Free Trade and Energy Consumption Nexus: The European Union and Türkiye

İbrahim ÖZAYTÜRK*

ABSTRACT

Due to the contribution of fossil fuels to global warming, nations have begun to explore alternative energy generation techniques. In the new century, energy production has favored renewable energies that do not cause environmental damage as much as fossil fuel energy. The rise in renewable energy generation has correspondingly led to an increased utilization of this energy source. Consequently, researchers have begun the investigation of elements that may influence the utilization of renewable energy. The correlation between renewable energy consumption, the focus of this study, and free trade has emerged as a pertinent inquiry for scholars. This study will examine the correlation between the use of renewable energy and fossil fuels with regard to free trade and will compare the outcomes derived from fossil fuel energy and renewable energy usage. A connection between the utilization of renewable energy, the focus of this study, and free trade has emerged as a topic of inquiry among scholars. This study will examine the correlation between free trade and the utilization of renewable energy vs fossil fuels, comparing the outcomes associated with each energy source. The impact of free trade on both categories of energy use may be determined in this manner. This research examines yearly data spanning the years 1990 to 2022. The study utilized panel data analysis to pick Türkiye's principal trading partners among the European Union (EU) members (Germany, France, Spain, Italy, and the United Kingdom). The panel unit root test was conducted, and based on the findings, the Augmented Autoregressive Distributed Lag (ARDL) bounds test/PMG technique was considered suitable. The research indicates that free trade influences renewable energy consumption in the end, whereas it affects fossil fuel consumption in the short term. Only France, Italy, and the United Kingdom observe the impact of free trade on the use of renewable energy. This condition aligns with the energy policies implemented by the governments. Conversely, the impact of free trade on fossil fuel use in any nation is also significant and aligns with anticipated outcomes. This is also relevant to the advancement and refinement of the related technologies. The study offers advice to researchers and industry professionals seeking cost benefits in free trade, as well as for policymakers about the energy policies they want to enact.

***Key Words**: International Economic, Free Trade, Renewable Energy Consumption, Fossil Fuel Consumption*

***JEL Classification**: F14, F18, P18*

Serbest Ticaret ve Enerji Tüketim Bağlantısı: Avrupa Birliği ve Türkiye

ÖZ

Fosil yakıtlardan enerji elde etmenin küresel ısınmaya neden olmasıyla birlikte, ülkeler alternatif enerji üretim yolları arayışına girmişlerdir. Bilindiği üzere çevre kirliliğine neden olmayan yenilebilir enerjiler, yeni yüzyılla birlikte enerji üretiminde tercih edilir hale gelmiştir. Yenilenebilir enerji üretiminin artmasıyla birlikte bu yeni enerji kaynağının kullanımında da artış meydana gelmiştir. Bunun sonucu olarak da yenilenebilir enerji kullanımını etkileyebilecek olan değişkenlerde araştırmacılar tarafından araştırılmaya başlanmıştır. Bu çalışmanın konusunu da oluşturan

*Assoc. Prof. Niğde Ömer Halisdemir University, Department of Finance Banking and Insurance, e-mail: ibrahim.ozayturk@ohu.edu.tr, ORCID Bilgisi: 0000-0001-5292-6313

(Makale Gönderim Tarihi: 20.02.2025 / Yayına Kabul Tarihi:01.03.2026)
Doi Number: 10.18657/yonveek.1643921
Makale Türü: Araştırma Makalesi

yenilenebilir enerji kullanımı ülkeler arasında yapılan serbest ticaret ilişkisi bu noktada araştırmacılar tarafından cevabı aranan bir soru haline gelmektedir. Bu çalışmada, ülkeler arasındaki serbest ticaret ile yenilenebilir enerji ve fosil yakıt kullanımının ilişkisi araştırılacak ve ayrıca fosil yakıttan elde edilen enerjilerin kullanımı ve yenilenebilir enerji kullanımından elde edilen sonuçlar karşılaştırılacaktır. Bu sayede serbest ticaretin etkisinin iki tür enerji kullanımına da etkisi bulunabilecektir. Bu çalışmada, 1990-2022 yılları arasını kapsayan yıllık verilerden yararlanılmaktadır. Panel veri analizinin tercih edildiği çalışmada, Avrupa Birliği (AB) üyesi ülkelerden Türkiye'nin en önemli ticaret partneri olan (Almanya, Fransa, İspanya, İtalya ve Birleşik Krallık) ülkeler seçilmiştir. Önce panel birim kök testi yapılmış ve elde edilen sonuçlar neticesinde Gecikmesi Dağıtılmış Otoregresif (ARDL) Sınır Testi/PMG yöntemi uygun görülmüştür. Yapılan analizler sonucunda, serbest ticaret yenilenebilir enerji kullanıma uzun dönemde etki ederken, fosil yakıt kullanımını kısa vadede etkilemektedir. Serbest ticaretin yenilenebilir enerji kullanımına etkisi yalnızca Fransa, İtalya ve Birleşik Krallık'ta gözlemlenmektedir. Bu durum, ülkelerin yürürlüğe koyduğu enerji politikasıyla uyumludur. Diğer taraftan, serbest ticaretin herhangi bir ülkede fosil yakıt kullanımına etkisi açısında da önemlidir ve beklentilerle uyumluluk göstermektedir. İlgili teknolojilerin geliştirilmesi ve gelişmişliğiyle de ilgili ve tutarlı olduğu söylenebilir. Yapılan çalışma, konuyla ilgilenen araştırmacılara ve sektör çalışanlarına serbest ticarette maliyet avantajı yakalamaları açısından, politika yapıcılarına ise uygulamaya koymayı planladıkları enerji politikaları açısından fikir verebilmektedir.

