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Research Article

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THE RELATIONSHIP BETWEEN ENVIRONMENTAL TAXES AND ECOLOGICAL FOOTPRINT IN TÜRKİYE: AN ANALYSIS IN THE CONTEXT OF THE EKC HYPOTHESIS

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Abstract: Growing concerns over climate change and environmental degradation have brought public policy instruments to the forefront of efforts toward achieving sustainable development. This study examines the influence of environmental taxation and renewable energy on Türkiye's ecological footprint within the Environmental Kuznets Curve (EKC) framework, using annual data from 1994 to 2023. The analysis adopts the Augmented ARDL approach to examine long-term dynamics. The results confirm the EKC hypothesis for Türkiye, indicating that environmental taxes reduce the ecological footprint, while renewable energy's effect is statistically insignificant. Calculations based on coefficients obtained from the Augmented ARDL estimator indicate that the per capita income threshold value for the economic growth-environmental pollution relationship in Türkiye is $9,288. Increases in per capita income above this threshold have a pollution-reducing effect. Accordingly, for the period after 2012, the increase in per capita income in Türkiye contributes to a reduction in environmental pollution, consistent with the EKC hypothesis, as it is above a certain threshold. Such a finding implies that increases in welfare beyond a certain point contribute to the development of environmental sensitivity. Additional robustness analyses conducted with alternative estimators—FMOLS, DOLS, and CCR—produce consistent outcomes. These findings highlight the significance of environmental fiscal measures in advancing environmental sustainability and suggest that environmental taxes can function as an effective policy tool for reducing environmental pressures in Türkiye.

Keywords: Ecological Footprint, Environmental Taxes, Renewable Energy, EKC, Türkiye.

JEL Code: H23, Q56, Q58, C32.

TÜRKİYE'DE ÇEVRE VERGİLERİ VE EKOLOJİK AYAK İZİ İLİŞKİSİ: EKC HİPOTEZİ BAĞLAMINDA BİR ANALİZ

Özet: İklim değişikliği ve çevresel bozulmanın giderek artan etkileri, sürdürülebilir kalkınma hedeflerine ulaşmada kamu politikası araçlarının önemini ön plana çıkarmaktadır. Bu çalışma, 1994–2023 dönemine ait yıllık veriler kullanılarak, Çevresel Kuznets Eğrisi (EKC) hipotezi çerçevesinde çevre vergileri ve yenilenebilir enerjinin Türkiye'nin ekolojik ayak izi üzerindeki etkilerini incelemektedir. Analizde uzun dönem ilişkilerini değerlendirmek amacıyla Genişletilmiş ARDL yaklaşımı uygulanmıştır. Bulgular, Türkiye için EKC hipotezinin geçerli olduğunu ve çevre vergilerinin ekolojik ayak izini azalttığını göstermektedir. Buna karşılık, yenilenebilir enerjinin etkisinin istatistiksel olarak anlamlı olmadığı tespit edilmiştir. Genişletilmiş ARDL tahmincisinden elde edilen katsayılara dayalı hesaplamalar, Türkiye'de ekonomik büyüme-çevre kirliliği ilişkisi için kişi başına düşen gelir eşik değerinin 9.288 dolar olduğunu göstermektedir. Bu eşiğin üzerindeki kişi başına gelirdeki artış kirliliği azaltıcı bir etkiye sahiptir. Buna göre, 2012 sonrası dönem için Türkiye'de kişi başına gelirdeki artış, EKC hipoteziyle tutarlı olarak, belirli bir eşiğin üzerinde olduğu için çevre kirliliğinin azalmasına katkıda bulunmaktadır. Böylesi bir bulgu, refah düzeyindeki belirli bir noktadan sonraki artışın beraberinde çevreye karşı duyarlılığın gelişmesine katkı sağladığını ima etmektedir. Ayrıca, alternatif tahmin yöntemleri (FMOLS, DOLS ve CCR) ile yapılan sağlamlık analizlerinde de benzer sonuçlara ulaşılmıştır. Elde edilen bulgular, çevresel sürdürülebilirliğin sağlanmasında çevre vergileri gibi mali araçların önemine dikkat çekmekte ve bu vergilerin çevresel baskıları azaltmada etkili bir politika aracı olabileceğini göstermektedir.

