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RESEARCH ARTICLE

The impact of the US interest rate and oil prices on renewable energy in Turkey: a bootstrap ARDL approach

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Abstract

This research investigates the spillover effect of the US interest rate and oil prices on renewable energy utilization in Turkey. By employing a novel bootstrap autoregressive distributed lag approach on annual data from 1985 to 2016, the empirical findings and discussions represent the first contribution to the energy economics literature. The findings of this research confirm that the US interest rate has a significant spillover effect on the use of renewable energy in Turkey through the channels of income and local interest rate. Due to limited foreign exchange reserves, high foreign debt, low international reserves, and devaluation of the local currency, the Turkish economy is highly intertwined with the US economy through international investment and trade. All these factors reinforce the spillover influence of the US interest rate on energy consumption in Turkey. Moreover, this study affirms that the price of oil has a negative impact on renewable energy use through the real income channel. In order for Turkey to realize its investments in renewable energy resources more reliably and sustainably, the study suggests that policymakers should revise the current economic growth model by making it more resilient to external shocks such as the US interest rate, exchange rate, and oil prices.

Keywords Bootstrap ARDL · External shocks · Renewable energy consumption · Interest rate · Oil prices

Introduction

As an emerging economy, Turkey has the 20th largest nominal gross domestic product (GDP) in the world and the 11th largest GDP on a purchasing power parity basis. With its growing economy, Turkey is still heavily dependent on imported energy sources, and about 88% of its energy consumption comes from non-renewable sources. Energy demand and consumption are expected to continue to increase in Turkey (Pata, 2018). However, non-renewable energy resources such as natural gas, oil, and coal cannot renew themselves and are spontaneously depleted after a certain period. The use of these types of energy sources harms the environment and the ozone layer by increasing carbon dioxide (CO_2) emissions (Wolde-Rufael and Weldemeskel, 2020). With the increasing use of non-renewable energy in Turkey, the biocapacity is decreasing, ecological footprint and CO_2 emissions are increasing, which negatively affects the environmental quality (Pata and Lorente, 2021). For this reason, it is important for Turkey to turn to renewable energy sources, as they are eco-friendly and do not have such a negative impact on the environment.

According to the World Bank (2021), Turkey is one of the most energy-intensive countries with the highest rates of increase in greenhouse gas emissions among emerging economies during the period 1985–2016. Turkey still has considerable potential to reduce CO_2 emissions by switching from using non-renewable energy to renewable energy. However, as shown in Fig. 1, Turkey has not managed to increase the share of renewable energy in total energy over the 30 years. Turkey has not yet regained the share of renewable energy from the 1990s. Various internal and external factors facing Turkey may play a role in this situation.