Anahtar Kelimeler: *Uluslararası İktisat, Serbest Ticaret, Yenilenebilir Enerji Tüketimi, Fosil Yakıt Tüketimi*

JEL Sınıflandırması: *F14, F18, P18*

INTRODUCTION

Fossil fuels, utilized since the early 19th century, have increasingly grown essential alongside global technology advancements in the 20th and 21st centuries. Fossil fuels, such as coal, oil, and natural gas, constitute the majority of our current energy consumption. The majority of transportation vehicles utilized in everyday life function on oil, a fossil fuel, whereas most of the power consumed is derived from natural gas. Consequently, environmental degradation is escalating, and global warming is attaining critical levels.

In recent years, due to global warming, there has been a worldwide trend toward the use of renewable energy, prompting nations to advocate for its further adoption within their cultures. The applications of renewable energy, regarded as clean energy, and its use in daily life are progressively expanding. In 1990, the proportion of renewable energy in primary energy consumption among EU-27 nations was 4.3%, increasing to 24.5% in 2023 (The Statistical Office of The European Union [Eurostat], 2024). The utilization of renewable energy can also mitigate environmental damage.

Multiple factors influence the utilization of renewable energy and fossil fuels. While costs are paramount, a country's trading relations influence its energy use. The frequency and amount of free commerce among nations might be seen as a determinant of the sort of energy utilized in the associated trade. The limited adoption of renewable energy, particularly in the shipping and transportation sectors, coupled with the prevailing preference for fossil fuel vehicles, is a significant factor contributing to the increased utilization of fossil fuels. However, numerous academics scrutinize the influence of free trade on energy consumption.

This study will examine the impact of free trade on the utilization of renewable energy and fossil fuels. Literature reviews (Hughes and Meckling, 2017; Zhang et al., 2021; Thompson and Toledo, 2022) often address the influence of renewable energy and fossil fuels on free trade. This study investigates an alternative facet of the influence. This research is distinct from others in this regard. Moreover, it may elucidate the notion that free trade confers economic benefits to nations. This study will fill in a gap because there has not been one of this size before and examines Türkiye and its five major trading partners. The research question of the study at this point is as follows: How does free trade among selected country groups affect the use of renewable energy and fossil fuels? Owing to the extensive number of nations, the study employed panel data analysis, maintaining a substantial dataset to guarantee more exact and reliable conclusions. The outcomes were analyzed in both the long-term and short-term contexts. Consequently, the assessments conducted concurrently with the research will be more precise.

The study is organized into four parts. The initial portion serves as the introduction, providing a broad assessment and introductory information. This section provides information on the study and elucidates its topic matter. The second part of the study reviews literature pertinent to the issue under investigation. This section enumerates studies that can substantiate the research. The subsequent section elucidates the analysis performed in the study. This part explains the ideas that guided the research that was used to write an accurate and complete commentary on the topic that was studied. This section presents the findings of the empirical application. The final portion of the study presents the conclusion and policy recommendations. This part evaluates the outcomes derived from the study and concurrently formulates policy recommendations based on these findings.

I. LITERATURE REVIEW

Undertaking a comprehensive review of the literature provides a robust theoretical foundation for the investigation. Disclosing the correlation between variables and substantiating it with additional research offers insights to scholars engaged in the topic on the study's validity. Consequently, this section undertakes a thorough and extensive literature review.

