evidence indicates that natural resource rents may support environmental sustainability under specific conditions. For instance, Zafar et al. (2019) find that natural resource rents can positively affect environmental sustainability in the United States (US), highlighting the role of advanced institutional capacity and human capital. Moreover, Ulucak et al. (2020) demonstrate that while natural resource rents increase CO_2 emissions in OECD countries, their effect on broader environmental indicators such as the ecological and carbon footprint is statistically insignificant, suggesting that economic structure and energy mix play a mediating role.

The literature examining geopolitical risk and environmental sustainability also reports divergent findings. Several studies suggest that heightened geopolitical risk may improve environmental sustainability by dampening economic activity, reducing energy demand, and slowing down environmentally harmful production processes (Anser et al., 2021b; Kızılkaya et al., 2024). This mechanism appears particularly relevant for countries like Türkiye, where geopolitical tensions may curb industrial output and emissions in certain periods. Conversely, other studies argue that geopolitical risk undermines environmental sustainability by discouraging foreign investment, delaying renewable energy deployment, and increasing reliance on carbon-intensive domestic energy sources (Luo & Sun, 2024; Yilanci et al., 2025). Furthermore, Chu et al. (2023) highlight the importance of time horizons, showing that geopolitical risk may harm environmental sustainability in the short run while generating favorable long-run effects through structural economic adjustments. These findings underline the nonlinear and context-dependent nature of the geopolitical risk–environment nexus.

More recent studies have adopted integrated frameworks to jointly analyze natural resource rents and geopolitical risk as simultaneous determinants of environmental sustainability. Evidence from multi-country analyses generally indicates that both higher resource rents and elevated geopolitical risk exacerbate environmental degradation, reinforcing each other through channels such as policy uncertainty and delayed green investments (Chen et al., 2023; Lin et al., 2024). However, this relationship is not uniform across countries. Li et al. (2024) report that geopolitical risk reduces environmental sustainability, whereas natural resource rents may enhance it under certain institutional settings. Similarly, country-specific evidence from India shows that geopolitical risk can support environmental sustainability while natural resource rents weaken it, emphasizing the importance of national characteristics and energy policies (Villanthenkodath & Pal, 2024). These contrasting results suggest that the combined effects of geopolitical risk and resource rents are highly sensitive to institutional quality, governance, and economic structure.