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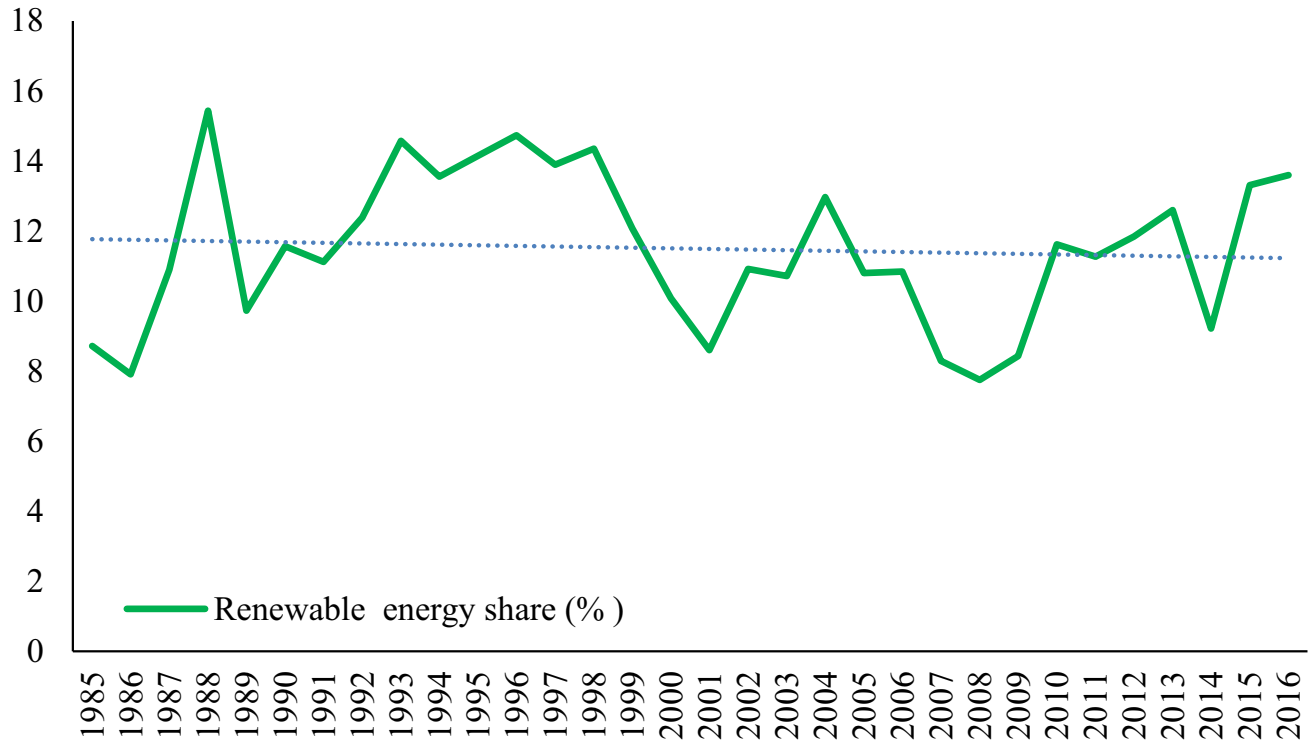

Fig. 1 Renewable energy share in total energy consumption (Our World in Data, 2021)

Turkey's high external debt and import-dependent export structure make it a vulnerable country to external shocks, which can lead to delays in renewable energy investments. In this sense, this paper aims to explore the influence of oil prices (OP) and US interest rates on the scale of renewable energy deployment.

Turkey imports more than 76% of its energy needs from abroad (Telli et al., 2021). Therefore, fluctuations in OP can have a considerable effect on economic performance and energy consumption. In addition, OP has a substantial impact on consumer options. An increase in OP may lead them to postpone the purchase of appliances that use energy sources (oil, gas, and coal). Thus, consumers' options will change by switching to the use of renewable energy sources such as solar, wind, and wave. Consequently, the use of renewable energy will increase as it replaces fossil fuels.

Since oil is used as an important factor of production, it is an indispensable source of energy for many countries. In this context, Lardic and Mignon (2006) and Rafiq et al. (2009) have shown that OP significantly affect economic indices. This significant effect can be attributed to various economic indices, e.g., (oil-importing country) versus (oil-exporting country). As an oil-importing country, any increase in OP may have a negative impact on Turkey's economic indices. If the economic indicators deteriorate, it is not possible to make infrastructure investments for renewable energy and allocate the necessary funds. In this sense, this study aims to test the interaction between oil price and the level of renewable energy utilization in Turkey. Furthermore, this study tests the influence of the US interest rate on the level of renewable energy consumption.

The US economy is the largest in the world and potentially has the strongest influence on the global economy. This strong influence is due to interconnectedness and size of the US economy. The US share of global GDP was 15.9% in 2020 (World Bank, 2021). US exports reached around 8% of global exports (Walmsley et al., 2021). The US currency is also the most widely used currency in the global trade. Therefore, alterations in US monetary policy have a direct impact on global financial conditions. It is no surprise, then, that changes in the US economy can have an impact on the global economies.