Dedeoğlu and Kaya (2013) investigated the correlation between energy use and bilateral commerce in their research. The authors conducted a Granger causality test using data from 25 OECD nations spanning the years 1980 to 2010. The analysis indicates that the connections between energy consumption and exports, as well as energy consumption and imports, are co-integrated, demonstrating bidirectional Granger causality for both pairs. Jebli, Youssef, and Ozturk (2015) examine the short-term and long-term relationships among CO_2 emissions, gross domestic product, renewable energy usage, and international trade. Researchers employed panel data analysis for a study including 24 sub-Saharan African nations from 1980 to 2010. Writers found that in the short term, Granger causality analysis shows that emissions and economic growth are linked in both directions. In the long term, the error correction term is statistically significant for trade, emissions, and the use of renewable energy. Chen (2018) examined the impacts of economic development, carbon emissions, and international commerce on renewable energy. Using GMM analysis and a dataset from 1996 to 2013, they found that the effect of renewable energy on the important variables changes depending on where they are. The research conducted by Alola, Bekun, and Sarkodie (2019) examined the critical factors necessary for achieving the sustainable development goals related to mitigating environmental pollution in EU member states. The study implementing the ARDL/PMG analytic approach utilized a dataset covering the period from 1997 to 2014 for 19 EU nations. The authors indicated that conventional energy usage contributes to environmental pollution, but innovative renewable energy technologies enhance environmental efficiency. Zafar et al. (2019) examines the influence of trade openness on renewable and nonrenewable energy consumption via the lens of the Environmental Kuznets Curve (EKC) paradigm. Morgan Stanley Capital International's (MSCI) categorization guides the analysis of emerging economies from 1990 to 2015. This empirical study employs a cross-sectional dependency (CD) test and a second-generation panel unit root test for accurate estimates. The Pedroni and Westerlund panel cointegration tests are employed to assess long-run equilibrium. Trade openness negatively impacts both renewable and nonrenewable energy use, reflecting these economies' essential shift towards globalization. Alam and Murad (2020) investigated the influence of economic development, trade liberalization, and technology advancement on renewable energy in their study. The study employed the ARDL/PMG-MG analytical approach, utilizing 43 years of data from 25 OECD nations. The authors determined that economic development, trade liberalization, and technological innovation significantly influence the long-term usage of renewable energy in OECD countries. Zeren and Akkuş (2020) studied the correlation between renewable and non-renewable energy use and trade liberalization. The study employed panel analysis utilizing data from emerging nations spanning the years 1980 to 2015. The authors determined that the utilization of non-renewable energy was the primary factor contributing to the rise in trade openness. Khan et al. (2020) examines the interplay between renewable energy usage, international commerce, and environmental quality in Nordic countries from 2001 to 2018. This study employed the CIPS unit root test to assess stationarity and the cross-sectional dependency test to identify cross-sectional reliance concerns. The data indicated a considerable positive correlation between renewable energy and foreign commerce in Nordic nations. Ike et al. (2020) examine the impact of renewable energy usage, energy pricing, and trade on emissions in G-7 nations. The environmental Kuznets curve theory is confirmed at both the panel and country-specific levels; nevertheless, the impact of renewable energy use and trade varies among nations. The findings indicate that renewable energy and energy costs negatively influence CO_2 emissions, whereas trade volume significantly increases CO_2 emissions. Murshed (2020) seeks to empirically examine the alignment of national trade liberalization policies with the promotion of widespread adoption of renewable energy resources across 71 low-, lower-middle-, and upper-middle-income countries in South Asia, East Asia, the Pacific, Central Asia, Latin America, Caribbean islands, and Sub-Saharan Africa. Annual time series data from 2000 to 2017 is utilized to conduct panel data cointegration and regression studies. The findings from the cointegration analysis indicate enduring relationships between trade liberalization policies and renewable energy usage metrics. Wang and Zhang (2021) examined the correlation between free trade and renewable energy in their research. In their analysis, they analyzed a dataset encompassing 186 nations from the years 1990–2015. The study, utilizing panel data analysis, revealed that the impact of free trade on renewable energy varied among nations with differing income levels. Zhang et al. (2021) examines the impact of trade liberalization on renewable energy use in 35 OECD nations from 1999 to 2018. Writers have constructed a panel smooth transition regression model. The empirical findings indicate a pronounced nonlinear correlation between trade openness and renewable energy utilization. Ilechukwu and Lahiri (2022) examines the effects of a nation's reliance on renewable energy consumption within its overall energy usage on international trade. The authors used a dataset covering the period 1990-2014 for 152 countries. In their study using panel data analysis, they found a rise in the use of renewable energy as a share of total energy results, on average decline in exports and an increase in imports. Therefore, the adoption of renewable energy diminishes trade competitiveness. Wang et al. (2022) examine the relations of renewable energy, trade openness, industrialization, technology, economic development and ecological footprint in G-7 countries from 1990 to 2020, utilizing the theoretical framework of the STIRPAT model. The empirical calculations of CS-ARDL indicate that clean energy contributes to the reduction of environmental pollutants in both the long and short term. Ebaidalla (2024) employs the newly published Government Revenue Dataset (2023) to examine the complex relationship among taxes, technical innovation, trade openness, and renewable energy investment across a sample of the top 37 renewable energy-producing nations from 1996 to 2021. The findings from the cross-section ARDL (CS-ARDL) and pooled mean group ARDL (PMG-ARDL) models demonstrate a substantial impact on renewable energy investment in all model parameters, both in the short and long term.

II. DATA AND METHODOLOGY

The research examines the correlation between free trade and the use of renewable energy, as well as the correlation between free trade and fossil fuel consumption, using a yearly dataset spanning from 1990 to 2022. The dataset includes the EU nations with the most significant international trade with Turkiye.

Upon examining the pertinent literature, it is believed that the research issue addresses a gap in the existing body of work. The study indicates that the variables are significant for model consistency, except the control variable (Ehrlich and Holdren 1971; York et al., 2003; Yue et al., 2013; Wang and Zhang, 2021). In model 1, renewable energy consumption (Rec) was designated as the dependent variable, whereas fossil fuel usage (Ffc) was identified as the dependent variable in model 2. Moreover, free trade (To) was established as the control variable for both models. The models used is thus in the form of $REC = f(TO, POP, WEL, TECH)$

for model 1 and $FFEC = f(TO, POP, WEL, TECH)$ for model 2. Table 1 provides information for the variables.

Table 1. Variable Descriptions

Indicator/ Calculation Methods	Code	Log./Orig.	Source
Renewable Energy Consumption (%)	REC	Original	World Bank -WB
Fossil Fuels Consumption (TWh)	FFC	Logarithmic	Energy Institute – Statistical Review of World Energy
Trade Openness (Index)	TO	Original	Penn World Table
Population Growth (%)	POP	Original	World Bank -WB
Gross Domestic Product (GDP) Per Capita ($)	WEL	Logarithmic	World Bank -WB
Economic Complexity Index (ECI)	TECH	Original	Harvard University - Atlas

The models chosen for the investigation are presented in the following section*.