Table 1. Literature Summary

Author(s)	Countries /Period	Method(s)	Variables	Main Findings
Natural Resource Rents vs. Environmental Sustainability				
Zafar et al. (2019)	US 1970–2015	ARDL, Granger Causality	EF, NRR, GDP, EN, FDI, HC	NRR positively affect environmental sustainability.
Ahmad et al. (2020)	22 Emerging countries 1984–2016	CS-ARDL, AMG, D-H Causality	EF, NRR, GDP, INO	NRR negatively affect environmental sustainability.
Ulucak et al. (2020)	26 OECD countries 1980–2016	AMG	CO_2, EF, CF, NRR, GDP, EN	NRR increases CO_2 emissions, but it has no statistically significant effect on the EF or CF.
Jahanger et al. (2022)	73 Developing countries 1990–2016	PMG-ARDL	EF, NRR, GDP, FDI, GI, TEC, HC	NRR negatively affect environmental sustainability.
Zhou et al. (2024)	BRICS countries 1994–2018	OLS, GMM, FGLS, PCSE	CO_2, EF, NRR, GDP, REN, TFP	NRR negatively affect environmental sustainability.
Shuayb et al. (2025)	10 African countries 1990-2021	CS-ARDL, CCEMG	CO_2, NRR, GDP, REN, EI, GVR	NRR negatively affect environmental sustainability.
Geopolitical Risk vs. Environmental Sustainability				
Anser et al. (2021b)	5 Emerging countries 1995–2015	FMOLS, DOLS, AMG, D-H Causality	EF, GPR, EPU, GDP, EN, REN, POP	GPR positively affect environmental sustainability.
Chu et al. (2023)	E7 countries 1995–2018	PMG-ARDL	EF, CO_2, GPR, WUI, GDP, EN, EC	GPR harm the environmental sustainability in the short term but have beneficial effects over the long term.
Kızılkaya et al. (2024)	Türkiye 1985–2019	Fourier Shin, Fourier T-Y Causality	CO_2, GPR, GDP, REN, POP	GPR positively affect environmental sustainability.
Luo & Sun (2024)	27 countries 1990–2020	Panel quantile regression	CO_2, GPR, REN, FDI, GOV, ICT, EPS	GPR negatively affect environmental sustainability.
Yilanci et al. (2025)	Türkiye 1985–2021	Time-varying, Wavelet Coherence	EF, GPR, EPU GDP, EN	GPR negatively affect environmental sustainability.
Natural Resources Rents, Geopolitical Risk vs. Environmental Sustainability				
Chen et al. (2023)	38 countries 1970–2021	GMM, FGLS, Granger N. Causality	CO_2, GPR, NRR, GDP, REN	GPR and NRR negatively affect environmental sustainability.
Li et al. (2024)	38 countries 2002–2020	Panel quantile regression	CO_2, GPR, NRR, GDP, COR, EI	GPR reduces environmental sustainability, while NRR enhance it.
Lin et al. (2024)	36 countries 2000–2020	Two-step SGMM	CO_2, GPR, NRR, REN, GI, PCI	GPR and NRR negatively affect environmental sustainability.
Villanthenkodath & Pal (2024)	India 1990–2019	ARDL, DYNARDL	EF, CO_2, GPR, WUI, NRR, REN, GDP, LCF	GPR supports environmental sustainability, while NRR weaken it.

Note: CF: Carbon footprint. **CO_2:** Carbon dioxide emission. **EC:** Economic complexity. **EF:** Ecological footprint. **EI:** Energy intensity. **EN:** Energy consumption. **EPU:** Economic policy uncertainty. **EPS**: Environmental policy stringency. **FDI:** Foreign direct investment. **GDP:** Gross domestic product per capita. **GI:** Globalization Index. **GOV:** Government expenditure. **GPR:** Geopolitical risk. **GVR:** Governance. **HC:** Human capital. **ICT:** Information and communications technology. **INO:** Technological innovation. **LCF:** Load capacity factor. **NRR:** Natural resource export rate. **PCI:** Productivity capacity index. **POP:** Population. **REN:** Renewable energy. **TEC:** Technological progress. **TFP:** Total factor productivity. **WUI:** World uncertainty index.

Despite the expanding body of literature, notable gaps persist in understanding the environmental implications of natural resource rents and geopolitical risk, particularly in the context of Türkiye. Existing studies largely rely on cross-country analyses, which may overlook country-specific dynamics and limit the depth of policy-relevant insights. Moreover, the mixed empirical findings underscore the importance of context-sensitive approaches that account for structural characteristics and external shocks. Against this background, the present study contributes to the literature by offering Türkiye-specific evidence on the joint effects of natural resource rents and geopolitical risk on environmental sustainability, thereby providing more nuanced implications for policymakers in resource-dependent and geopolitically sensitive economies.

4. Data and Econometric Methodology

4.1. Data

This study employs annual data from 1985 to 2021 for Türkiye to analyze the impact of natural resources rents and geopolitical risk on ecological footprint, following the model outlined in Equation 1.

$$\mathrm{lnEF_t} = \alpha_0 + \beta_0 \mathrm{lnNRR_t} + \beta_1 \mathrm{lnGPR_t} + \beta_2 \mathrm{lnGDP_t} + \beta_3 \mathrm{lnEC_t} + \varepsilon_t \quad (1)$$

EF denotes the ecological footprint, which serves as a proxy for environmental sustainability. NRR represents natural resource rents, while GPR refers to the geopolitical risk index. These two variables constitute the primary focus of the empirical analysis. In addition, two widely used control variables in environmental economics are included to account for broader economic and energy-related factors. GDP represents real per capita gross domestic product, capturing the level of economic development, and EC denotes per capita energy consumption, serving as a proxy for energy use and efficiency. The analysis period concludes in 2021 due to data availability constraints. Table 2 provides comprehensive definitions and measurement details for all variables included in the study.

