

THE DETERMINANTS OF RENEWABLE ENERGY CONSUMPTION: ASYMMETRIC EFFECTS OF TRADE IN TÜRKIYE¹

Assoc. Prof. Muhammed BENLİ

Bilecik Seyh Edebali University, Faculty of Economics and Administrative Sciences

ORCID ID: <https://orcid.org/0000-0001-6486-8739>

Miřanur GÖKAYDIN

Bilecik Şeyh Edebali Üniversitesi, Institute of Graduate Studies

ORCID ID: <https://orcid.org/0009-0008-9082-7576>

Abstract

This study uses the Linear and Nonlinear Autoregressive Distributed Lag models to examine the symmetric and asymmetric effects of trade on renewable energy consumption in Türkiye for the period 1987-2023. The study specifically investigates whether trade expansions and contractions have different effects on renewable energy consumption in both the short and long term. It also explores the roles of foreign direct investment, oil prices, GDP per capita, and inflation as additional factors influencing renewable energy consumption. The results indicate that GDP per capita has a significant and positive effect on renewable energy consumption, while foreign direct investment and oil prices show mixed results. These findings suggest that economic growth supports the transition to renewable energy, but other factors, such as foreign direct investment, may slow the transition by focusing on traditional energy sectors. The empirical findings also reveal that trade contractions have a significant and negative effect on renewable energy consumption, whereas trade expansions show an insignificant effect. The results confirm the asymmetric relationship between trade and renewable energy, emphasizing the need for targeted policies to mitigate the negative impacts of trade contractions and maximize the benefits of trade expansions. Policymakers should focus on increasing local renewable energy capacity, reducing dependence on imported technologies, and aligning trade policies with sustainable energy goals. By addressing the vulnerabilities arising from trade contractions, Türkiye can strengthen its renewable energy sector and ensure long-term energy sustainability.

Keywords: Renewable Energy, Foreign Trade, NARDL.

¹ This study is derived from the master's thesis titled "Two Essays on the Relationship Between Renewable Energy and Foreign Trade", prepared by Miřanur Gökaydın under the supervision of Associate Professor Muhammed Benli

Yenilenebilir Enerji Tüketiminin Belirleyicileri: Türkiye’de Ticaretin Asimetrik Etkileri

Özet

Bu çalışma, Türkiye’de 1987-2023 dönemi için dış ticaretin yenilenebilir enerji tüketimi üzerindeki simetrik ve asimetrik etkilerini incelemek amacıyla Doğrusal ve Doğrusal Olmayan Gecikmesi Dağıtılmış Otoregresif modellerini kullanmaktadır. Çalışma, özellikle ticaret hacmindeki genişleme ve daralmaların kısa ve uzun dönemde yenilenebilir enerji tüketimi üzerinde farklı etkilerinin olup olmadığını incelemektedir. Çalışmada ayrıca doğrudan yabancı yatırım, petrol fiyatları, kişi başına düşen GSYH ve enflasyonun yenilenebilir enerji tüketimini etkileyen ek faktörler olarak rolleri de ele alınmaktadır. Sonuçlar, kişi başına düşen GSYH’nin yenilenebilir enerji tüketimi üzerinde anlamlı ve pozitif bir etkiye sahip olduğunu; ancak doğrudan yabancı yatırım ve petrol fiyatlarının karmaşık sonuçlar verdiğini göstermektedir. Bu bulgular, ekonomik büyümenin yenilenebilir enerjiye geçişi desteklediğini, ancak doğrudan yabancı yatırım gibi diğer faktörlerin geleneksel enerji sektörlerine yönelerek yenilenebilir enerji geçişini yavaşlatabileceğini işaret etmektedir. Ampirik bulgular, ayrıca, ticaret hacmindeki daralmaların yenilenebilir enerji tüketimi üzerinde anlamlı ve negatif bir etkiye sahip olduğunu, ticaret hacmindeki genişlemelerin ise anlamsız bir etki gösterdiğini ortaya koymaktadır. Sonuçlar, ticaret ve yenilenebilir enerji arasındaki asimetrik ilişkiyi doğrulamakta ve ticaret hacmindeki daralmaların yenilenebilir enerji tüketimi üzerindeki olumsuz etkilerini hafifletmeye ve ticaret genişlemelerinin faydalarını maksimize etmeye yönelik politikaların gerekliliğini vurgulamaktadır. Politika yapıcılar, yerel yenilenebilir enerji kapasitesini artırmaya, ithal teknolojilere bağımlılığı azaltmaya ve ticaret politikalarını sürdürülebilir enerji hedefleriyle uyumlu hale getirmeye odaklanmalıdır. Türkiye, ticaret hacmindeki daralmalardan kaynaklanan kırılma noktaları ele alarak yenilenebilir enerji sektörünü güçlendirebilir ve uzun vadeli enerji sürdürülebilirliğini sağlayabilir.

Anahtar Kelimeler: Yenilenebilir Enerji, Dış Ticaret, NARDL

Introduction

In recent decades, the global transition towards renewable energy has emerged as a critical response to growing concerns over climate change, energy security, and environmental degradation (Saygin and Çetin, 2010). Nations worldwide are actively seeking sustainable energy solutions to reduce their dependence on fossil fuels (Vigoya et al., 2020). Renewable energy, which includes sources such as wind, solar, hydropower, and biomass, offers a viable pathway to achieving these objectives while promoting long-term economic growth and environmental sustainability (Chou et al., 2023).