The shocks from developed economies such as the US economy can affect Turkey's economy through different transmission mechanisms, such as exchange rate and interest rate channels. Many empirical studies have attempted to examine the impact of the US dollar and interest rates on global economies (see, e.g., Canova, 2005; Andritzky et al, 2007; Miniane and Rogers 2007; Wongswan, 2009; Belke et al., 2017; Naresh et al., 2018; Iacoviello and Navarro, 2019; Samour et al., 2020; Yaman et al., 2020; Alhodiry et al., 2021). Andritzky et al. (2007) suggested that the US interest rate matters more for countries with less transparent policies and lower credit ratings. Miniane and Rogers

(2007) reported that the influence of the US interest rate channel on the global market depends on countries' capital controls. In addition, they conjecture that the influence of US interest rate on the global market depends on countries' external debt and capital controls. Wongswan (2009) opined that financial linkages play a significant role in determining the response of the world economy to any change in the US interest rate channel. The US monetary policy, i.e., interest and exchange rates, has a strong impact on emerging market economies. Therefore, any change in the US interest rate may affect various economic indices in emerging markets, such as capital inflows, local prices, local exchange rate, trade balance, aggregate demand, GDP, foreign direct investment, and international trade. For instance, a tight US monetary policy can lead to a significant increase in interest rates in emerging markets, which in turn is associated with a depreciation of the local exchange rate and increases the price level (Canova, 2005). The spillover effect of the US interest rate effect has strong implications for countries that rely on external debt and for economies whose fiscal policies are more closely linked to the USA such as Turkey. In this context, Georgiadis (2016) suggested that the magnitude of spillovers depends on a number of country characteristics, including financial market integration, external debt, exchange rate regime, trade openness, and industry structure. For example, economies that are more integrated with global capital markets experience larger spillover effects from the US interest rate. Given all of this, changes in US macroeconomic policy can cause an external price shock in Turkey, leading to costly and delayed investments in renewable energy.

Against this background, this study focuses on Turkey, which is heavily intertwined with the US economy through international investment and trade. Therefore, we would expect the spillover effect of the USA on the use of renewable energy in Turkey to depend on how this rate affects trade, economic growth, foreign direct investment (FDI), and the local interest rate. In this regard, the influence of the US interest rate on the use of renewable energy in emerging economies such as Turkey can be significant in two ways. First, any change in the US interest rate can affect domestic monetary policy. For instance, an increase in the US interest rate leads to an appreciation of the US currency. Conversely, it may lead to a devaluation of the Turkish currency (Arbaa and Varon, 2019). In response to a depreciation of the local currency, the first line of defense of central banks is to increase short-term interest rates (Inoue and Rossi, 2019). Thus, an increase in local interest rates affects positively the cost of investment financing and hence a decrease in investment in new renewable projects. In addition, any significant change in interest rates affects the consumption of cars and electric machines, which in turn affects energy consumption. Second, any change in the US interest rate can affect cash flow and foreign investment in Turkey. It can also affect trade, FDI, and real income. For these reasons, it is important to examine the potential impact of US macroeconomic policies on renewable energy consumption in Turkey.

The remainder of this study is organized as follows: Section 2 provides the literature review. Section 3 introduces the data, model, and methodology. Section 4 and 5 show the empirical findings and conclusions, respectively.

Literature review

Many empirical studies have examined the impact of macroeconomic factors such as real income on the level of renewable energy consumption. Using different methodologies and time periods for different countries, Balcilar et al. (2018), Eren et al. (2019), Mukhtarov et al. (2020), Simionescu et al. (2020), and Samour et al. (2022) found that economic growth positively affects renewable energy consumption. However, none of them studied the possible influence of external shocks such as the US interest rate on the level of renewable energy consumption. Therefore, we cannot address the relationship between renewable energy consumption and the US interest rates in developing countries here. Instead, we divide the literature section into two parts: (i) the effect of US interest rates and exchange rates on economic indices, and (ii) the effect of OP on economic variables and renewable energy. In this way, we show that the US interest rate and OP affect macroeconomic indicators and can indirectly change energy investment and consumption. In addition, we observe the direct effect of OP on renewable energy by examining previous studies for different countries.

Some studies have attempted to explore the impact of the US interest rate channel on global economies. In this area, several empirical studies confirmed a powerful impact of the US interest rates on global economic indices: Kim (2001) used a vector autoregressive regression (VAR) model and demonstrated that US interest rate policy has a strong impact on global economic indices. Canova (2005) showed that monetary policy shocks in the US cause significant fluctuations in economic growth in Latin America. Belke et al., (2017) proved that the US interest rate channel significantly affects local interest rates in 11 selected countries. Iacoviello and Navarro (2019) confirmed the significant effect of the US interest rate channel on emerging economies.