Table 2. Variable Definitions

Symbol	Description	Measurement	Source
EF	Ecological Footprint	Global hectares per capita	Global Footprint Network
NRR	Natural Resources Rents	Total natural resources rents (% of GDP)	WDI
GPR	Geopolitical Risk	Index	Matteo Iacoviello website
GDP	Economic Growth	GDP (constant 2010 US$)	WDI
EC	Energy Consumption	Per capita (gigajoule)	BP Statistical Review

In order to stabilize variance, attenuate potential heteroskedasticity, and enable the interpretation of estimated coefficients in terms of elasticities, all variables were transformed into their natural logarithmic form. The choice of variables is guided by the prevailing empirical literature, which identifies natural resource dependence, geopolitical uncertainty, economic scale effects, and energy intensity as key determinants of the ecological footprint.

4.2. Econometric Methodology

To examine the relationship specified in Equation (1), this study applies advanced time series techniques, specifically the Fourier ADL and the RALS Fourier ADL cointegration methods. Yilanci et al. (2023) have extended the Fourier ADL cointegration test proposed by Banerjee et al. (2017) by integrating the RALS approach. The RALS method provides significant advantages. First, it is more powerful than traditional cointegration tests because it incorporates information from non-normal errors, which many conventional tests overlook. Second, the RALS approach captures nonlinear interactions among variables, thereby accounting for potential nonlinear dynamics and relationships in the data (Lee et al., 2015).

The Fourier ADL test is based on the following model specification:

$$\Delta y_{1t} = \gamma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \delta_1 y_{1,t-1} + \gamma' y_{2,t-1} + \varphi' \Delta y_{2t} + \epsilon_t \quad (2)$$

In equation (2), γ and φ denote the parameter vectors and y_{2t} represents the explanatory variables. Following Im & Schmidt (2008), the RALS term is defined as follows:

$$\widehat{w}_t = [\hat{e}_t^2 - m_2, \hat{e}_t^3 - m_3 - 3m_2\hat{e}_t]' \quad (3)$$

In equation (3), $\hat{e}_t$ shows the residuals obtained from Equation (2) and $m_j = T^{-1}\sum_{t=1}^{T}\hat{e}_t^j$. The RALS cointegration regression is obtained by augmenting $\widehat{w}_t$ to Equation (2):

$$\Delta y_{1t} = \gamma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \delta_1 y_{1,t-1} + \gamma' y_{2,t-1} + \varphi' \Delta y_{2t} + \widehat{w}_t \gamma + v_t \quad (4)$$

In the RALS-FADL test, equation (4) is estimated using ordinary least squares and the t-statistic is calculated. The asymptotic distribution of the test statistic is provided in equation (5):

$$t^* \rightarrow \rho t + \sqrt{1-\rho^2} Z \quad (5)$$

In equation (5), t and t^* indicate Fourier ADL and RALS Fourier ADL test statistics, respectively. Z represents the standard normal random variable; ρ is the long-run correlation between residuals (ϵ_t) of equation (2) and residuals (v_t) of equation (4).

5. Findings

Before conducting the cointegration analysis, it is crucial to assess the stationarity characteristics of the variables using unit root tests. In the first stage of the econometric procedure, we employ both the Augmented Dickey-Fuller (ADF) test and the Fourier ADF test to examine the stationarity of the series. Since applying Fourier tests without accounting for nonlinearity can lead to a substantial loss of power, we utilize F-statistics to determine the presence of a nonlinear trend in the series. As noted by Enders and Lee (2012), traditional unit root tests are more suitable when the underlying data-generating process is linear. Therefore, in cases where the Fourier trigonometric terms are statistically insignificant, we rely on the results of the standard ADF test. Table 3 reports the ADF and Fourier ADF unit root test results for ecological footprint, natural resources rents, geopolitical risk, economic growth, and energy consumption.