Despite the clear benefits of renewable energy, the factors that influence its adoption are complex and challenging. Among these factors, international trade has been recognized as a potentially crucial driver of renewable energy consumption, offering both opportunities and challenges. Trade, by facilitating the exchange of goods, services, and technologies, can contribute to the diffusion of renewable energy technologies across borders, fostering innovation and improving access to cleaner energy sources (Gallagher, 2014; Garsous and Worack, 2021). However, the relationship between trade and renewable energy consumption is not straightforward. It is influenced by several factors, including the structure of trade, the nature of foreign direct investment (FDI), and the dynamics of global energy markets (Nasim et al., 2023).

The relationship between trade and renewable energy consumption can be understood from both theoretical and empirical perspectives. On the one hand, trade can promote the adoption of renewable energy technologies by providing access to foreign markets, investments, and innovations that are

critical for the development of renewable energy infrastructure (Leal-Arcas et al., 2016; Ebaidalla, 2024). Increased trade can facilitate the transfer of energy-efficient technologies and best practices, allowing countries to diversify their energy sources and reduce dependence on non-renewable energy (Pigato et al., 2020).

On the other hand, trade expansion is often accompanied by increased energy demand, particularly in developing economies where industrial growth is fueled by traditional energy sources such as coal, oil, and gas (Dorian et al., 2020). This suggests that trade might not always lead to a higher share of renewable energy in the energy mix, especially if trade is concentrated in energy-intensive industries. Furthermore, the role of FDI, which is often closely linked with trade, may also affect the energy mix. If FDI is primarily directed towards traditional energy sectors or industrial projects that rely on non-renewable energy, it may hinder the growth of renewable energy consumption (Kang et al., 2021; Adekunle, 2023; Handri, 2023).

While previous studies have often explored the linear relationship between trade and renewable energy consumption (Omri and Nguyen, 2014; Rasoulinezhad and Saboori, 2018; Alam and Murad, 2020; Wang and Zhang, 2021; Lee et al., 2021; Vural, 2021), recent empirical research suggests that this relationship may be nonlinear and asymmetric (Alkhateeb and Mahmood, 2019; Qamruzzaman and Jianguo, 2020; Zhang et al., 2021). Positive changes in trade (i.e., trade expansions) may have different effects on renewable energy consumption compared to negative changes (i.e., trade contractions). For instance, periods of trade expansion might not necessarily lead to higher renewable energy consumption if trade is concentrated in traditional, energy-intensive sectors. In contrast, trade contractions could force countries to become more self-reliant and focus on domestic renewable energy sources as a means of achieving energy security.

This asymmetry between the effects of trade expansions and contractions has important implications for understanding the dynamics of energy transitions in the context of global economic integration. For example, in the case of a trade reduction, countries may be compelled to shift towards renewable energy to reduce dependence on fossil fuel imports. Conversely, trade increases may not immediately translate into renewable energy adoption if the primary sectors driving trade growth are not aligned with clean energy objectives.

Given these complexities, a Nonlinear Autoregressive Distributed Lag (NARDL) model provides an appropriate methodological framework to capture both the short-term and long-term asymmetries in the relationship between trade and renewable energy consumption. The NARDL model allows for the decomposition of trade into its positive and negative components, thus enabling a deeper analysis of how trade impacts renewable energy consumption across different phases of economic activity.

Türkiye, as a rapidly industrializing economy, offers an intriguing case study for exploring the nonlinear relationship between trade and renewable energy consumption. As a member of the G20 and a pivotal player in regional energy markets, Türkiye's energy strategy is shaped by a delicate balance between growing energy demand and the need to transition toward a more sustainable energy system (Salvarli and Salvarli, 2017; Tanil, 2023). Over the past two decades, Türkiye has made significant strides in expanding its renewable energy capacity, particularly in wind and solar power, but it remains heavily reliant on fossil fuel imports to meet its growing energy needs (Kirtay, 2010; Akyuz, 2015; Uğurlu and Gokcol, 2017)

Türkiye's trade patterns are diverse, spanning energy-intensive sectors such as manufacturing, automotive, and textiles, alongside burgeoning renewable energy technologies. However, the extent to which trade contributes to the growth of renewable energy consumption in Türkiye is still an open

question. While trade expansion has boosted the economy, it is unclear whether this has facilitated the widespread adoption of renewable energy or reinforced dependence on traditional energy sources.

Moreover, Türkiye's energy policy has been influenced by its position as a regional energy hub, connecting Europe and Asia through pipelines and energy infrastructure (Roberts, 2010; Yorkan, 2011; Huseynov, 2017). This strategic role in the global energy market adds further complexity to the relationship between trade and renewable energy consumption, particularly in terms of foreign investment and energy security considerations.

The objective of this study is to examine the asymmetric effect of trade on renewable energy consumption in Türkiye, using the NARDL framework. Specifically, the study aims to investigate whether trade expansions and contractions have different impacts on renewable energy consumption in both the short and long run. We also attempt to explore the role of other key macroeconomic variables, such as FDI, oil prices, GDP per capita, and inflation, in influencing renewable energy consumption. Furthermore, this study provides policy recommendations based on the findings to promote a more sustainable trade-energy nexus in Türkiye. By decomposing trade into its positive and negative changes, this study will provide a deeper understanding of how international trade affects the energy transition in Türkiye, with important implications for policymakers aiming to balance economic growth with environmental sustainability.