2.1. Empirical Models

The IPAT model, developed by Ehrlich and Holdren (1971), was first developed to examine the impact of population growth on the environment. The IPAT equation is as follows:

$$I = P \times A \times T \quad (1)$$

I: Represents environmental impact
P: Represents demographic factors
A: Represents per capita GDP
T: Represents energy intensity

The IPAT equation had some limitations, which showed it wasn't enough for new needs. This led to the development of the STIRPAT model by York and others in 2003. Alongside the IPAT model, the variables of wealth and technology were incorporated into the equation, resulting in the model's final formulation as seen in equation 2:

$$I_n = aP_n^b \times A_n^c \times T_n^d \times e_n \quad (2)$$

In this context, n denotes the chosen country. b, c, and d denote the coefficients of the variables P, A, and T. a denotes the constant term. This study examines the models derived from the IPAT and STIRPAT frameworks, as shown in equations 3 and 4.

Model 1: $Rec_{it} = \beta_0 + \beta_1 To_{it} + \beta_2 Pop_{it} + \beta_3 LnWel_{it} + \beta_4 Tech_{it} + \varepsilon_{it}$ (3)

Model 2: $LnFfc_{it} = \beta_0 + \beta_1 To_{it} + \beta_2 Pop_{it} + \beta_3 LnWel_{it} + \beta_4 Tech_{it} + \varepsilon_{it}$ (4)

The chosen dependent variables are renewable energy consumption (Rec) and fossil fuel consumption (Ffc), with free trade data (To) include as a control variable.

2.2. Cross-Sectional Dependence

Diverse methodologies are employed to assess cross-sectional dependency. The Breusch and Pagan (1980) research tested for cross-sectional dependency, with the test statistic articulated as follows (Pesaran et al., 2008):

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \bar{\rho}_{ij}^2, \chi^2\, N(N-1)/2 \quad (5)$$

* Descriptive statistics and all post estimation tests for Model 1 and 2 are provided in the Appendix.

Assuming the null hypothesis is valid, the LM test exhibits an asymptotic chi-square distribution with N (N-1)/2 degrees of freedom. The LM test is valid when N is minimum and T is sufficiently big. Pesaran (2004) delineates the test statistic as follows (Pesaran et al. 2008):

$$CD = \sqrt{\frac{2T}{N(N-1)}} (\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \bar{\rho}_{ij} \tag{6}$$

Under the null hypothesisH_0, when T is sufficiently large, the limit of the function N (0, 1) approaches $N \to \infty$ (N approaching infinity). In contrast to the LM test, its mean is 0 at constant T and N values. The Breusch and Pagan (1980) test does not reject the null hypothesis when the variables have a mean of zero. To address this issue, $CDLM_{adj}$tests were created by Pesaran et al. (2008). Pesaran et al. (2008) formulated the LM test using the variance and mean of the LM statistics.

$$LM(\rho)_{adj} = \sqrt{\frac{2}{\rho(2N-\rho-1)}} \sum_{s=1}^{p} \sum_{j=1}^{N-s} \frac{(T-K)\bar{\rho}_{i,i+s}^2 - \mu_{Ti,i+s}}{\rho_{Ti,i+s}} N(0,1) \tag{7}$$

M_{Tij} and V_{Tij} represent the mean and variance, respectively. Under the null hypothesis, as $T \to \infty$ (T approaches infinity) followed by $N \to \infty$ (N approaching infinity), LM_{adj} exhibits an asymptotically normal distribution. The test hypotheses are as follows:

H_0: There exists no cross-sectional dependency.
H_1: Cross-sectional dependency exists.

Tests for cross-sectional dependency were performed on the variables, as seen in Table 2. The appropriate panel unit root test was performed considering the condition of cross-sectional dependency. Based on this result, the next part of the study uses second-generation panel unit root tests that take cross-sectional dependency into account.

Table 2. Cross-Section Independence Test

	Model 1		**Model 2**	
Tests	**Statistics**	**P-Value**	**Statistics**	**P-Value**
LM	*76.17*	*0.0000*	*77.06*	*0.0000*
LM $_{adj*}$	*31.15*	*0.0000*	*31.60*	*0.0000*
LM $_{CD}$	*7.873*	*0.0000*	*5.978*	*0.0000*

* *Two-sided test*

2.3. Cross-Sectionally Augmented Dickey Fuller (CADF) Panel Unit Root Test

The CADF test proposed by Pesaran (2007) is presented on equation 9 (Pesaran, 2007):

$$\Delta y_{it} = \alpha_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta \bar{y}_t + e_{it} \tag{8}$$

$$t_i = (N,T) = \left(\frac{\Delta y_i' \bar{M}_w y_{i-1}}{\bar{\sigma}(y_{i-1}' \bar{M}_w y_{i-1})^{1/2}} \right) \tag{9}$$

The computation of panel statistics is as follows:

$$CIPS(N,T) = t - bar = N^{-1} \sum_{i-1}^{N} t_i(N,T) \tag{10}$$

The CIPS statistic is derived by averaging the t statistics of each cross-section. The stationarity of the series was checked using the CADF test, which was created by Pesaran (2007) and is a second-generation unit root test that can be used when there is cross-section dependence between the countries in the panel for the variables used in the study. The CADF test is reliable in scenarios where T>N and N>T. Stationarity for each nation is assessed by comparing the values of these test statistics with the crucial values from the CADF table of Pesaran (2007). In the CADF test, the null hypothesis H_0 posits that the series are non-stationary. The H_1 hypothesis posits that the series is stationary.

The research used the CADF panel unit root test. Table 3 presents the outcomes derived from the administered test. The results indicate that the variables vary based on the presence of unit roots. The dependent variables (*Rec* and *Ffc*) in models 1 and 2 exhibit unit roots. This condition is analogous in both the constant and the constant with trend. The variable (*To*), which was used as the control variable in the study's models and is a measure of free trade, also has unit roots in both the constant form and the constant and trend form. Unlike the other variables, the one that shows gross national product per capita (*Wel*) does not have unit roots. The variables that show the population growth rate (Pop) and the economic complexity index (*Tech*) do. This instance demonstrates that the ARDL analysis approach is appropriate for the study's models.