Table 3. ADF and Fourier ADF Unit Root Tests

Variable	Freq.	Fourier ADF	F-stat.	ADF
EF	1	-2.437	33.962*	-1.269
ΔEF	4	-11.247*	0.546	-10.506*
NRR	1	-3.133	11.493*	-2.396
ΔNRR	2	-7.077*	0.975	-6.365*
GPR	3	-1.211	4.433***	-0.467
ΔGPR	3	-8.431*	0.607	-7.867*
GDP	1	-0.011	26.457*	0.311
ΔGDP	4	-0.882	3.739	-6.087*
EC	1	-0.422	21.594*	-1.361
ΔEC	4	-8.619*	2.877	-7.170*

Note: * and *** demonstrate statistical significance at the 1% and 10% level, respectively.

The results of the unit root tests fail to reject the null hypothesis for all series, suggesting that none of the series are stationary at their levels. However, the findings indicate that all series become stationary at their first differences. These findings confirm that all series are integrated of order one, I(1), thereby meeting the necessary precondition for conducting cointegration analysis.

In the second stage of the econometric analysis, we employ the Fourier ADL, RALS Fourier ADL, and Gregory and Hansen (1996) cointegration tests to investigate the existence of long-run relationships. Traditional cointegration techniques that overlook structural breaks may produce biased estimates. To address this issue, our study employs both the Fourier cointegration tests, which captures structural breaks gradually and smoothly, and Gregory-Hansen cointegration test that accounts for sudden structural changes.

Table 4. Fourier ADL and RALS Fourier ADL Cointegration Tests

Min AIC	**Freq.**	**Fourier ADL**	**RALS Fourier ADL**	**Rho**
-3.386	2	-5.287*	-4.915**	0.924
		Critical Values		
		1%	5%	10%
Fourier ADL		-5.279	-4.573	-4.200
RALS Fourier ADL		-5.104	-4.398	-4.036

Note: * and ** demonstrate statistical significance at the 1% and 5% level, respectively. The critical values of Fourier ADL and RALS Fourier ADL tests are obtained from Ilkay et al. (2021) and Yilanci et al. (2023), respectively.

Table 4 presents the results of the cointegration tests. As the test statistics from the Fourier ADL and RALS Fourier ADL cointegration methods exceed the 5% critical values, the null hypothesis of no cointegration is rejected. This reveals the presence of a cointegration relationship between ecological footprint and natural resources rents, geopolitical risk, economic growth, and energy consumption. Accordingly, the long-run analysis conducted with the level values of the series will avoid the risk of spurious regression. On the other hand, we apply the Gregory and Hansen (1996) cointegration test to assess the robustness of the findings from the Fourier ADL and RALS Fourier ADL tests. As shown in Table 5, the Gregory-Hansen test also confirms the existence of a long-run relationship among the variables, supporting the results obtained from the Fourier ADL and RALS Fourier ADL methods.

Table 5. Gregory-Hansen Cointegration Test

Lag	**t-stat.**	**Break Date**	**Decision**
0	-9.001*	2008	Cointegration
	Critical Values		
1%	5%	10%	
-6.92	-6.41	-6.17	

Note: * demonstrates statistical significance at the 1% level.

The final stage of the econometric analysis investigates the impact of positive and negative changes in natural resources rents, geopolitical risk, economic growth, and energy consumption on ecological footprint in Türkiye. For this purpose, we apply the dynamic ordinary least squares (DOLS) regression method proposed by Stock and Watson (1993). The DOLS approach incorporates the leads and lags of all explanatory variables, helping to address potential endogeneity issues and serial correlation in the error terms—common concerns in OLS estimation (Esteve & Requena, 2006). By accounting for possible reverse causality and feedback effects among the variables, DOLS provides asymptotically unbiased and efficient estimates of the long-run coefficients. This feature is particularly important in the context of environmental–economic relationships, where bidirectional interactions are likely to prevail. Table 6 presents the DOLS estimation results, which also incorporate trigonometric terms into the model specification.