Data and Methodology

In this study, we analyze the impact of trade on renewable energy consumption in Türkiye using time series data on renewable energy consumption, trade, real GDP per capita, oil price, inflation, and FDI for the period 1987–2023. All series, except for inflation, are in their natural logarithmic form, allowing us to interpret the estimated coefficients in elasticity form. Summary information about the data used in the analysis is presented in Table 1, and the descriptive statistics of the series are provided in Table 2.

Table 1. Summary of the Variables

Target Variable	Proxy Variable	Symbol	Definiton	Source
Renewable Energy Consumption	Primary energy consumption from renewable sources	<i>REC</i>	Share of primary energy consumption from renewable sources	Our World in Data
Trade	Trade openness	<i>TRADE</i>	The sum of exports and imports of goods and services (% of GDP)	The World Bank (WB) – World Development Indicators (WDI)
Economic Growth	Real GDP per capita	<i>GDP_{pc}</i>	GDP per capita (constant 2015 US\$)	The WB – WDI
Oil Price	Brent oil price	<i>OIL</i>	Europe Brent Spot Price FOB (Dollars per Barrel)	Central Bank of the Republic of Türkiye
Foreign Direct Investment	FDI inflows	<i>FDI</i>	Foreign direct investment, net inflows (% of GDP)	The WB – WDI

Inflation	Inflation based on consumer prices	<i>INF</i>	Inflation, consumer prices (annual %)	The WB – WDI
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Table 2. Descriptive Statistics

Variables	No. of obs.	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
<i>REC</i>	37	13.278	2.839	8.238	19.008	0.299	2.523
<i>TRADE</i>	37	48.489	11.475	30.476	81.170	0.587	3.484
<i>GDP_{pc}</i>	37	8277.257	2888.171	4957.363	14630.370	0.669	2.196
<i>OIL</i>	37	47.365	30.903	10.540	110.800	0.653	2.192
<i>FDI</i>	37	1.149	0.835	0.132	3.623	1.135	4.002
<i>INF</i>	37	38.579	31.310	6.251	105.215	0.419	1.696
<i>lnREC</i>	37	2.564	0.217	2.109	2.945	-0.162	2.481
<i>lnTRADE</i>	37	3.854	0.236	3.417	4.397	-0.064	2.709
<i>lnGDP_{pc}</i>	37	8.965	0.336	8.509	9.591	0.326	1.780
<i>lnOIL</i>	37	3.634	0.697	2.355	4.708	-0.024	1.684
<i>lnFDI</i>	37	-0.129	0.773	-2.026	1.287	-0.196	2.305

Source: Author's calculations

To examine the symmetric and asymmetric effects of trade on renewable energy consumption in Türkiye, this study employs the Autoregressive Distributed Lag (ARDL) and the NARDL models. The ARDL model, developed by Pesaran and Shin (1999) and Pesaran et al. (2001), is a widely used econometric technique estimating both short-run and long-run relationships between variables in a single equation framework. One of the main advantages of the ARDL model is that it does not require all variables to be of the same order of integration. The model can handle a mix of I(0) and I(1) variables, which is particularly useful when dealing with macroeconomic time series data. Furthermore, the ARDL model estimates both short-run and long-run dynamics simultaneously. The short-run dynamics are captured through the lagged differences of the variables, while the long-run relationship is derived from the levels of the variables. The ARDL approach uses a bounds testing procedure to check for the presence of a long-run relationship (cointegration) between the dependent variable and the explanatory variables. If the F-statistic from the bounds test exceeds the upper bound critical value, there is evidence of cointegration (Harris and Sollis, 2003).

In the ARDL model, the dependent variable is regressed on both its own lagged values and the lagged values of the independent variables. The model is typically written as follows:

$$\Delta y_t = \alpha + \omega y_{t-1} + \theta x_{t-1} + \sum_{i=0}^{p-1} (\varphi_i \Delta y_{t-i}) + \sum_{i=0}^{q-1} (\gamma_i \Delta x_{t-i}) + u_t \quad (1)$$

While the ARDL model provides insights into the linear relationship between trade and renewable energy consumption, it does not account for potential asymmetries in how positive and negative changes in trade affect renewable energy. To address this limitation, the study employs the NARDL model, which extends the ARDL framework to capture asymmetric effects.

The NARDL model, introduced by Shin et al. (2014), decomposes the independent variable (trade) into positive and negative components to capture potential differences in the effects of trade expansions (increases in trade) and trade contractions (decreases in trade) on renewable energy consumption. This decomposition allows for the exploration of whether trade expansions and contractions have different impacts on renewable energy consumption, both in the short run and long run.

In the NARDL model, specifically, x_t is decomposed into its positive and negative components as follows:

$$\begin{aligned} x_t^+ &= \sum_{i=1}^t \Delta x_i^+ \\ &= \sum_i \max(\Delta x_i^+, 0) \end{aligned} \quad (2)$$

$$\begin{aligned} x_t^- &= \sum_{i=1}^t \Delta x_i^- \\ &= \sum_i \min(\Delta x_i^-, 0) \end{aligned} \quad (3)$$

This decomposition allows one to assess whether expansions and contractions in variable x have differential impacts on y in both the short run and long run. Then the NARDL model can be specified as follows:

$$\Delta y_t = \alpha + \omega y_{t-1} + \theta^+ x_{t-1}^+ + \theta^- x_{t-1}^- + \sum_{i=0}^{p-1} (\varphi_i \Delta y_{t-i}) + \sum_{i=0}^{q-1} (\gamma_i^+ \Delta x_{t-i}^+ + \gamma_i^- \Delta x_{t-i}^-) + u_t \quad (4)$$

Findings

Before estimating the ARDL and NARDL models, it is essential to ensure that the variables are stationary. The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are employed to test the stationarity of the variables, confirming that they are either I(0) or I(1). The results of tests are presented in Table 3. The findings show that none of the variables is integrated at second order.