Anahtar Kelimeler: Ekolojik Ayak İzi, Çevre Vergileri, Yenilenebilir Enerji, EKC, Türkiye.

JEL Kodu: H23, Q56, Q58, C32.

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Introduction

Significant increases in energy demand and the overexploitation of natural resources, coupled with ever-increasing global economic activity, have become key threats to environmental sustainability. In this process, not only CO_2 emissions but also consumption exceeding the renewable capacity of natural resources exacerbate environmental problems. In this context, the ecological footprint (EFP) indicator, developed to comprehensively measure countries' environmental pressures, is central to discussions of sustainable development. An analysis of Türkiye reveals a recent significant increase in its EFP, while its biocapacity has been declining (Figure 1). This demonstrates that environmental pressures are beginning to exceed sustainable limits, and that Türkiye has rapidly transitioned from a country with ecological reserves in the pre-1980 period to a country with an ecological deficit in the post-1980 period.

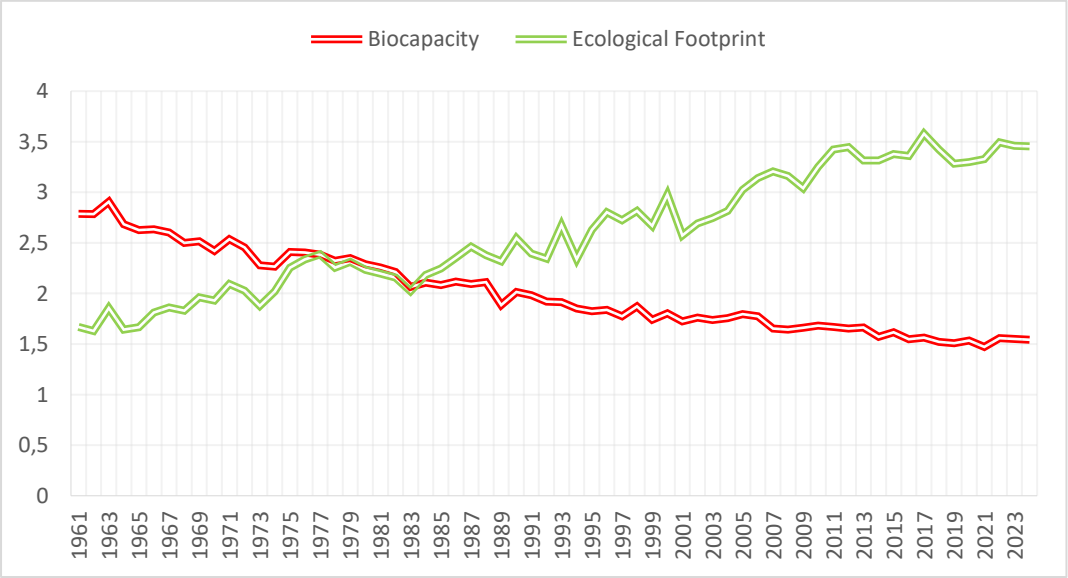


Figure 1. Course of Ecological Balance in Türkiye (1961-2024)
Source: Global Footprint Network (2025)

In this context, policy tools for reducing the EFP are being discussed both nationally and, more extensively, in the international literature. Environmental taxes (ET), whose theoretical foundations lie in the pioneering work of Pigou (1920), are among the most frequently discussed and evaluated fiscal instruments. Theoretically, ET aims to internalize the costs of activities that cause environmental pollution, thereby shifting economic agents' behavior toward more environmentally friendly choices. In addition to their goal of reducing environmental deterioration, ET encourage the adoption of renewable energy (Bozatli & Akca, 2023) and green innovations (Fang et al., 2022). Although ET are theoretically considered to have such positive effects, their effectiveness depends on many factors, including optimal tax design, countries' energy profiles, economic development priorities, and institutional capacity.

Numerous findings in international literature such as Shayanmehr et al. (2023), Mehboob et al. (2024) and Liu (2025) support the role of ET in reducing environmental pollution. However, evidence from Türkiye remains inconclusive regarding the nexus between ET and environmental quality. For example, Esen and Dündar (2021), Özbek (2023), and Biçer and Biniş (2024) found that ET contributes to reducing environmental degradation, whereas Telatar and Birinci (2022) as well as Şenel and Kalaycı (2025) reported that this relationship was statistically insignificant. Furthermore, as far as we can observe, Akkaya and Hepsag (2021) appear to be the only study that examines the EKC hypothesis from the perspective of ET in

Türkiye. Moreover, the mixed evidence on renewable energy's environmental effects and the limited investigation of ET together indicate a significant research gap in the existing literature. Therefore, analyzing the impact of ET on Türkiye's EFP, while simultaneously assessing the validity of renewable energy consumption (REN) and of the EKC, would be a significant contribution to the existing literature.