Table 6. The Long-Run Coefficients

Variable	Dependent Variable: EF			
	Coefficient	**Std. Error**	**t-stat.**	**Prob.**
NRR	0.063	0.018	3.525	0.002
GPR	-0.016	0.006	-2.760	0.011
GDP	0.521	0.118	4.431	0.000
EC	0.309	0.134	2.308	0.030
C	-4.664	0.635	-7.350	0.000
SS	-0.007	0.005	-1.488	0.150
CC	0.019	0.005	3.596	0.002

Note: "CC" and "SS" represent the cosine and sine Fourier functions, respectively.

The DOLS estimation results reveal a positive and statistically significant coefficient for natural resource rents (0.063). Specifically, a 1% increase in natural resource rents leads to an approximately 0.06% rise in the ecological footprint in Türkiye. This finding suggests that higher resource rents intensify extraction activities and reinforce energy-intensive production structures, thereby increasing environmental pressure (H_2 is supported). The result is consistent with previous studies reporting that natural resource rents deteriorate environmental sustainability, particularly in emerging and developing economies (Ahmad et al., 2020; Chen et al., 2023; Jahanger et al., 2022; Villanthenkodath & Pal, 2024; Zhou et al., 2024).

On the other hand, the estimated coefficient for geopolitical risk is negative and statistically significant (-0.016). Specifically, a 1% increase in geopolitical risk leads to a 0.02% decline in the ecological footprint in Türkiye. This outcome indicates that heightened geopolitical uncertainty may temporarily reduce environmental pressure by constraining economic activity, investment, and energy demand (H_1 is supported). This finding aligns with the evidence provided by Anser et al. (2021b) and Villanthenkodath and Pal (2024), who document that geopolitical risk can support environmental sustainability under certain economic conditions.

Furthermore, the estimated coefficients for economic growth and energy consumption are positive and statistically significant. In particular, a 1% increase in economic growth and energy consumption results in a 0.52% and 0.31% rise in the ecological footprint in Türkiye, respectively. These results reflect the scale and energy-intensity effects of economic expansion and are consistent with earlier studies emphasizing the growth–environment trade-off and the environmental consequences of higher energy use (Ahmad et al., 2020; Ulucak et al., 2020; Zafar et al., 2019).

6. Conclusion and Policy Implications

This study investigates the effects of natural resource rents, geopolitical risk, economic growth, and energy consumption on Türkiye's ecological footprint using annual data for the period 1985–2021. The empirical analysis employs Fourier ADL, RALS Fourier ADL, Gregory-Hansen cointegration tests, and the DOLS method. The findings reveal that natural resource rents, economic growth, and energy consumption have positive and statistically significant effects on the ecological footprint, whereas geopolitical risk appears to reduce environmental pressure.

While geopolitical risks may contribute to temporary reductions in environmental degradation, they cannot function as effective environmental control tools independently. However, in the context of a strong economic structure, political stability, and reduced regional tensions, geopolitical factors can play a balancing role in mitigating environmental pressures. Accordingly, policymakers and international organizations should prioritize supporting peace initiatives, enhancing diplomatic engagement, and implementing strategies to mitigate regional conflicts, thereby ensuring geopolitical stability and enabling effective environmental governance.

Sustainable development requires that current generations improve their well-being without compromising the rights and needs of future generations. This can be achieved by reinvesting revenues derived from natural capital into its sustainable management; otherwise, such revenues risk depleting natural assets. In line with the empirical finding that natural resource rents increase Türkiye's ecological footprint, environmental policies should explicitly target the way resource-based revenues are utilized. Policies aimed at strengthening Türkiye's environmental sustainability should therefore focus on maintaining a stable macroeconomic framework and promoting effective natural resource management. Key measures include supporting existing legislation with technological innovation, taxing fossil fuels, accelerating the transition to environmentally friendly energy technologies, reducing dependence on resource-intensive sectors, and implementing carbon pricing and environmental taxation mechanisms. Such policies directly address the environmentally harmful impact of resource rents identified in this study.