Table 3. CADF Panel Unit Root Test Result

	CADF			
	Model 1		**Model 2**	
Variables	**Constant**	**Constant & Trend**	**Constant**	**Constant & Trend**
	t-Statistic	**t-Statistic**	**t-Statistic**	**t-Statistic**
Rec	*-0.116* *(0.998)*	*-1.345* *(0.997)*	-	-
Δ Rec	*-3.501**** *(0.000)*	*-3.671**** *(0.000)*	-	-
LnFfc	-	-	*0.001* *(0.998)*	*-1.707* *(0.961)*
ΔLnFfc	-	-	*-3.143**** *(0.000)*	*-3.203**** *(0.008)*
To	*-2.130* *(0.181)*	*-2.051* *(0.790)*	*-2.130* *(0.181)*	*-2.051* *(0.790)*
Δ To	*-3.089**** *(0.000)*	*-3.173**** *(0.010)*	*-3.089**** *(0.000)*	*-3.173**** *(0.010)*
Δ Pop	*-1.810* *(0.469)*	*-1.789* *(0.931)*	*-1.810* *(0.469)*	*-1.789* *(0.931)*
Pop	*-4.250**** *(0.000)*	*-4.260**** *(0.000)*	*-4.250**** *(0.000)*	*-4.260**** *(0.000)*
LnWel	*-2.507*** *(0.026)*	*-2.990*** *(0.035)*	*-2.507*** *(0.026)*	*-2.990*** *(0.035)*
Tech	*-1.037* *(0.974)*	*-1.281* *(0.998)*	*-1.037* *(0.974)*	*-1.281* *(0.998)*
ΔTech	*--2.726**** *(0.007)*	*-2.910** *(0.056)*	*--2.726**** *(0.007)*	*-2.910** *(0.056)*

Note: ***CADF*** - *Critical values, respectively: 1%***, 5%** and %10*; Constant: -2.550, -2.330 and -2.210 Constant and Trend: -3.060, -2.840, and -2.730.*

Consequently, the panel unit root analysis indicated that the models were appropriate for the ARDL limits test. Table 4 presents the values derived from the ARDL bounds test.

Table 4. ARDL Bound Test Result

		Model 1 (Rec)	
		PMG	
Variables		Coeff.	P-Values
	To	*0.49871*	*0.0000****
	Pop	*-4.72702*	*0.0650***
	LnWel	*6.85685*	*0.1050*
	Tech	*26.73424*	*0.0110***
Short Term	Ec__	*-0.11343*	*0.0020****
	D(To)	*0.00331*	*0.8400*
	D(Pop)	*-0.22788*	*0.2130*
	D(LnWel)	*0.22291*	*0.824*
	D(Tech)	*3.41094*	*0.006****

Table 4 demonstrates that the long-term association between renewable energy consumption (*Rec)* and free trade (*To*) is robust in the analysis of Model 1. The results indicate that a 1% increase in free trade among the specified nations leads to a *0.49871* rise in renewable energy use. However, looking at Table 5, which shows the outcomes of Model 2, we can see that free trade does not have much of an effect on the amount of fossil fuels used by the countries that were studied.

Table 4 indicates that, over the long run, both population increase (*Pop*) and technology advancements (*Tech*) in nations influence renewable energy use. Over the long run, a 1% rise in population growth results in a drop in renewable energy utilization by *-4.7270*. A 1% improvement in the technological levels of the pertinent nations significantly enhances renewable energy use, with a rate of *26.7342*. The results of Model 2 can be seen in Table 5. It is clear that only gross domestic product per capita (*Wel*) has an effect on fossil fuel use over the long term. A 1% rise in per capita gross domestic product results in a *0.8000* increase in fossil fuel use. In other words, the effect is perceived as beneficial.

Conversely, only the error correction parameter in model 1 is important and negative. Consequently, a long-term correlation exists between free trade and the utilization of renewable energy. Consequently, around 11% of the imbalances that arise in one period will be rectified in the subsequent period, indicating that equilibrium will be achieved in approximately 9 periods (Yerdelen-Tatoğlu, 2020: 274).

In the tables presenting the model findings, the analysis of the short-term effects of the variables yields different outcomes compared to the long-term ones. Upon examining the findings of Model 1 and Table 4, it becomes evident that none of the variables are statistically significant; in other words, the variables exert no short-term influence. Conversely, an analysis of Model 2 and Table 5 reveals that a 1% increase in free trade among nations leads to a *0.0052* reduction in fossil fuel use. A comparable outcome may be asserted for technical advancement. A 1% enhancement in technical advancement lowers fossil fuel use by *0.0082*. A 1% rise in per capita gross domestic product results in a *0.0701* increase in fossil fuel use.