Table 3. Unit Root Tests

Variable	ADF		PP	
	C	C/T	C	C/T
$\ln REC_t$	-2.579(0)	-3.061(0)	-2.497(2)	-3.041(2)
$\Delta \ln REC_t$	-8.144(0)***	-8.052(0)***	-9.915(13)***	-10.066(13)***
$\ln GDP_{pc_t}$	0.451(0)	-2.021(0)	1.179(6)	-2.048(2)
$\Delta \ln GDP_{pc_t}$	-6.646(0)***	-6.668(0)***	-6.972(5)***	-7.699(6)***
$\ln OIL_t$	-1.692(0)	-2.993(0)	-1.521(1)	-2.938(2)
$\Delta \ln OIL_t$	-7.932(0)***	-7.812(0)***	-8.696(7)***	-8.560(7)***
$\ln FDI_t$	-2.446(0)	-2.870(0)	-2.377(11)	-2.713(4)
$\Delta \ln FDI_t$	-7.355(0)***	-7.516(0)***	-8.483(15)***	-17.251(39)***
$\ln TRADE_t$	-1.652(0)	-4.482(1)***	-1.468(7)	-3.582(4)**
$\Delta \ln TRADE_t$	-6.931(1)***	-6.850(1)***	-9.864(23)***	-9.020(22)***
INF_t	-1.485(0)	-1.704(0)	-1.424(2)	-1.669(2)
ΔINF_t	-6.567(0)***	-6.478(0)***	-6.581(2)***	-6.486(2)***

Note: The lag lengths for the ADF test determined by the SIC and the appropriate bandwidths for the PP test determined by the Newey-West Bandwidth are given in parentheses.*** $p < 0.01$, ** $0.01 < p < 0.05$, * $0.05 < p < 0.10$

To examine whether a long-run cointegrating relationship exists between renewable energy consumption and the explanatory variables (trade, FDI, oil prices, GDP per capita, and inflation) we apply the bounds testing approach. If the F-statistic exceeds the critical values, we reject the null hypothesis of no cointegration, confirming the presence of a long-run relationship. The result of the bounds testing is given in Table 4. According to the results obtained, there is cointegration between the variables at 5% significance level. This also indicates that the estimated relationships are not spurious.

Table 4. Bounds Test

Model	Optimal Lag Length	F-stat
$F(\ln\text{REC}_t/\ln\text{TRADE}_t, \ln\text{GDP}_{pc_t}, \ln\text{FDI}_t, \ln\text{OIL}_t, \text{INF}_t)$	(1, 0, 1, 0, 1, 0)	4.803**
	Critical Values	
Significance Level	Lower Bound	Upper Bound
%1	4.257	6.040
%5	3.037	4.443
%10	2.508	3.763

Note: The optimal lag length determined using the AIC information criterion.

After confirming cointegration, the ARDL model is estimated. The short-run dynamics are captured through the lagged differences of the variables, while the long-run effects are derived from the levels of the variables. The results of the error correction model related to the cointegration test are summarized in Table 5, while the long-run coefficients are presented in Table 6.

Table 5. Error Correction Model (ECM)

Variable	Coefficient	Std. Error	t-stat
$\Delta\ln\text{GDP}_{pc_t}$	1.728***	0.537	3.218
$\Delta\ln\text{OIL}_t$	-0.012**	0.058	-0.207
ECT_{t-1}	-0.847***	0.145	-5.844
Constant	-3.406***	0.582	-5.854

Note: *** $p < 0.01$, ** $0.01 < p < 0.05$, * $0.05 < p < 0.10$

Table 6. Long Run Analysis Dependent Variable: $\ln\text{renewable}_t$

Variable	Coefficient	Std. Error	t-stat
$\ln\text{TRADE}_t$	-0.105	0.258	-0.408
$\ln\text{GDP}_{pc_t}$	0.807***	0.224	3.599
$\ln\text{OIL}_t$	-0.112	0.112	-1.002
$\ln\text{FDI}_t$	-0.136*	0.079	-1.719
INF_t	0.003*	0.002	1.708

Note: *** $p < 0.01$, ** $0.01 < p < 0.05$, * $0.05 < p < 0.10$

The results obtained from ECM shows that error correction term (ECT) has a coefficient of -0.847, which is highly significant. This indicates a strong adjustment speed back to equilibrium when there is a shock, with approximately 84.7% of the deviation from the long-run equilibrium being corrected in each period. The ECM results also imply that change in GDP_{pc} has a positive and significant effect on renewable energy consumption, with a coefficient of 1.728, indicating that short-term increases in GDP per capita positively influence renewable energy consumption. On the other hand, change in OIL has a negative, though only marginally significant, effect. Its coefficient is -0.012, suggesting that as oil prices increase, renewable energy consumption slightly decreases.