Additionally, multifaceted support mechanisms such as research grants, subsidized loans, public awareness campaigns, and educational programs promoting sustainable consumption should be introduced to encourage environmental innovation. Given that energy consumption is found to significantly increase the ecological footprint in Türkiye, priority should be given to policies that improve energy efficiency and reduce the energy intensity of economic growth. Clearly defined and strictly enforced environmental standards are essential for the success of these initiatives. Investments in natural capital should encompass not only physical infrastructure but also ecosystem restoration, enhanced resource efficiency, and the protection of renewable natural assets, including forests, water basins, soils, wetlands, and biodiversity. Considering the adverse environmental effects of natural resource rents, green mining practices and stricter regulations in extractive industries are particularly relevant for Türkiye. Revenues from non-renewable resources should be allocated toward financing renewable energy projects and importing environmentally friendly technologies, while legal frameworks protecting energy and water resources should be strengthened. Redirecting resource rents to renewable alternatives and ensuring that waste generation remains within ecological limits are crucial steps toward mitigating the environmental pressures associated with Türkiye's current growth and energy structure.

Despite these insights, this study has some limitations. The analysis is restricted to Türkiye, which may limit the generalizability of the findings to other countries or regions. Moreover, employing quantile-based estimation techniques could provide a more comprehensive understanding of the relationship between geopolitical risk, natural resource rents, and the ecological footprint. Future research could also adopt asymmetric modeling approaches to capture the differential effects of positive and negative shocks in geopolitical risk and natural resource rents on environmental degradation. Addressing these limitations would enhance the robustness and applicability of the results in broader international and policy contexts.

Declarations and Disclosures

Ethical Responsibilities of Authors: The authors of this article confirm that their work complies with the principles of research and publication ethics.

Conflicts of Interest: No potential conflict of interest was reported by the authors.

Funding: The study was supported by Malatya Turgut Ozal University Scientific Research Projects Coordination Unit with project number 25G05.

Author Contributions: The authors confirm contribution to the article as follows: Conceptualization and design, F. Kızılkaya; data collection, F. Mike and O. Kızılkaya; analysis of data and interpretation of results, O. Kızılkaya; writing the first draft of the manuscript, F. Kızılkaya, O. Kızılkaya, and F. Mike; review and editing, F. Mike and F. Kızılkaya. The manuscript/article was read and approved by all the authors, and all authors accepted responsibility for their article.

Plagiarism Checking: This article was screened for potential plagiarism using a plagiarism screening program.

References

Ahmad, M., Jiang, P., Majeed, A., Umar, M., Khan, Z., & Muhammad, S. (2020). The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: An advanced panel data estimation. *Resources Policy, 69*, 101817. https://doi.org/10.1016/j.resourpol.2020.101817

Anser, M. K., Syed, Q. R., & Apergis, N. (2021a). Does geopolitical risk escalate CO_2 emissions? Evidence from the BRICS countries. *Environmental Science and Pollution Research, 28*(35), 48011-48021. https://doi.org/10.1007/s11356-021-13973-y

Anser, M. K., Syed, Q. R., Lean, H. H., Alola, A. A., & Ahmad, M. (2021b). Do economic policy uncertainty and geopolitical risk lead to environmental degradation? Evidence from emerging economies. *Sustainability, 13*(11), 5866. https://doi.org/10.3390/su13115866

Antonakakis, N., Gupta, R., Kollias, C., & Papadamou, S. (2017). Geopolitical risks and the oil-stock nexus over 1899-2016. *Finance Research Letters, 23*, 165-173. https://doi.org/10.1016/j.frl.2017.03.027