The analysis aims to bridge the existing gaps in the literature from three standpoints: (I) It provides new findings from a perspective different from to the limited number of studies have analyzed the impact of ET on the EFP in Türkiye in a time-series context and that have yielded mixed results. (II) Within the framework of the EKC hypothesis, the impact of ET, economic growth, and REN on EFP is assessed holistically. (III) The use of the EFP indicator in empirical analysis offers a more comprehensive perspective that does not reduce environmental sustainability to CO_2 emissions alone.

The structure of the research is as follows: the subsequent section provides a comprehensive review of the relevant literature, followed by a concise description of the methodological framework. Thereafter, the empirical findings are examined in detail, and the study concludes with a discussion of the main results and corresponding policy implications.

Literature Review

The role of ET in reducing environmental pollution, rooted in the pioneering work of Pigou (1920), has attracted considerable attention in both national and international literature. The empirical studies (Akca and Bozatli, 2023; Liu, 2025; Mehboob et al., 2024; Murad et al., 2025; Radulescu et al., 2025; Saqib et al., 2025; Shayanmehr et al., 2023) often report that ET are important fiscal instruments in combating environmental pollution. In Türkiye, empirical studies examining the effects of ET on environmental pollution have gained significant momentum in recent years. These studies typically examine relationship between ET and environmental indicators, including CO_2 and other greenhouse gas emissions, EFP, and load-capacity factors. The summary findings from these studies investigating the impact of ET in Türkiye are presented in Table 1. Findings in the literature yield divergent conclusions regarding the impact of ET on environmental quality. While a significant portion of researchers on the subject for Türkiye (Akkaya and Hepsag, 2021; Bekun et al., 2025; Bişgin, 2025; Çebişli and Yelman, 2023; Şenel and Kalaycı, 2025; Telatar and Birinci, 2022) report a statistically insignificant relationship between ET and environmental pollution indicators, others (Akkuş, 2025; Biçer and Biniş, 2024; Esen and Dündar, 2021; Özbek, 2023; Sarıgül and Topcu, 2021) provide empirical evidence on the role of ET in reducing environmental degradation. Only Yavuz (2021) differs from these two views by emphasizing that the relationship in question is positive. Therefore, empirical evidence on the success of ET implemented in Türkiye is far from conclusive.

Table 1. Summary of Empirical Literature

Author(Year)	Dependent Variable	Period	Method	Finding
Esen and Dündar (2021)	Carbon Footprint	1994–2017	Time Series Techniques	Energy taxes reduce the carbon footprint.
Akkaya and Hepsağ (2021)	CO_2	1985–2021	Time Series Techniques	Fuel tax has no statistically significant effect on CO_2 emissions.
Sarıgül and Topcu (2021)	CO_2	1994–2015	Time Series Techniques	ET reduce CO_2 emissions.

Yavuz (2021)	EFP	1994–2017	Ordinary Least Squares	ET have an increasing effect on the EFP.
Yavuz and Ergen (2022)	EFP	1998–2016	Panel Causality	There is a unidirectional causality from ET to EFP in Türkiye.
Telatar and Birinci (2022)	EFP and CO_2	1994–2019	Time Series Techniques	In the long run, there is no significant relationship between ET and environmental pollution indicators.
Çebişli and Yelman (2023)	Greenhouse Gas Emissions	1990–2020	ARDL	ET have a statistically insignificant effect on greenhouse gas emissions.
Özbek (2023)	CO_2	1994–2021	ARDL	ET have a reducing effect on CO_2 emissions.
Biçer and Biniş (2024)	CO_2	1994–2021	ARDL	ET have a reducing effect on CO_2 emissions.
Bişgin (2025)	EFP	1994–2022	Fourier-Shin	In the long run, there is no significant relationship between ET and environmental pollution indicators.
Şenel and Kalaycı (2025)	EFP	1995–2021	ARDL	ET have a statistically insignificant effect on the EFP.
Akkuş (2025)	CO_2	–	Computable General Equilibrium	ET have a limited but reducing role in CO_2 emissions.
Bekun et al. (2025)	Load Capacity Factor	1990–2020	ARDL	ET have no statistically significant effect on the load capacity factor.