The results obtained for the long-run analysis suggest that $TRADE$ has an insignificant effect on renewable energy consumption in the long run, with a coefficient of -0.105. This suggests that trade does not have a statistically significant direct effect on renewable energy consumption over the long run in Türkiye. On the other hand, GDP_{pc} shows a significant positive long-run effect, with a coefficient of 0.807, reinforcing that economic growth leads to higher renewable energy consumption. OIL has an insignificant effect in the long run, with a coefficient of -0.112, indicating no strong long-run relationship between oil prices and renewable energy consumption. Moreover, FDI has a negative and weakly significant effect in the long run, with a coefficient of -0.136. This suggests that higher FDI may potentially reduce renewable energy consumption, though this finding is less robust. Finally, INF has a positive and marginally significant effect, with a small coefficient of 0.003. This suggests that inflation has a minimal but positive impact on renewable energy consumption in the long run.

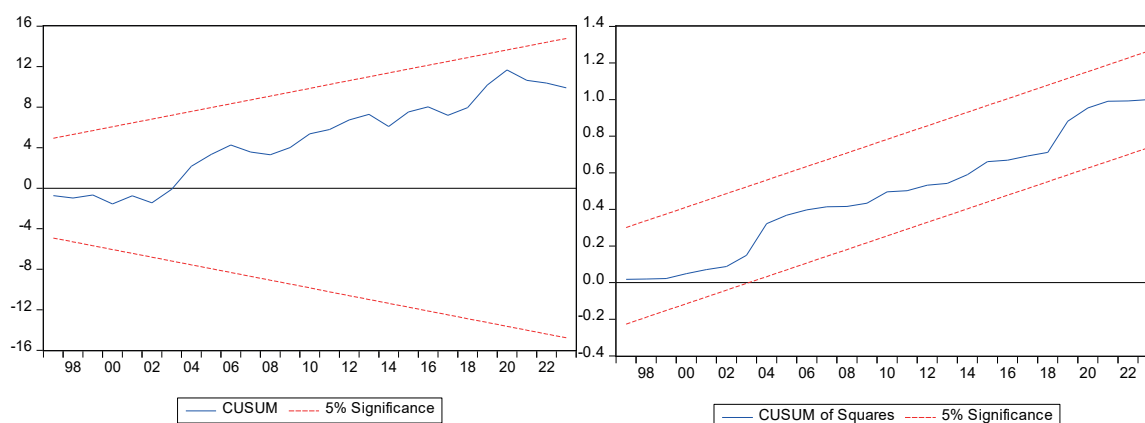
A series of diagnostic tests are conducted to ensure the robustness of the model, including tests for serial correlation, heteroscedasticity, and normality. The CUSUM and CUSUMSQ tests are applied to check the stability of the estimated coefficients over time. The results of the diagnostic tests applied to determine the appropriateness and stability of the ARDL model considered in this study, as well as the results of the CUSUM and CUSUMSQ tests, are presented in Table 7 and Figure 1, respectively. According to the diagnostic test results, there are no issues of autocorrelation, omitted variables, heteroskedasticity, or non-normal distribution in the linear model. The results of the CUSUM and CUSUMSQ tests indicate that the long-run coefficients are stable.

Table 7. Diagnostic Tests

Diagnosics/Diagnostic Test	Statistic
R2	0.670
Adjusted R2	0.572
F-Stat	6.851 (0.000)
BPG Het. Testi	5.714 (0.679)
BG Ser. Corr. LM Test	0.863 (0.649)
Ramsey RESET Test	2.388 (0.134)
J-B Normality Test	0.131 (0.937)

Note: Probability values in parantheses

Figure 1. CUSUM ve CUSUM of squares (ARDL)



The results of the NARDL model, which include the long-term relationships between the variables, as well as the short- and long-term asymmetry test results, and diagnostic test results are presented in Table 8. Similar to the linear ARDL model, in the NARDL model, the null hypothesis of “no asymmetric cointegration” is tested using the F-test statistic. Specifically, the presence of long-term asymmetric cointegration is determined using the F-test, through the Wald test for the null hypothesis that “the lagged level coefficients of all variables are equal to zero.” As shown in Table 6, the F_{PSS} test statistic of 6.588 which is statistically significant, confirms the existence of an asymmetric cointegration relationship among the variables. According to the empirical findings, the Wald test statistics for the long-term trade shock (W_{LR}) is significant, indicating the presence of an long run asymmetric relationship between shocks in trade and renewable energy consumption.