Banerjee, P., Arčabić, V., & Lee, H. (2017). Fourier ADL cointegration test to approximate smooth breaks with new evidence from crude oil market. *Economic Modelling, 67*, 114-124. https://doi.org/10.1016/j.econmod.2016.11.004

Caldara, D., & Iacoviello, M. (2022). Measuring geopolitical risk. *American Economic Review, 112*(4), 1194-1225. https://doi.org/10.1257/aer.20200658

Chen, L., Gozgor, G., Mahalik, M. K., Pal, S., & Rather, K. N. (2023). How does geopolitical risk affect CO2 emissions? The role of natural resource rents. *Resources Policy, 87*, 104321. https://doi.org/10.1016/j.resourpol.2023.104321

Chu, L. K., Doğan, B., Abakah, E. J. A., Ghosh, S., & Albeni, M. (2023). Impact of economic policy uncertainty, geopolitical risk, and economic complexity on carbon emissions and ecological footprint: An investigation of the E7 countries. *Environmental Science and Pollution Research, 30*(12), 34406-34427.

Daly, H. E. (1996). *Beyond growth: The economics of sustainable development*. Beacon Press.

Enders, W., & Lee, J. (2012). The flexible Fourier form and Dickey–Fuller type unit root tests. *Economics Letters, 117*(1), 196-199. https://doi.org/10.1016/j.econlet.2012.04.081

Esteve, V., & Requena, F. (2006). A cointegration analysis of car advertising and sales data in the presence of structural change. *International Journal of the Economics of Business, 13*(1), 111-128. https://doi.org/10.1080/13571510500520036

Gregory, A. W., & Hansen, B. E. (1996). Residual-based tests for cointegration in models with regime shifts. *Journal of Econometrics, 70*(1), 99-126. https://doi.org/10.1016/0304-4076(69)41685-7

Ilkay, S. C., Yilanci, V., Ulucak, R., & Jones, K. (2021). Technology spillovers and sustainable environment: Evidence from time-series analyses with Fourier extension. *Journal of Environmental Management, 294*, 1-11. https://doi.org/10.1016/j.jenvman.2021.113033

Im, K. S., & Schmidt, P. (2008). More efficient estimation under non-normality when higher moments do not depend on the regressors, using residual-augmented least squares. *Journal of Econometrics, 144*, 219-233. https://doi.org/10.1016/j.jeconom.2008.01.003

Intergovernmental Panel on Climate Change. (2014). *Climate change 2014: Impacts, adaptation, and vulnerability*. https://www.ipcc.ch/report/ar5/wg2/ (Access date: 12 June 2025).

Jahanger, A., Usman, M., Murshed, M., Mahmood, H., & Balsalobre-Lorente, D. (2022). The linkages between natural resources, human capital, globalization, economic growth, financial development, and ecological footprint: The moderating role of technological innovations. *Resources Policy, 76*, 102569. https://doi.org/10.1016/j.resourpol.2022.102569

Kızılkaya, F., Kızılkaya, O., & Mike, F. (2024). Does geopolitical risk escalate environmental degradation in Turkey? Evidence from a Fourier approach. *Environment, Development and Sustainability*, 1-22. https://doi.org/10.1007/s10668-024-05258-1

Lee, H., Lee, J., & Im, K. (2015). More powerful cointegration tests with non-normal errors. *Studies in Nonlinear Dynamics & Econometrics, 19*(4), 397-413. https://doi.org/10.1515/snde-2013-0060

Li, R., Wang, Q., & Guo, J. (2024). Revisiting the environmental Kuznets curve (EKC) hypothesis of carbon emissions: Exploring the impact of geopolitical risks, natural resource rents, corrupt governance, and energy intensity. *Journal of Environmental Management, 351*, 119663. https://doi.org/10.1016/j.jenvman.2023.119663