The existing literature on ET in Türkiye has only partially examined how economic growth and the transition toward renewable energy interact to shape environmental outcomes. Although empirical contributions are relatively few, most findings suggest that rising income levels in Türkiye are associated with higher environmental pressures (Esen and Dündar, 2021; Özbek, 2023; Sarıgül and Topcu, 2021; Şenel and Kalaycı, 2025; Yavuz, 2021), while the use of renewable energy sources tends to alleviate these pressures (Sarıgül and Topcu, 2021; Yavuz, 2021). Among these works, Akkaya and Hepsag (2021) are the only researchers who empirically examined the EKC in relation to ET and confirmed its validity for Türkiye during the study period.

Beyond literature directly addressing ET, broader national and international studies in Türkiye generally converge on the validity of the EKC, implying an inverted U-shaped relationship between economic growth and environmental degradation (Akca, 2021; Bozatli and Akca, 2024; Çağlar, 2022; Çamkaya, 2024; Destek, 2018; Koç et al., 2025; Özyakışır and Çamkaya, 2025; Pata, 2018).

When the role of renewable energy in mitigating environmental degradation is considered, the empirical record remains mixed. Several studies (Bozatli and Akca, 2024;

Çamkaya, 2024; Karaaslan and Çamkaya, 2022; Koç et al., 2025) report a pollution-reducing effect, whereas others (Afreefir and Khalifa, 2025; Dam and Sarkodie, 2023; Pata, 2018; Yurtkuran, 2020) find either statistically insignificant effects or limited effectiveness in reducing pollution.

A comprehensive evaluation of this body of work reveals that, despite an increasing scholarly interest in the environmental implications of taxation policies, systematic empirical research in Türkiye is still at an early stage. Most analyses have concentrated on the direct tax–pollution nexus, while studies embedding these instruments within a broader environmental–economic framework are still rare. Only one investigation explicitly linked the EKC to ET, indicating that the potential intermediary function of tax instruments within the growth–environment interaction has not yet been thoroughly explored. Moreover, the empirical literature on renewable energy's contribution to environmental outcomes remains inconsistent and incomplete. These observations demonstrate the necessity of adopting an integrated analytical perspective that jointly examines ET, REN, economic growth, and environmental quality in Türkiye. By addressing these dimensions together, the present research aims to enrich and extend the existing empirical evidence base.

Model and Methodology

This study conducted for Türkiye analyzes the interaction between ET and EFP. In doing so, it also questions the validity of the EKC hypothesis and the impact of REN. Annual data for 1994–2023 were employed; variable information and the model formulation are presented in Table 2 and Equation (1), respectively.

Table 2: Variables and Data Sources

Variable	Symbol	Unit	Source
Ecological Footprint	EFP	Per Capita	GFN
Economic Growth	GDP	Per Capita (Constant 2015 US$)	WDI
Renewable Energy Consumption	REN	Per Capita	Our World in Data
Environmental Taxes	TAX	% of GDP	OECD

$$\ln EFP_t = \beta_0 + \beta_1 ln\ GDP_t + \beta_2 ln\ \mathrm{GDP}_t^2 + \beta_3 ln\ \mathrm{REN}_t + \beta_4 ln\ \mathrm{TAX}_t + \varepsilon_t \quad (1)$$

In equation (1), β_0 and ε_t denote the constant and error terms, respectively. The 'ln' prefix on the variables indicates that a logarithmic transformation has been applied. The dependent variable is the ecological footprint. $\beta_1, \beta_2, \beta_3, \beta_4$ represents economic growth, the square of economic growth, renewable energy consumption, and environmental taxes, respectively. The EKC hypothesis, modeled by Grossman and Krueger (1991) and inspired by Kuznets's (1955) research on income levels and inequality, posits an inverted U-shaped relationship between economic growth and environmental pollution. Accordingly, within the scope of the EKC, β_1 and β_2 the coefficients of and are predicted to be statistically significantly positive and negative, respectively. The coefficients of β_3 and β_4 are expected to be negative and significant. Increasing the use of renewable energy is expected to reduce the environmental damage caused by the consumption of traditional fossil fuels. Furthermore, based on Pigou (1920), well-designed ET policies are predicted to reduce pollution.