Other empirical studies have shown that US interest rate policy affects significantly the global financial markets: Ehrmann and Fratzscher (2009) examined the impact of the US monetary policy on 50 selected foreign markets around the world. The outcomes show that the US monetary has a strong impact on foreign markets. The findings also suggest that the degree of financial integration with the US financial market is a significant determinant of the US monetary

policy transmission process to global markets. Ozatay et al. (2009) confirmed that US monetary policy significantly influences 18 different emerging markets in the world. Basu et al. (2014) suggested that any change in US monetary policy has a sharp impact on capital flows in India. Naresh et al. (2018) used the generalized moments method to study the impact of the US dollar on BRICS countries' stock indices. The results confirm that the volatility of the US dollar affects the stock market through the capital account and investments. Samour et al. (2020) affirmed that the US interest rate significantly affects the stock market of Turkey. Yaman et al. (2020) applied the model VAR model and found that US interest rate policy has a significant impact on Turkish banks. Alhodiry et al. (2021) used the autoregressive distributed lag (ARDL) test and found that US interest rate have a negative impact on the Turkish real estate market.

Moreover, several empirical studies indicate that OP have an impact on economic indices. In this line, Lardic and Mignon (2006) and Rafiq et al. (2009) have shown that OP significantly affect real income. Besides, some studies have explored the impact of OP on renewable energy. Marques and Fuinhas (2011) confirmed that an increase in oil price leads to a decrease in renewable energy use for 24 European Union countries. In China and Indonesia, Salim and Rafiq (2012) demonstrated that there is a negative link among prices of oil, and the level of renewable energy consumption. In Tunisia, Mbarek et al. (2014) and Brini et al. (2017) found that an increase in OP significantly affects renewable energy consumption. For G7 countries, Guo et al. (2021) approved the negative influence of OP on the level of renewable energy consumption. In Russia, Karacan et al. (2021) showed that OP negatively affect renewable energy consumption. In India and Pakistan, Murshed and Tanha (2021) used panel data model and proved that OP have a negative effect on the level of renewable energy consumption.

Given the importance of the US monetary policy, it is unsurprising that the influence of the US monetary policy on the global economy is frequently examined. Although much empirical research focuses on the impact of the US monetary policy on global markets and economies, the spillover effect of the US interest rate on the level of renewable energy use is ignored. In various studies, it has been determined that the US interest rate and exchange rate affect various factors such as economic growth, stocks, and interest rates of developing countries. However, although there are studies examining the effects of OP on renewable energy consumption in developing countries, there is no study investigating the effect of the US interest rate on renewable energy consumption in developing countries. With this study, we aim to fill the existing gap in the literature. Our study makes two main contributions to the literature. (i) The study is the first to analyze local interest rate, US interest rate, OP, and income as determinants of renewable energy consumption in Turkey. (ii) This study aims to present robust findings by using the newly developed bootstrap ARDL method. Thus, we believe that the empirical findings and discussions represent a first contribution to the literature on environmental studies.

Data, model, and methodology

Data and model

This study uses annual time series data covering the period 1985–2016. The empirical model of this study is formulated as follows:

$$\ln RE_C = \alpha_0 + \beta_1 \ln E_G + \beta_2 \ln US_I + \beta_3 TR_I + \beta_4 \ln O_P + \varepsilon_t \quad (1)$$

where ln means the logarithm of the selected variable of this study, RE_C, E_G, US_I, TR_I, and O_P are the abbreviations of the variables in the tested model. Abbreviations, units of measurement, and the source of these variables are presented in Table 1.

Table 2 shows the descriptive statistics of the variables. Economic growth has the highest mean and median values. The Turkish interest rate is the variable with the highest standard deviation, while the oil price is the lowest. The US interest rate is the variable with the lowest values. All variables are included in the analysis by performing their logarithmic transformation.