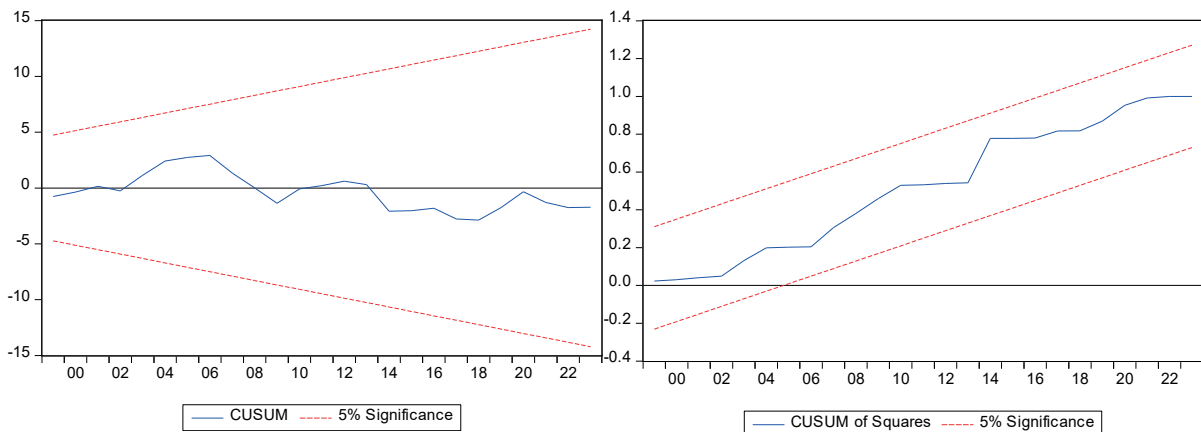
Table 8. NARDL Estimation Results

NARDL Model: $F(\ln renewable_t / \ln trade_t^+, \ln trade_t^-, \ln gdppc_t, \ln oil_t, \ln fdi_t, \ln inf_t)$			
Conditional Error Correction Model (CECM)			
Variable	Coefficient	Std. Error	t-ist
c	-8.534***	2.006	-4.255
$\ln REC_{t-1}$	-1.115***	0.170	-6.551
$\ln TRADE_{t-1}^+$	0.148	0.222	0.669
$\ln TRADE_{t-1}^-$	0.902**	0.365	2.475
$\ln GDP_{pc_t}$	1.346***	0.277	4.863
$\ln OIL_{t-1}$	-0.066	0.083	-0.794
$\ln FDI_{t-1}$	-0.220***	0.066	-3.344
INF_t	0.001	0.002	0.854
$\Delta \ln TRADE_t^+$	-0.616	0.422	-1.460
$\Delta \ln OIL_t$	0.073	0.072	1.025

$\Delta \ln FDI_t$	-0.093	0.063	-1.466
Error Correction Model			
c	-8.534***	1.132	-7.536
$\Delta \ln TRADE_t^+$	-0.616*	0.329	-1.875
$\Delta \ln OIL_t$	0.073	0.052	1.414
$\Delta \ln FDI_t$	-0.093**	0.041	-2.270
ECT_{t-1}	-1.115***	0.147	-7.562
Long-run Coefficients			
$\ln TRADE^+$	0.133	$\ln TRADE^-$	(-) 0.810**
$\ln GDP_{pc}$	1.208***	$\ln OIL$	-0.059
$\ln FDI$	-0.197***	INF	0.001
Long- and Short-Run Asymmetry Tests			
Long-run W_{LR}		Short-Run W_{SR}	
W_{LR}	8.718***	W_{SR}	0.550
Diagnostic Tests			
F_{PSS}	6.588*** (0.000)	R^2	0.766
χ^2_{SER}	0.341 (0.715)	R^2_{Adj}	0.672
χ^2_{HET}	9.016 (0.531)	F_{ist}	8.173***
χ^2_{NORM}	0.881 (0.644)	Cus_{um}	Stable
χ^2_{RAMSEY}	0.019 (0.892)	$Cusum(sqr)$	Stable
DW	1.857		

Note: Probability values in parantheses. χ^2_{SER} , χ^2_{HET} , χ^2_{NORM} , χ^2_{RAMSEY} represent the Breusch-Godfrey LM autocorrelation, Breusch-Pagan heteroscedasticity, normal distribution, and model specification error test statistics, respectively. Cusum and Cusum of squares (sqr) represent the stability test statistics. *** $p < 0.01$, ** $0.01 < p < 0.05$, * $0.05 < p < 0.10$.

Figure 2. CUSUM ve CUSUM of squares (NARDL)



According to the results obtained from the NARDL model, the effect of a positive trade shock on renewable energy consumption is positive (0.133) and statistically insignificant. On the other hand, a negative trade shock affects renewable energy consumption in a statistically significant and negative direction (-0.810). In other words, the findings suggest that the effect of trade on renewable energy consumption is not fully passed through.

The insignificant positive long-run coefficient for trade increases suggests that, over the long run, increases in trade openness may not have a strong or sustained effect on renewable energy consumption. While increases in trade might bring more access to technology, capital, and global markets, this may not be translating into a meaningful increase in renewable energy consumption over the long run. For instance, trade increases may be focused on sectors that do not heavily rely on renewable energy technologies. If much of the trade growth is in traditional energy-intensive sectors (e.g., manufacturing, heavy industry), then even though trade is growing, it may not lead to significant long-term shifts in energy consumption patterns toward renewables. The policy environment might not be fully geared toward capitalizing on trade growth to foster renewable energy. Even though trade increases, if government incentives and frameworks aren't promoting renewable energy adoption, the long-run impact remains limited.

The negative and significant long-run coefficient for trade reductions implies that when trade decreases over the long run, it has a detrimental effect on renewable energy consumption. In other words, a contraction in trade leads to less renewable energy adoption or consumption over time. When trade contracts, access to global markets for renewable energy technologies, expertise, and capital may shrink. This reduction in access could impede the adoption of renewable energy, as a country may become more reliant on existing fossil fuel infrastructure in the absence of trade-driven innovation and imports. A reduction in trade could lead to lower government revenues (through reduced exports), and this might reduce public or private investment in long-run renewable energy infrastructure. Trade contractions might also discourage foreign investment in renewable energy projects, thereby reducing growth in this sector. Furthermore, trade reductions can limit the transfer of technologies and innovation that are critical for renewable energy adoption, especially in developing or emerging economies. Less exposure to cutting-edge global technology due to decreased trade may slow renewable energy progress.