To predict the proposed model, a time series procedure consisting of four consecutive stages was applied. Initially, the stationary of the variables were examined using both the standard ADF test (Dickey & Fuller, 1979) and a variant that accounts for a possible structural break. Subsequently, the presence of a long-run equilibrium relationship was explored using the Augmented ARDL (A-ARDL) proposed by Sam et al. (2019). While the ARDL model introduced by Pesaran et al. (2001) remains widely used, subsequent studies have raised methodological concerns about its assumptions. Sam et al. (2019) emphasized that conventional ARDL estimation may become unreliable when the dependent variable is not strictly integrated of order one, I(1), because the standard F-test alone can yield misleading results in degenerate cases. To mitigate such limitations, Sam et al. (2019) proposed an auxiliary F-independent test, which complements the conventional F- and t-statistics. The validity of the cointegration relationship only emerges when all test statistics jointly exceed their corresponding critical values.

$$F-general \mid H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0 \tag{2}$$

$$t-dependent \mid H_0: \beta_1 = 0 \tag{3}$$

$$F-independent \mid H_0: \beta_2 = \beta_3 = \beta_4 = 0 \tag{4}$$

To capture the long-run association among the variables, this study employs the A-ARDL procedure originally introduced by Sam et al. (2019). Subsequently, the robustness of the estimated coefficients is evaluated by re-estimating the model using alternative econometric strategies. The reliability of the long-run parameters is reinforced through the application of three distinct cointegration estimators—CCR (Park, 1992), DOLS (Stock and Watson, 1993), and FMOLS (Phillips and Hansen, 1990)—each correcting for endogeneity and serial correlation in different ways.

Empirical Results

In the first stage of empirical research, the unit root properties of the series were examined using the traditional ADF test and the ADF test with a break, and the findings are reported in Table 3.

Table 3. Unit Root Tests

Variables	ADF		Break ADF	
	I (0)	*I (1)*	*I (0)*	*I (1)*
EFP	-2.463 (0.134)	-7.397* (0.000)	-3.830 (0.222)	-7.288* (0.000)
GDP	0.078 (0.958)	-4.851* (0.000)	-1.621 (0.999)	-5.208* (0.000)
GDP²	0.239 (0.970)	-4.803* (0.000)	-1.536 (0.999)	-5.183* (0.000)
REN	1.206 (0.997)	-6.276* (0.000)	-2.687 (0.835)	-7.055* (0.000)
TAX	-2.930*** (0.054)	–	-3.356 (0.469)	-6.697* (0.000)

Note: *, **, and *** correspond to rejection of the null hypothesis of a unit root at the 1%, 5%, and 10% significance levels, respectively. Lag lengths were determined using the Akaike Information Criteria (AIC).

ADF results in Table 3 indicate that all variables, except ET, are stationary at first difference. However, according to the ADF test with break, all series are stationary after first difference. Because investigating the cointegration relationship using the A-ARDL method is appropriate in this context, tests were conducted within the scope of the model in Equation (1).

Table 4 reports the bounds and diagnostic test results for the cointegration relationship. Table 5 presents the critical values to confirm the validity of the cointegration relationship.

Table 4. Cointegration Results

Dependent Variable: EFP			**Diagnostic Tests**				
Model (2, 3, 3, 1, 3)	**Statistic**	**Value**	X_{SC}	X_{H}	X_{N}	X_{FF}	**C/CSQ**
$efp = f(gdp, gdp^2, ren, tax)$	$F_{general}$	5.33**	0.338 (0.722)	1.045 (0.487)	0.220 (0.895)	0.476 (0.507)	Stable Stable
	$t_{dependent}$	-5.00*	**Cointegration (✓)**				
	$F_{independent}$	6.39**	**Diagnostic Control (✓)**				

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

Table 5. A-ARDL Critical Values

	Lower Bound I(0)			**Upper Bound I(I)**		
Test	**%1**	**%5**	**%10**	**%1**	**%5**	**%10**
$F_{general}$ (Narayan, 2005)	4.76	3.35	2.75	6.67	4.77	3.99
$t_{dependent}$ (Pesaran, 2001)	-3.43	-2.86	-2.57	-4.60	-3.99	-3.66
$F_{independent}$ (Sam et al. 2019)	4.15	2.80	2.22	6.83	4.70	3.84