Next, we describe the unit root, cointegration, and causality tests employed in this study, respectively. Afterward, we examine the spillover effect of the USA on renewable energy in Turkey.

Table 1 The description of the variables and sources of the data

Abbreviation	Unit of measurement	Source of date
RE_C	Renewable energy consumption as share of total energy (%)	World Bank (2021)
E_G	GDP (constant 2010 in US$ per-capita)	World Bank (2021)
US_I	Short-term US interest rate (%)	OECD (2021a)
TR_I	Short-term TR interest rate (%)	OECD (2021a)
O_P	Brent crude oil prices (US dollars/barrel)	OECD (2021b)

Table 2 The descriptive statistics of the data

	ln RE_C	ln E_G	ln TR_I	ln US_I	lnO_P
Mean	2.89	26.48	3.263	0.53	3.51
Median	2.87	26.34	3.66	1.43	3.26
Maximum	3.23	27.58	5.21	2.17	4.60
Minimum	2.44	25.05	0.488	−2.65	2.66
Std. dev	0.27	0.82	1.166	1.63	0.67
Observations	32	32	32	32	32

Methodology

Unit root tests

The ARDL approach can be employed to check the cointegration between the series and estimate the coefficient of the tested variables. Before estimating the coefficients, the present study examined the level of stationarity of the selected variables using various unit root tests. As the traditional unit root tests did not consider the timing of the structural breaks, the study uses one structural break unit root test of Zivot and Andrews (1992) (ZA). Meanwhile, the study applies the unit root test of Clemente et al. (1998) (CMR), which considers two structural breaks.

Bootstrap ARDL approach

To analyze the long- and short-term elasticities, the study uses the bootstrap ARDL approach recently proposed by McNown et al. (2018). Since conventional cointegration tests require a unique integration order, the ARDL model developed by Pesaran et al. (2001) is becoming increasingly popular and suitable for time series data that have different integration orders. An ARDL model in the form of an unrestricted error correction model can be represented as in Eq. (2):

$$\begin{aligned}\Delta \ln \mathrm{RE}_{\mathrm{C}} &= \alpha_0 + \sum_{\mathrm{i}=0}^{\mathrm{a}} \delta_1 \Delta \ln \mathrm{RE}_{C\,t-\mathrm{i}} + \sum_{\mathrm{i}=1}^{\mathrm{b}} \delta_2 \Delta \ln \mathrm{E}_{\mathrm{Gt-i}} + \sum_{\mathrm{i}=1}^{\mathrm{c}} \delta_3 \Delta \ln \mathrm{US}_{I\,t-\mathrm{i}} \\ &+ \sum_{\mathrm{i}=1}^{\mathrm{d}} \delta_4 \Delta \ln \mathrm{TR}_{I\,t-\mathrm{i}} + \sum_{\mathrm{i}=1}^{\mathrm{e}} \delta_5 \Delta \ln \mathrm{O}_{P\,t-\mathrm{i}} + \sigma_1 \ln \mathrm{RE}_{C\,t-\mathrm{i}} + \sigma_2 \ln \mathrm{E}_{G\,t-\mathrm{i}} + \sigma_3 \ln \mathrm{US}_{I\,t-\mathrm{i}} \\ &+ \sigma_4 \ln \mathrm{TR}_{I\,t-\mathrm{i}} + \sigma_5 \ln \mathrm{O}_{P\,t-\mathrm{i}} + \varepsilon_{\mathrm{t}}\end{aligned} \tag{2}$$

where Δ is the first difference operator, α_0 represents the constant term, ε_t means the error term, $\delta_1, \delta_2, \delta_3, \delta_4$, and$\delta_5$ are the estimated short-run coefficients,$\sigma_1, \sigma_2, \sigma_3, \sigma_4, \sigma_5$ are the long-run coefficients, and a, b, c, d, and e represent the optimal lag lengths.