Lin, T. X., Gozgor, G., Rather, K. N., Mahalik, M. K., & Lau, C. K. M. (2024). How do natural resource rents and productive capacity affect carbon emissions? Evidence from developed and developing countries. *Resources Policy*, *93*, 105095. https://doi.org/10.1016/j.resourpol.2024.105095

Luo, H., & Sun, Y. (2024). Effects of geopolitical risk on environmental sustainability and the moderating role of environmental policy stringency. *Scientific Reports*, *14*(1), 10747. https://doi.org/10.1038/s41598-024-60773-5

Sachs, J. D., & Warner, A. M. (1995). *Natural resource abundance and economic growth* (NBER Working Paper No. 5398). National Bureau of Economic Research. https://doi.org/10.3386/w5398

Shuayb, A. S. S., Dube, S., Khalifa, W., Deka, A., Kareem, P. H., & Cavusoglu, B. (2025). The impact of natural resources rent, renewable energy, and governance on the environmental sustainability—Evidence from resource-rich countries. In *Natural resources forum* (Vol. 49, No. 2, pp. 1842-1858). Oxford, UK: Blackwell Publishing Ltd. https://doi.org/10.1111/1477-8947.12459

Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica, 61*(4), 783-820. https://doi.org/10.2307/2951763

Republic of Türkiye Ministry of Environment, Urbanization and Climate Change, *Kyoto Protocol.* https://iklim.gov.tr/kyoto-protokolu-i-35 (Access date: 8 August 2025).

Republic of Türkiye Ministry of Foreign Affairs, Vienna Convention and Montreal Protocol. https://www.mfa.gov.tr/viyana-sozlesmesi-ve-montreal-protokolu.tr.mfa (Access date: 8 August 2025).

Ulucak, R., & Ozcan, B. (2020). Relationship between energy consumption and environmental sustainability in OECD countries: The role of natural resources rents. *Resources Policy*, *69*, 101803. https://doi.org/10.1016/j.resourpol.2020.101803

Villanthenkodath, M. A., & Pal, S. (2024). Environmental degradation in geopolitical risk and uncertainty contexts for India: A comparison of ecological footprint, CO2 emissions, and load capacity factor. *Energy and Climate Change, 5*, 100122. https://doi.org/10.1016/j.egycc.2023.100122

Wackernagel, M., & Rees, W. (1998). *Our ecological footprint: Reducing human impact on the Earth* (Vol. 9). New Society Publishers.

Wang, K. H., Kan, J. M., Jiang, C. F., & Su, C. W. (2022). Is geopolitical risk powerful enough to affect carbon dioxide emissions? Evidence from China. *Sustainability, 14*(13), 7867. https://doi.org/10.3390/su14137867

Yilanci, V., Ulucak, R., Zhang, Y., & Andreoni, V. (2023). The role of affluence, urbanization, and human capital for sustainable forest management in China: Robust findings from a new method of Fourier cointegration. *Sustainable Development, 31*(2), 812-824. https://doi.org/10.1002/sd.2421

Yilanci, V., Mike, F., Ursavaş, U., & Kızılkaya, O. (2025). Economic and geopolitical risk factors on environmental sustainability in Türkiye: A time-varying and wavelet coherence analysis. *Quality & Quantity*, 1-21. https://doi.org/10.1007/s11135-025-02442-x

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 investment on the ecological footprint: The case of the United States. *Resources Policy, 63*, 101428. https://doi.org/10.1016/j.resourpol.2019.101428

Zhang, S., Shinwari, R., Zhao, S., & Dagestani, A. A. (2023). Energy transition, geopolitical risk, and natural resources extraction: A novel perspective of energy transition and resources extraction. *Resources Policy, 83*, 103608. https://doi.org/10.1016/j.resourpol.2023.103608

Zhou, X., Patel, G., Mahalik, M. K., & Gozgor, G. (2024). Effects of green energy and productivity on environmental sustainability in BRICS economies: The role of natural resources rents. *Resources Policy*, *92*, 105026. https://doi.org/10.1016/j.resourpol.2024.105026

This Page Intentionally Left Blank