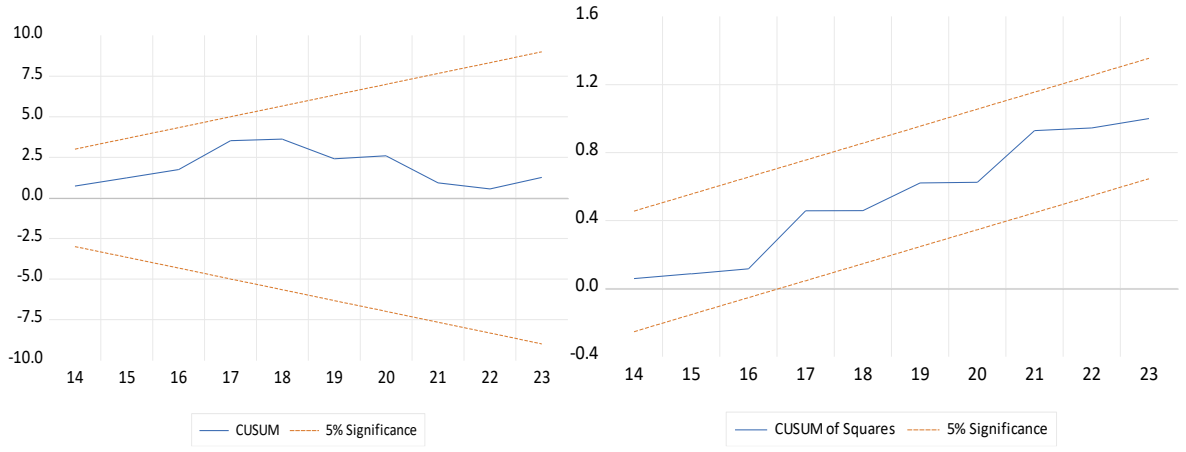


Figure 2. CUSUM and CUSUMSQ Graphs

All three test statistics in Table 4 are greater than the relevant critical values presented in Table 5. Accordingly, the null hypothesis of no cointegration was rejected, and the series were found to move together in the long run. However, for the estimated model to be valid and reliable, it must meet certain assumptions. The findings of the diagnostic tests in Table 4 indicate that the model is free of autocorrelation and heteroscedasticity problems, the series are normally distributed, and the functional form is significant. Furthermore, to ensure the reliability of the obtained parameters, the CUSUM and CUSUMSQ plots must be stable. As shown in Figure 2, both plots indicate parameter stability. Accordingly, there is no problem in estimating the model. Table 6 presents the long-term forecast results calculated using the A-ARDL method.

Table 6. A-ARDL Long-Term Forecast Results

	Dependent Variable: EFP		
Variables	**Coefficient**	**t-statistic**	**Probability Values**
GDP	15.695	6.691	0.000*
GDP²	-0.853	-6.490	0.000*

REN	-0.022	-0.364	0.723
TAX	-0.123	-3.342	0.007*

Note: The term * indicates statistical significance at the 1% level.

(I) The empirical evidence from this study provides robust support for the EKC in Türkiye. This finding regarding the validity of the EKC is consistent with research conducted in Türkiye (Destek, 2018; Pata, 2018; Akca, 2021; Çağlar, 2022; Çamkaya, 2024; Bozatli and Akca, 2024; Özyakışır and Çamkaya, 2025; Koç et al., 2025). Calculations based on coefficients obtained from the A-ARDL estimator indicate that the threshold value of per capita income for the economic growth–environmental pollution relationship in Türkiye is $9,288. Beyond this point, an increase in per capita income has a pollution-reducing effect. The relationship between per capita income and the threshold value during the study period is illustrated in Figure 3.