McNown et al. (2018) updated the conventional ARDL by adding the *F*-independent test for the coefficients of the independent variables. In the bootstrap ARDL test, the critical values (CV) are generated by bootstrap simulation based on the integration properties of each tested series, which in turn solves the instability problem of the conventional cointegration tests. In particular, the new technique allows endogeneity for all explanatory examined variables. In this sense, the bootstrap ARDL test increases the power of *t* test and *F* tests. The conventional ARDL approach considers the *F*-overall and *t*-dependent tests and disregards the *F*-independent test. Using the *F*-independent test together with the *t* test and the *F*-overall test provides robust cointegration results (Pata and Caglar, 2021). A reader interested in finding out how to apply the bootstrap ARDL test can also look at Figure 1A in the study by Pata and Kumar (2021).

In determining the level of cointegration relationship, the values ofF_{overall}, $t_{\text{dependent}}$, and $F_{\text{independent}}$ should be statistically significant and exceed the CVs to have an integration relation between the variables under study (McNown et al., 2018). The null hypothesis of the $F_{\text{independent}}$ test:H_0 :$\sigma_2{=}\sigma_3{=}\sigma_4{=}\sigma_5{=}0$ is tested against the alternative hypothesis:H_1:$\sigma_2{\neq}\sigma_3{\neq}\sigma_4{\neq}\sigma_5{\neq}0$. The null hypotheses of the F_{overall} and $t_{\text{dependent}}$ tests are presented in Eq. (3).

$$\text{For } \mathrm{F}_{\text{overall}}\ \mathrm{H}_0 : \sigma_1 = \sigma_2 = \sigma_3 = \sigma_4 = \sigma_5 = 0,\ \text{for } \mathrm{t}_{\text{dependent}}\ \mathrm{H}_0 : \sigma_1 = 0 \tag{3}$$

The error correction model to estimate the coefficient in short-run relation is presented in Eq. (4):

$$\begin{aligned}\Delta lnRE_C = \alpha_0 &+ \sum_{i=1}^{\partial} \delta_1 \Delta lnRE_{C\,t-mi} + \sum_{i=1}^{\partial} \delta_2 \Delta lnE_{Gt-i} + \sum_{i=1}^{\partial} \delta_3 \Delta lnUS_{I\,t-i} \\ &+ \sum_{i=1}^{\partial} \delta_4 \Delta lnTR_{I\,t-i} + \sum_{i=1}^{k} \delta_2 \Delta lnO_{P\,t-i} + \omega ECT_{t-1} + u_t\end{aligned} \tag{4}$$

where $\boldsymbol{\alpha_0}$ represents the constant term, u_t is the white-noise error term, δ_1,δ_2,δ_3,δ_4,δ_5, and δ_6 are estimated short-run coefficients. In Eq. (4), $\omega \mathrm{ECT}_{t-1}$ is the error correction term (ECT) lagged by one period. When ECT is negative (−) and statistically significant, it implies the adjustment speed of the long-term equilibrium.

To confirm the flawlessness of the tested model, we employ the following diagnostic tests: The J-B normality

test X^{D1}_{NORMAL} to check normality, X^{D2}_{SERIAL} to check no-autocorrelation, ARCH X^{D3}_{ARCH} to check no-heteroscedasticity, and Ramsey RESET test X^{D4}_{RESET} to check the structural suitability of the model. Also, we apply the cumulative sum (CUSUM) and its squared form (CUSUM-SQ) to test the stability of the model. Finally, we use Granger causality analysis to examine the direction of a causal relationship between the analyzed series.

Empirical analysis and result discussion

As a first step, the study tests the stationary of the time series data using ZA and CMR unit root tests. The results of these tests are shown in Table 3 based on the structural breaks. The outcomes illustrate that RE_C, E_G, US_I, TR_I, and O_P are not stationary at level. In contrast, the outcomes demonstrated that all variables are stationary at first differences [I(1)]. This means that all variables have a certain order of integration. Therefore, a novel cointegration test is utilized in this study to check the existence of cointegration.

The outcomes of the bootstrap ARDL of co-integration test are shown in Table 4. Since all three test statistics exceed the critical value of 5% in absolute terms, there is a co-integration link.among,RE_C,E_G,US_I,TR_I, andO_P.