Table 5. ARDL Bound Test Result

		Model 2 (LnFfc)	
		PMG	
Variables		Coeff.	P-Values
Long Run (LR)	To	*0.00122*	*0.9260*
	Pop	*0.30704*	*0.1230*
	LnWel	*0.80003*	*0.0460***
	Tech	*-0.53363*	*0.4950*
Short Run (SR)	Ec__	*0.01038*	*0.6200*
	D(To)	*-0.00526*	*0.0000****
	D(Pop)	*-0.01765*	*0.3360*
	D(LnWel)	*0.07014*	*0.0000****
	D(Tech)	*-0.00822*	*0.0260***

Upon examining Table 6, which presents the findings for each nation, it becomes evident that only the error correction coefficients for Germany, the UK, and Turkiye are statistically significant. This indicates that the discrepancies present in one period will be rectified in the subsequent period according to the rates specified by the coefficients in the table. In contrast to the findings shown in Table 4, Table 6 reveals that free trade is significant for France, Italy, and the UK when analyzing the data for each nation. Based on these values, it can be inferred that free trade enhances the utilization of renewable energy just in France, but it exerts a diminishing influence in Italy and the UK.

Table 6. ARDL – PMG by Country (Dependent Variable: Rec)

	To		Pop		LnWel		Tech		Ec__	
Country	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value
Germany	*0.0033*	*0.8400*	*-0.2278*	*0.2130*	*0.2229*	*0.8240*	*3.4194*	*0.0060 (***)*	*-0.1134*	*0.0020 (***)*
France	*0.2649*	*0.0030 (***)*	*-6.7868*	*0.1570*	*-4.1248*	*0.2290*	*-3.6639*	*0.4700*	*-0.0635*	*0.5520*
Spain	*-0.0506*	*0.409*	*-0.9503*	*0.2160*	*-2.6103*	*0.2640*	*-1.0436*	*0.6480*	*-0.0434*	*0.04430*
Italy	*-0.8009*	*0.0120 (**)*	*1.1742*	*0.0020 (***)*	*-2.6757*	*0.0570 (*)*	*1.1632*	*0.3150*	*0.0054*	*0.8150*
UK	*-0.0847*	*0.0160 (**)*	*1.0831*	*0.0160 (**)*	*-2.0965*	*0.0620 (*)*	*-4.3112*	*0.0060 (***)*	*0.0648*	*0.0120 (**)*
Turkiye	*-0.0279*	*0.5790*	*0.9088*	*0.1960*	*-1.2981*	*0.3090*	*-7.6289*	*0.0060 (***)*	*-0.0217*	*0.0490 (**)*

Table 7's assessment reveals that Italy's error correction coefficient *(0.0059)* is the only significant value. Conversely, the analysis indicates that free trade positively influences fossil fuel use across all examined nations. This impact differs from the data presented in Table 6.

Table 7. ARDL – PMG by Countries (Dependent Variable: LnFfc)

	To		Pop		LnWel		Tech		Ec__	
Country	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value
Germany	*0.0034*	*0.0010 (***)*	*0.0114*	*0.2800*	*0.0336*	*0.5960*	*0.0220*	*0.7480*	*0.0044*	*0.7490*

France	*0.0043*	*0.0610 (*)*	*-0.0476*	*0.7210*	*0.0884*	*0.3440*	*0.1045*	*0.3830*	*0.0326*	*0.2330*
Spain	*0.0087*	*0.0000 (***)*	*0.0579*	*0.0250 (**)*	*0.1752*	*0.0200 (**)*	*0.0856*	*0.1970*	*0.0481*	*0.2220*
Italy	*0.0059*	*0.0000 (***)*	*-0.0658*	*0.0000 (***)*	*0.1745*	*0.0020 (***)*	*-0.0048*	*0.9150*	*0.0416*	*0.0980 (*)*
UK	*0.0065*	*0.0050 (***)*	*-0.3071*	*0.2960*	*0.1727*	*0.0200 (**)*	*0.0126*	*0.8930*	*0.0254*	*0.1340*
Turkiye	*0.0026*	*0.0970 (*)*	*-0.0313*	*0.1600*	*0.1794*	*0.0000 (***)*	*0.2008*	*0.0160 (**)*	*-0.0897*	*0.1660*

Analysis of the study's application results indicates that free trade predominantly influences the nation's fossil fuel use. Despite the varying significant levels in Table 7, it is evident that the short-run and long-run consequences of free trade differ. The next part presents the findings and recommendations for pertinent individuals and institutions derived from these results.

CONCLUSION AND RECOMMENDATIONS

The pursuit of alternative energy sources that minimize environmental pollution, along with a preference for renewable energy over fossil fuels, has led to a significant growth in renewable energy production due to global warming. The growing inclination toward renewable energy, regarded as clean energy, is linked not just to environmental degradation but also captivates academics due to its numerous economic benefits.

This research analyzes the impact of free trade on the utilization of renewable energy and fossil fuels in both the short and long term. The study utilized the five EU nations with whom Turkiye engages in the most commerce as its data set. This aims to explore potential cost benefits in free trade between Turkiye and the relevant nations. The period from 1990 to 2022 was selected as the data set for the investigation. The ARDL limits test and PMG analysis were employed to investigate the link between free trade and energy consumption in both the short and long term, as well as at the individual nation level. To conduct these tests in advance, the CADF unit root test was executed. Consequently, it was determined that the limits test was suitable.