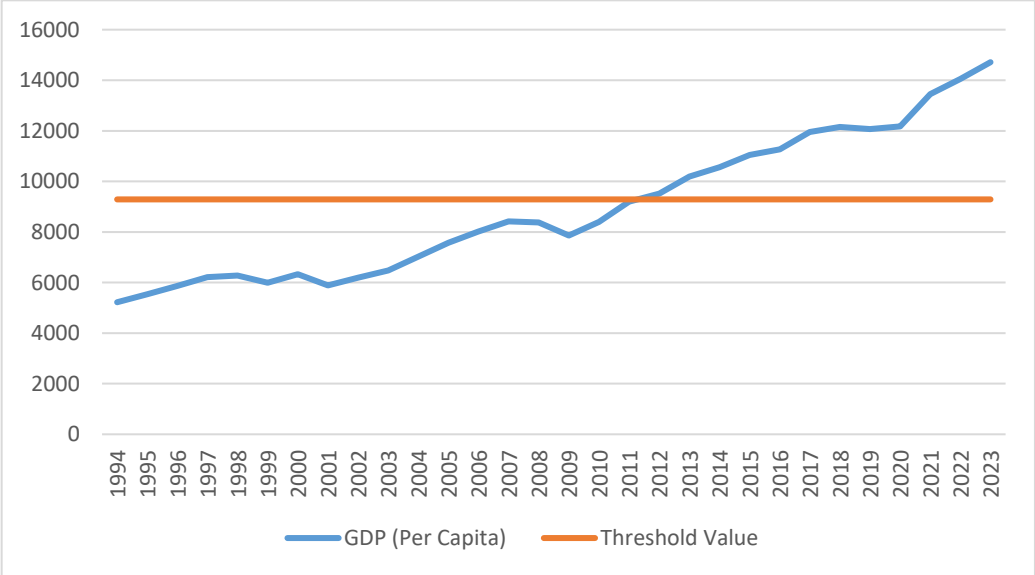


Figure 3. Per Capita Income and EKC Threshold Value in Türkiye

As shown in Figure 3, the relationship between per capita income and the threshold value differs before and after 2012. Accordingly, while an increase in per capita income was associated with increased environmental pollution before 2012, this effect reversed after 2012. Currently in Türkiye the increase in per capita income contributes to a reduction in environmental pollution because it is above a certain threshold, consistent with the EKC hypothesis. However, based on the alternative estimator results presented in Table 7, the threshold values are $10,564 (FMOLS), $9,890 (DOLS), and $10,246 (CCR). When these values are taken into account, the main result remains unchanged; however, the year in which the threshold is crossed differs. Overall, such a finding implies that increases in welfare beyond a certain point are accompanied by heightened environmental sensitivity.

(II) Empirical analysis indicates that REN does not exert a statistically significant influence on Türkiye's EFP. This outcome suggests that the current scale and composition of REN in the country have not yet reached a level capable of mitigating environmental pressure. The existing body of empirical research for Türkiye presents diverse and sometimes contradictory evidence regarding the environmental implications of REN. Nevertheless, the nonsignificant relationship observed in this study is consistent with several previous studies that reported similar findings (Afreefir & Khalifa, 2025; Dam & Sarkodie, 2023; Pata, 2018; Yurtkuran, 2020). According to Our World in Data (2025), REN accounted for 19.79% of total

energy consumption in Türkiye in 2024. This means that approximately one-fifth of energy consumption comes from renewable sources, while the remaining four-fifths comes from fossil fuels. Therefore, the continued heavy dependence of economic activities on fossil fuels and the low share of REN are significant contributors to this effect. Although investments in renewable energy play a role in increasing its share of the total, in the short term such investment can increase environmental pollution during initial stages due to production processes. Considering the government's significant incentives for renewable energy in the near term and the rapid increase in investments in this sector, the impact of REN on environmental quality is likely to become more pronounced and more effective in future periods.

(III) ET have a negative and statistically significant effect on EFP. Accordingly, ET are effective fiscal tools for reducing Türkiye's EFP. While this empirical finding regarding the pollution-reducing effect of ET differs from a significant portion of the existing literature (Yavuz, 2021; Akkaya and Hepsag, 2021; Telatar and Birinci, 2022; Çebişli and Yelman, 2023; Bişgin, 2025; Şenel and Kalaycı, 2025; Bekun et al. 2025), it supports the findings of the other portion of the literature (Esen and Dündar, 2021; Sarıgül and Topcu, 2021; Özbek, 2023; Biçer and Biniş, 2024; Akkuş, 2025). The empirical literature on ET in Türkiye does not indicate a clear relationship. However, the empirical results of this study show that a 1% increase in ET reduces the EFP by 0.123%. Such a finding has important implications for policy effectiveness. Although the impact of ET is consistent with theoretical expectations and with findings in the empirical literature, the effect size obtained is quite low. In this context, increasing the expected effect by adjusting the design of ET in Türkiye is important for combating environmental pollution.