Having demonstrated and confirmed the cointegration relationship among the variables, the study estimates the short-run and long-run coefficients based on the ARDL approach. The outcomes in Table 5 illustrate that the real income coefficient is positive and significant. Thus, a significant increase in real income in Turkey stimulates renewable energy use in the short and long run. This outcome is in line with the results of Balcilar et al. (2018), Eren et al. (2019), Mukhtarov et al. (2020), and Simionescu et al. (2020).

The local interest rate coefficient is negative but insignificant. This finding is inconsistent with Samour et al. (2021) who confirmed a significant relationship between energy consumption and local interest rate.

Moreover, the outcomes from the ARDL approach show that the coefficient of the US interest rate is negative and statistically significant. Thus, an increase in the US interest rate will lead to a decrease in the use of renewable energy in both the short and long run. Hence, this study provides new empirical evidence that the US interest rate affects negatively the use of renewable energy in Turkey. According to the findings of the study, the US interest rate has a more significant effect on renewable energy consumption than the local interest rates.

Furthermore, the outcomes of this research indicate that the relationship between OP and renewable energy use is

Table 3 The results of unit roots tests

	ZA test		CMR test		
Variables	Test statistics	Bread-date	Test statistics	Bread-date 1	Bread-date 2
$lnRE_C$	− 1.215	1994	− 2.473	1999	2002
lnE_G	− 2.361	2001	− 2.775	1989	2001
$lnUS_I$	− 3.001	2008	− 2.973	2008	2009
$lnTR_I$	− 1.973	1998	− 3.225	1996	2001
lnO_p	− 1.997	1998	− 2.414	1989	1999
$\Delta lnRE_C$	− 5.557***	1993	− 6.441***	2002	2008
ΔlnE_G	− 7.624***	2012	− 6.122***	1996	2010
$\Delta lnUS_I$	− 6.013***	2009	− 7.001***	1989	2008
$\Delta lnTR_I$	− 7.001***	2001	− 8.910***	1994	2001
ΔlnO_p	− 6.337***	2013	− 6.320***	1990	2009

The asterisk *** means statistical sign at the 1% level

Table 4 The findings of the bootstrap ARDL test

Model		$F_{overall}$	$t_{dependent}$	$F_{independent}$
$RE_C=f(E_G, US_I, TR_I, O_P)$		6.10***	−3.19***	6.30***
Critical values ARDL)1,0,0,1,1)	1%	4.10	−3.95	6.11
	5%	3.38	−3.01	4.99
	10%	2.85	−2.65	3.85

The asterisk *,**.*** means statistical sign at a 1%, 5%, and 10% level

Table 5 Short and long-run ARDL analysis

Dependent variable = RE_C			
Variable	Coefficient	*t*-stat	*p* value
ΔlnE_G	0.012**	0.210	0.020
$\Delta lnUS_I$	−0.001*	−0.015	0.070
$\Delta lnTR_I$	−0.030	−0.315	0.110
ΔlnO_P	−0.310***	−0.661	0.000
lnE_G	0.012**	0.210	0.020
$lnUS_I$	−0.011**	−0.205	0.010
$lnTR_I$	−0.015	−0.351	0.060
lnO_P	−0.222*	−0.485	0.080
ECT_{t-1}	−0.620***	−2.109	0.000
R^2	0.970		
Diagnostic tests	*p* value		
X^{D1}_{NORMAL}	0.661 (0.631)		
X^{D2}_{SERIAL}	1.250 (0.441)		
X^{D3}_{ARCH}	1.610 (0.851)		
X^{D4}_{RESET}	1.013 (0.750)		

The asterisk *,**,*** means statistical sign at a 1%, 5%, and 10% level

negative in both the short and long run, implying that an increase in OP leads to a decrease in renewable energy use. This result is in line with the findings of Salim and Rafiq (2012), Mbarek et al. (2014), and Guo et al. (2021). The coefficient of ECT implies that the rate of adjustment has a negative sign and is statistically significant at the 1% level. This result confirms that there is a long-run linkage between the variables from short-run to long-run equilibrium.

We confirm the reliability of these results about the coefficients with diagnostic tests. The findings of the diagnostic tests show that the error term of the model has no problems with autocorrelation, non-normality, and heteroskedasticity. The Ramsey-reset test also confirms that the studied model is formed correctly. Moreover, the CUSUM and CUSUM-SQ tests in Fig. 2 show that the estimated coefficients of the ARDL model are stable.