Analysis of the results indicates that free trade exerts a long-term influence on the utilization of renewable energy. The nascent and evolving nature of technologies employed in renewable energy elucidates the enduring importance of the analysis. Enhancing free trade with pertinent nations can augment the use of renewable energy. Analysis indicates that a 1% increase in trade can result in a *0.49871* rise in renewable energy use. An augmentation of free trade with nations possessing the requisite production technologies for renewable energy might enhance the use of renewable energy in the trading country. The nascent and developmental stage of renewable energy technologies prolongs this condition. Conversely, the antiquity of fossil fuel-producing technologies may provide swifter economic returns on purchases made through free trade, resulting in short-term economic benefits. However, the unfavorable outcomes of the analysis, in contrast to the positive results associated with renewable energy, necessitate an alternative viewpoint. A 1% rise in free trade results in a *0.00526* reduction in fossil fuel use. Expenses can shed light on this issue. Traders' use of technology utilizing renewable energy resources, particularly in product shipping, significantly lowers fossil fuel consumption. When looking at the effects of free trade on energy use from a different angle, it is clear that using fossil fuels in production costs producers a lot, while using renewable energy saves them money (for example, by lowering their electricity bills). These cost benefits can facilitate the sale of items to nations engaged in free trade at more competitive pricing. Simultaneously, governmental subsidies for renewable energy use also elevate consumption rates. The impact of free trade on the utilization of renewable energy is both constant and significant.

After the findings according to country, it was discovered that the influence of free trade on the usage of renewable energy sources is only apparent in France, Italy, and the United Kingdom. This circumstance is consistent with the energy policy that the nations have put into effect. On the other hand, the extent to which free trade affects the consumption of fossil fuels in any nation is significant. The circumstances are consistent with what was anticipated. The fact that there is a connection between free trade and energy use demonstrates that the findings of the study provide vital insights for businesspeople and government officials alike. This study has the potential to furnish scholars and industry professionals useful insights into the issue at hand, particularly with regard to the pursuit of cost advantages in free trade, as well as into the energy policies that policymakers desire to put into practice. Moreover, this study has the ability to deliver these insights.

Statement of Research and Publication Ethics

The principles of research and publication ethics of the Journal of Management and Economics were followed throughout the entire process of the article.

Conflict of Interest Statement

There is no conflict of interest with any institution or person within the scope of the study.

REFERENCES

Alam, M. M., & Murad, M. W. (2020). The Impacts of Economic Growth, Trade Openness and Technological Progress on Renewable Energy Use in Organization for Economic Co-Operation and Development Countries. *Renewable Energy, 145*, 382-390.

Alola, A. A., Bekun, F. V., & Sarkodie, S. A. (2019). Dynamic Impact of Trade Policy, Economic Growth, Fertility Rate, Renewable and Non-Renewable Energy Consumption on Ecological Footprint in Europe. *Science of the Total Environment, 685,* 702-709.

Ben Jebli, M., Ben Youssef, S., & Ozturk, I. (2015). The Role of Renewable Energy Consumption and Trade: Environmental Kuznets Curve Analysis for Sub-Saharan Africa Countries. *African Development Review, 27*(3), 288-300.

Breusch, T.S., & Pagan, A.R. (1980). The Lagrange Multiplier Test and Its Applications to Model Specification in Econometrics. *The Review of Economic Studies, 47*(1), 239-253.

Dedeoğlu, D., & Kaya, H. (2013). Energy Use, Exports, Imports and GDP: New Evidence from the OECD Countries. *Energy Policy*, 57, 469-476.

Ebaidalla, E. M. (2024). The Impact of Taxation, Technological Innovation and Trade Openness on Renewable Energy Investment: Evidence from the Top Renewable Energy Producing Countries. *Energy, 306*, 132539.

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of Population Growth: Complacency Concerning This Component of Man's Predicament is Unjustified and Counterproductive. *Science*, *171* (3977), 1212-1217.

EUROSTAT (2024). Renewable energy statistics. Retrieved by https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Renewable_energy_statistics on February 2025.

Hughes, L., & Meckling, J. (2017). The Politics of Renewable Energy Trade: The US-China Solar Dispute. *Energy Policy, 105*, 256-262.

Ilechukwu, N., & Lahiri, S. (2022). Renewable-Energy Consumption and International Trade. *Energy Reports, 8*, 10624-10629.

Ike, G. N., Usman, O., Alola, A. A., & Sarkodie, S. A. (2020). Environmental Quality Effects of Income, Energy Prices and Trade: The Role of Renewable Energy Consumption in G-7 Countries. *Science of the Total Environment, 721*, 137813.

Khan, S. A. R., Yu, Z., Belhadi, A., & Mardani, A. (2020). Investigating the Effects of Renewable Energy on International Trade and Environmental Quality. *Journal of Environmental Management, 272,* 111089.

Murshed, M. (2020). Are Trade Liberalization Policies Aligned with Renewable Energy Transition in Low- and Middle-Income Countries? An Instrumental Variable Approach. *Renewable Energy, 151*, 1110-1123.

Pesaran, M.H. (2004). General Diagnostic Test for Cross Section Dependence in Panels. *University of Cambridge,* 1-39.

Pesaran, M. H. (2007). A Simple Panel Unit Root Test in the Presence of Cross-Section Dependence. *Journal of Applied Econometrics, 22*(2), 365-312.

Pesaran, M. H., Ullah, A., & Yamagata, T. (2008). A Bias Adjusted LM Test of Error Cross Section Independence. *The Econometrics Journal, 11*(1), 105-127.

Thompson, H., & Toledo, H. (2022). Renewable Versus Nonrenewable Energy for Canada in a Free Trade Agreement with China. *Energy Economics*, 105, 105716.

York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: Analytic Tools for Unpacking the Driving Forces of Environmental Impacts. *Ecological Economics*, *46*(3), 351-365.

Wang, Q., & Zhang, F. (2021). Free Trade and Renewable Energy: A Cross-Income Levels Empirical Investigation Using Two Trade Openness Measures. *Renewable Energy, 168*, 1027-1039.