Table 7. Alternative Estimator Results

	Dependent Variable: EFP		
Variables	**FMOLS**	**DOLS**	**CCR**
GDP	14.159*	13.846*	15.270*
	(7.998)	(3.412)	(8.673)
	[0.000]	[0.006]	[0.000]
GDP^2	-0.764*	-0.752*	-0.826*
	(-7.816)	(-3.315)	(-8.483)
	[0.000]	[0.007]	[0.000]
REN	0.012	-0.046	0.012
	(0.403)	(-0.453)	(0.296)
	[0.689]	[0.659]	[0.769]
TAX	-0.066**	-0.124***	-0.063**
	(-2.692)	(-2.011)	(-2.431)
	[0.012]	[0.071]	[0.022]

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

The results obtained by re-estimating these findings using alternative methods are reported in Table 7. Accordingly, all estimators support the results obtained using the A-ARDL method and the inferences drawn in this context. Overall, the results suggest that the EKC is valid in Türkiye for the period under consideration. While ET have a reducing effect on the EFP, REN does not have a statistically significant effect.

Discussion and Conclusion

This study empirically investigates the influence of ET on Türkiye's EFP by applying advanced time-series econometric techniques within a comprehensive framework that integrates renewable energy dynamics and the EKC. The results generate three central insights. First, the findings confirm that the EKC mechanism is relevant in the Turkish context over the

analyzed period. The estimated parameters reveal that at early stages of economic development, growth intensifies environmental pressure; however, beyond a certain income level, continued expansion tends to alleviate environmental degradation. This curvilinear relationship conforms to theoretical expectations and aligns with prior evidence of an inverted-U relationship between economic growth and environmental outcomes in Türkiye. Second, REN does not exert a statistically significant influence on the EFP. This suggests that although the share of renewable energy in Türkiye's overall energy portfolio has increased, the current scale, efficiency, and technological advancement of renewables have not yet reached the threshold required to produce tangible improvements in environmental quality. Furthermore, although investments in renewable energy may increase environmental pressures in the short term because of production-related factors, this effect is likely to be reversed in the long term. Finally, ET have a significant positive impact on reducing the EFP. This result reveals that ETs are an effective fiscal tool to support environmental sustainability in Türkiye, and confirms findings reported in the literature.

The findings confirm the crucial role of ET in the design of environmental policy. ET policy is directly linked to Türkiye's commitments under the Paris Climate Agreement, both strategically and financially. To increase the effectiveness of ET in Türkiye, tax design must first be aligned with environmental performance criteria. In this context, establishing a direct emissions-based tax structure, rather than relying on indirect taxes on energy consumption, could strengthen the guiding effect of ET. Furthermore, gradual reductions in fossil fuel subsidies and the implementation of a tax policy tailored to emissions-intensive sectors will increase the effectiveness of ET.

Furthermore, channeling revenues from ET into sustainable areas such as renewable energy infrastructure, energy efficiency investments, and green R&D projects will strengthen the impact of environmental policies and enhance their sustainability. The failure of REN to create a significant impact on environmental quality suggests that policymakers should reassess current energy transition policies. In this context, increasing the technological intensity investments renewable energy, expanding private sector incentives, and developing energy storage and transmission infrastructure are crucial. Consequently, the coordinated design of ET and energy transformation policies is crucial for Türkiye to achieve its environmental sustainability goals.

This study has several limitations. It assumes a linear relationship between ET and the EFP. Therefore, future studies that address a potential nonlinear relationship using threshold models or investigate asymmetric effects would provide valuable insights. Furthermore, the total impact of ET was taken into account. Future researchers should examine the impact of transport, pollution, resource, and energy taxes, which are subcomponents of ET, to enable more comprehensive assessments.

Author Contribution

All processes of this study (design, data collection, analysis, writing, and editing) were carried out by the author.

Ethical Statement

There is no need for ethics committee approval for the prepared study.

Conflicts of Interest

The author(s) has no conflict of interest to declare.

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