On the other hand, the insignificance of *OIL* and *INF* in the analysis may seem unexpected; however it is reasonable depending on the context and structure of our model. Türkiye has been transitioning significantly toward renewable energy, which indicates that the role of oil prices may be diminishing. As renewable energy becomes a larger part of the energy mix, fluctuations in oil prices may have less

impact on overall energy consumption patterns. Moreover, if the share of energy imports related to oil is decreasing as a result of this transition, the effect of oil prices on renewable energy consumption might become less significant. Furthermore, countries often sign long-term contracts for oil imports at fixed prices or stable rates, which reduces the immediate impact of fluctuating oil prices on energy consumption. Also, investments in renewable energy infrastructure are generally driven by long-term policy objectives, which may not be highly sensitive to short-term fluctuations in oil prices. Another explanation is that if Türkiye has strong government policies promoting renewable energy adoption, such as subsidies for renewable energy projects or tariffs on fossil fuels, these policies might buffer the economy from the direct effects of changes in oil prices. This could mean that renewable energy consumption is increasingly decoupled from the global oil market.

Similarly, inflation, while important for general economic activity, may have a limited direct impact on renewable energy consumption if the investments in renewable energy infrastructure are determined more by long-term government policies, international commitments (like the Paris Agreement), and technological innovation rather than macroeconomic conditions such as inflation. Even in inflationary periods, the energy sector—particularly renewable energy—may be relatively insulated from inflationary pressures due to fixed pricing, subsidies, or government interventions. Furthermore, in many industries, inflation might increase the cost of inputs, but for energy infrastructure, some of these costs might be passed on to consumers through fixed tariffs, or absorbed through government subsidies. This reduces the immediate impact of inflation on renewable energy investment and consumption. Moreover, if renewable energy technologies (e.g., solar panels, wind turbines) have already been benefiting from decreasing costs due to economies of scale and technological innovation, inflation might not significantly affect their adoption.

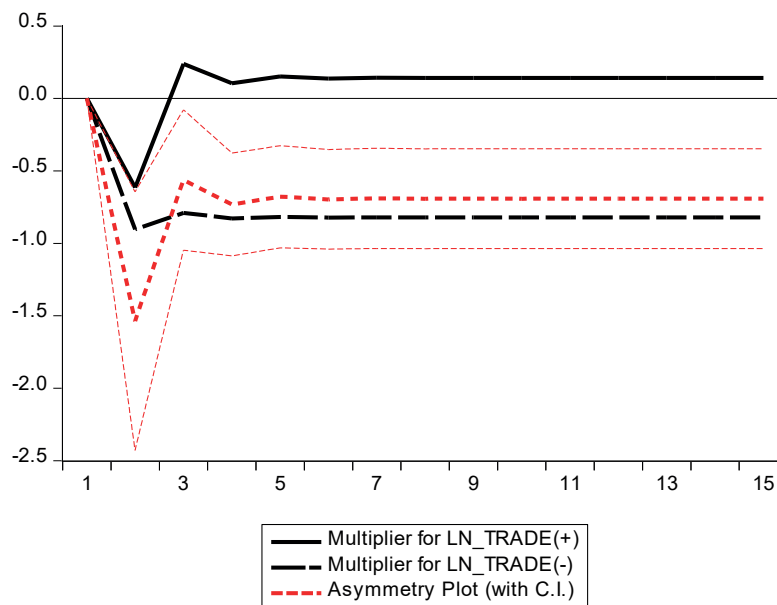
A negative coefficient for *FDI* in our analysis of renewable energy consumption might seem counterintuitive, as FDI is generally expected to boost energy infrastructure, including renewable energy. However, there are several plausible reasons for this result, depending on the context of our study. If a significant portion of FDI inflows into Türkiye are directed toward fossil fuel energy projects or other non-renewable energy sectors, this could explain the negative relationship. In such a case, FDI may reinforce reliance on traditional energy sources (oil, gas, coal), potentially crowding out investment in renewable energy. Also, if Türkiye receives large investments in natural gas extraction or coal-based energy plants, these investments might delay or reduce the urgency of adopting renewable energy. Moreover, FDI inflows may be primarily directed toward sectors unrelated to renewable energy, such as real estate, manufacturing, or consumer goods, which do not contribute to the growth of renewable energy infrastructure. As a result, these FDI inflows might not support renewable energy consumption and could even divert resources from more sustainable energy investments. FDI in energy-intensive industries (e.g., steel, chemicals) may increase demand for traditional energy sources, reducing the incentive to adopt renewable energy.

The significant and positive coefficient for GDP per capita indicates that economic development has a strong and positive effect on renewable energy consumption. This finding is consistent with theoretical expectations and empirical evidence suggesting that wealthier countries or regions tend to invest more in clean energy technologies as part of their development trajectory. On the one hand, as GDP per capita increases, it reflects an overall improvement in the country's economic well-being and financial capacity. This financial strength allows both the government and private sector to allocate more resources to infrastructure development, including renewable energy projects. Renewable energy technologies, such as solar panels, wind turbines, and energy storage systems, often require substantial upfront capital investments. Countries or regions with higher income levels are better equipped to fund these technologies, leading to higher renewable energy consumption over time. On the other hand, higher GDP per capita is typically associated with greater environmental awareness and increased demand for

cleaner energy sources. As economies grow, citizens and policymakers tend to prioritize sustainable development and environmental protection. This leads to greater support for renewable energy policies, subsidies, and incentives. Also, wealthier populations are more likely to push for greener energy solutions, aligning with the Environmental Kuznets Curve (EKC) hypothesis, which suggests that as income levels rise, societies shift from resource-intensive industries toward cleaner, more sustainable practices.