Wang, W., Rehman, M. A., & Fahad, S. (2022). The Dynamic Influence of Renewable Energy, Trade Openness, and Industrialization on the Sustainable Environment in G-7 Economies. *Renewable Energy,* 198, 484-491.

Yerdelen-Tatoğlu, F. (2020). *Panel Zaman Analizi-Stata Uygulamalı (3. Baskı)*. İstanbul: Beta Basım Yayım.

Yue, T., Long, R., Chen, H., & Zhao, X. (2013). The Optimal CO2 Emissions Reduction Path in Jiangsu Province: An Expanded IPAT Approach. *Applied Energy, 112*, 1510-1517.

Zafar, M. W., Mirza, F. M., Zaidi, S. A. H., & Hou, F. (2019). The Nexus of Renewable and Nonrenewable Energy Consumption, Trade Openness, And CO 2 Emissions in the Framework of EKC: Evidence from Emerging Economies. *Environmental Science and Pollution Research, 26,* 15162-15173.

Zeren, F., & Akkuş, H. T. (2020). The Relationship between Renewable Energy Consumption and Trade Openness: New Evidence from Emerging Economies. *Renewable Energy, 147*, 322-329.

Zhang, M., Zhang, S., Lee, C. C., & Zhou, D. (2021). Effects of Trade Openness on Renewable Energy Consumption in OECD Countries: New Insights from Panel Smooth Transition Regression Modelling. *Energy Economics, 104,* 105649.

APPENDIX:

Description Stations for Model 1

	REC	TO	POP	LNWEL	TECH
Mean	*10.58182*	*54.96354*	*0.544537*	*10.04714*	*1.336318*
Median	*10.6*	*53.85315*	*0.451375*	*10.24317*	*1.44355*
Maximum	*26.1*	*89.6*	*1.872085*	*10.86409*	*2.33549*
Minimum	*0.6*	*23.5116*	*-1.853715*	*7.685372*	*0.003711*
Std. Dev.	*5.980601*	*12.75947*	*0.559987*	*0.71187*	*0.605654*
Skewness	*0.154319*	*0.53828*	*0.083944*	*-1.561502*	*-0.540896*
Kurtosis	*2.413891*	*3.733152*	*4.369831*	*5.014722*	*2.493171*
Jarque-Bera	*3.619948*	*13.99605*	*15.71313*	*113.9511*	*11.77398*
Probability	*0.163658*	*0.000914*	*0.000387*	*0*	*0.002775*
Sum	*2095.2*	*10882.78*	*107.8183*	*1989.334*	*264.5909*
Sum Sq. Dev.	*7046.215*	*32072.41*	*61.77625*	*99.8315*	*72.26286*
Observations	*198*	*198*	*198*	*198*	*198*

Normality Test for Model 1

Mean	*-5.301542*
Median	*-0.304606*
Max	*10.93479*
Min	*-7.482137*
Std. Dev.	*3.828121*
Skewness	*0.564926*
Kurtosis	*2.960535*
J-B	*10.54451*
Prob.	*0.005132*

Testing for Slope Heterogeneity for Model 1

	Delta	P-Value
	12.755	*0.000*
Delta adj	*14.101*	*0.000*

Description Stations for Model 2

	LNFFC	TO	POP	LNWEL	TECH
Mean	*7.4053*	*54.96354*	*0.544537*	*10.04714*	*1.336318*
Median	*7.418528*	*53.85315*	*0.451375*	*10.24317*	*1.44355*
Maximum	*8.217133*	*89.6*	*1.872085*	*10.86409*	*2.33549*
Minimum	*6.199761*	*23.5116*	*-1.853715*	*7.685372*	*0.003711*
Std. Dev.	*0.446125*	*12.75947*	*0.559987*	*0.71187*	*0.605654*

Skewness	*-0.297962*	*0.53828*	*0.083944*	*-1.561502*	*-0.540896*
Kurtosis	*2.958027*	*3.733152*	*4.369831*	*5.014722*	*2.493171*
Jarque-Bera	*2.944328*	*13.99605*	*15.71313*	*113.9511*	*11.77398*
Probability	*0.229429*	*0.000914*	*0.000387*	*0*	*0.002775*
Observations	*198*	*198*	*198*	*198*	*198*

	Normality Test for Model 2
Mean	*2.781235*
Median	*0.006751*
Max	*0.463989*
Min	*-0.45391*
Std. Dev.	*0.173928*
Skewness	*-0.121528*
Kurtosis	*2.773039*
J-B	*0.912346*
Prob.	*0.633704*

Testing for Slope Heterogeneity for Model 2		
	Delta	**P-Value**
	14,794	*0.000*
Delta adj	*16,356*	*0.000*

Multicollinearity Test for Model 1 and Model 2	
Variables	**VIF**
LnWel	*3.17*
Tech	*2.45*
Pop	*1.62*
To	*1.61*
Mean VIF	*2.21*

Note: *No Multicollinearity problem if VIF<5*

Autocorrelation Test for Model 1 and Model 2		
	Coefficient	**Coefficient**
Durbin-Watson	*1.971348*	*1.977765*

Note*: No autocorrelation problem if the values close to 2.*

	Model 1		Model 2	
Tests	**Ki-Sq**	**P-Value**	**Ki-Sq**	**P-Value**
BPGodfrey	*1.66163*	*0.6455*	3.51082	0.4762
White Test	*11.99956*	*0.1512*	*11.32569*	*0.2356*

Note: *No heteroscedasticity problem and higher order autocorrelation problem.*