Finally, the dynamic multiplier graph illustrating the asymmetric relationship between trade and renewable energy consumption is presented in Figure 3. This graph specifically shows the short- and long-term asymmetric responses of renewable energy consumption to positive and negative shocks.

Figure 3. Dynamic Multiplier Graph



The black solid line represents the multiplier for positive changes in trade. Initially, there seems to be a spike upwards, but over time, the effect flattens and becomes insignificant around zero. This aligns with our previous findings, where positive changes in trade were positive but insignificant in the long run. This suggests that, in response to positive changes in trade, renewable energy consumption initially rises but does not sustain the momentum over the long run, indicating a limited lasting effect.

The black dashed line shows the multiplier for negative changes in trade. There is a sharp negative effect in the first few periods, followed by a gradual flattening but remaining at a negative value. This reflects the negative and significant long-run impact of trade reductions on renewable energy consumption that we found. This suggests that when trade declines, the negative effect on renewable energy consumption is both immediate and persistent over the long run.

The red dashed line represents the asymmetry between positive and negative changes in trade. The confidence intervals (C.I.) surrounding this line show that there is a significant difference between how positive and negative changes in trade affect renewable energy consumption. This confirms that long-run asymmetry exists, as the response to trade increases and trade decreases are not symmetric. Trade reductions have a more pronounced and sustained negative impact compared to the minimal or negligible impact of trade increases.

In sum, positive changes in trade have no substantial long-term effect on renewable energy consumption. While there might be a short-term rise, the effect diminishes over time. Negative changes in trade lead to a significant and persistent reduction in renewable energy consumption, confirming the long-term negative impact of trade contractions. The asymmetric impact indicates that while trade expansions provide limited benefits for renewable energy, trade contractions result in a marked reduction in renewable energy consumption. Our analysis suggests that policymakers need to be particularly cautious during periods of trade contraction, as they have a disproportionately large negative effect on renewable energy consumption. Strengthening domestic renewable energy policies and reducing reliance on global trade for energy technology imports could help mitigate this risk.

Conclusion

This study examines the symmetric and asymmetric effects of trade on renewable energy consumption in Türkiye for the period 1987-2023 using the NARDL model. The findings suggest that trade reductions have a significant and negative impact on renewable energy consumption, while trade expansions show an insignificant effect. These results highlight the asymmetric nature of the relationship, indicating that while trade contractions lead to substantial setbacks in renewable energy adoption, trade increases do not necessarily drive significant growth in renewable energy consumption.

The results offer several important policy implications. On the one hand, the significant negative impact of trade contractions suggests that the renewable energy sector in Türkiye is vulnerable to global trade disruptions. Reducing this vulnerability could be achieved by strengthening domestic production capabilities for renewable energy technologies and decreasing reliance on imported components. On the other hand, the insignificance of trade expansions suggests that simply increasing trade may not automatically result in higher renewable energy consumption unless targeted policies are in place to promote renewable energy technologies and investments.

One potential advantage of focusing on trade expansions is the opportunity for increased access to renewable energy technology, which can foster innovation and enhance energy infrastructure. However, without supportive policies, trade growth might remain concentrated in energy-intensive sectors that do not align with sustainability goals. Similarly, a reduction in trade might compel Türkiye to focus more on domestic renewable energy, but it could also lead to a decrease in foreign investment and innovation, slowing the transition to cleaner energy sources.

In light of these findings, policymakers should consider implementing more targeted measures that encourage the alignment of trade growth with renewable energy objectives. This might include incentives for renewable energy imports and exports, stronger partnerships in the renewable energy sector, and policies that buffer the sector from external trade shocks. Additionally, greater emphasis on fostering domestic renewable energy production would ensure that the country remains resilient in times of global economic uncertainty.

Ultimately, promoting a sustainable and secure energy future for Türkiye requires both domestic and international efforts that address the challenges posed by global trade dynamics. By developing policies that mitigate the risks associated with trade contractions while capitalizing on the opportunities of trade expansions, Türkiye can better position itself to achieve its renewable energy goals.

Furthermore, negative effect of FDI on renewable energy consumption might be a signal that policy adjustments are needed to direct FDI toward renewable energy projects. This could include better incentives, more favorable regulatory frameworks, and stronger enforcement of sustainability goals. Also, to reverse the negative relationship, policies that encourage “green FDI” (foreign investment

specifically targeted at renewable energy) could be crucial. This could involve tax incentives, subsidies, or international partnerships focused on clean energy development.

Given the positive relationship between GDP per capita and renewable energy consumption, it suggests that policies aimed at fostering economic development can also indirectly promote the adoption of renewable energy. For example, i) incentivizing private investment in renewable energy projects by offering tax breaks, subsidies, or low-interest loans; ii) supporting R&D in clean energy technologies to improve efficiency and reduce costs; iii) encouraging public awareness campaigns to highlight the environmental and economic benefits of renewable energy, thereby increasing demand for clean energy solutions as income levels rise. In conclusion, the positive and significant coefficient for GDP per capita reinforces the idea that as Türkiye continues to experience economic growth, it is likely to increase its consumption of renewable energy. This result aligns with global trends, where economic prosperity enables countries to transition toward greener, more sustainable energy systems.

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