Finally, the Granger causality results are reported in Table 6. The result shows that the *t*-statistics for the lagged value of ECT provide evidence that there is a unidirectional causal relation from E_G, US_I, TR_I, and O_P to RE_C, in the long run. The empirical findings from the short run affirm that there is a unidirectional causal link from real income, the US interest rate, local interest rate, and OP to renewable energy use in Turkey .

The empirical findings of the short-run analysis also illustrate that there is a causal linkage from the US interest rate to the domestic interest rate channel, OP, and real income. These results confirm that the US interest rate affects the level of renewable energy use in Turkey through the channels of real income, local interest rate, and OP. Meanwhile, these results prove that there is a significant effect of domestic interest rates on renewable energy use and economic growth. Moreover, the empirical findings from the short run indicate that there is a causal linkage from the OP to real income. These findings approve the significant effect of OP on Turkey's renewable energy use through the real income channel.

The study suggests that any change in the US interest rate may affect domestic monetary policy. The US is the world's largest economy, and there is significant potential for developing countries such as Turkey to be exposed to

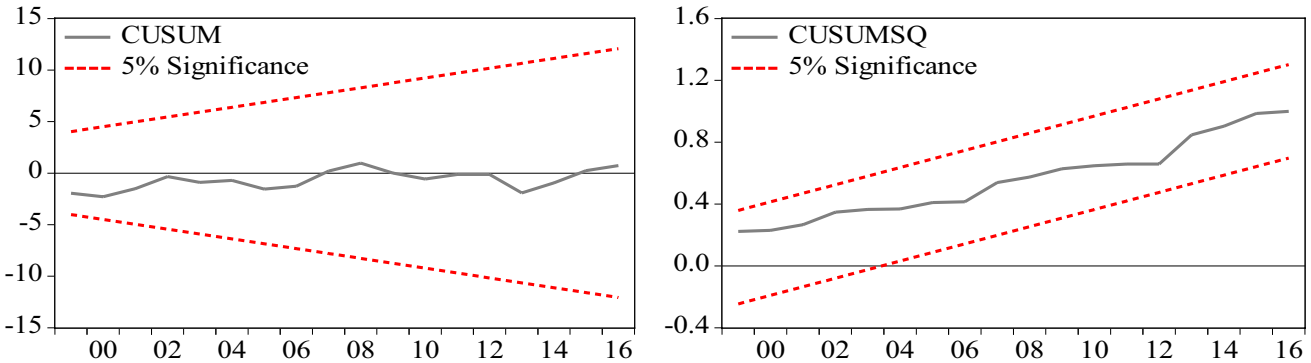

Fig. 2 The results of CUSUM and CUSUMSQ tests

Table 6 Granger causality analysis

	$\Delta lnRE_C$	ΔlnE_G	$\Delta lnUS_I$	$\Delta lnTR_I$	ΔlnO_p	ECT_{t-1}
$\Delta lnRE_C$	-	8.11**	6.110	6.272*	6.794*	−0.372**
ΔlnE_G	0.110	-	7.411**	1.619	6.337*	−0.316
$\Delta lnUS_I$	1.331	2.013	-	0.316	5.001	0.210
$\Delta lnTR_I$	2.112	2.001	6.910*	-	3.946	−0.310
ΔlnO_p	1.993	2.337	7.663**	0.916	-	−0.210

The asterisk *, ** mean statistical sign at 5% and 10% level

fluctuations due to the volatility of US monetary policy, as there is a risk that investors will withdraw their investments from emerging markets if the Federal Reserve System continues to raise interest rates. Therefore, any change in the interest rate may affect the local interest rate and investment level in Turkey. In response to the devaluation of the local currency, the first line of defense of central banks is to raise short-term interest rates. An increase in the local interest rate leads to an increase in the cost of investment financing and thus a decrease in investment in new projects. In addition, any change in the interest rate affects the production of clean technologies, which in turn affects the consumption of renewable energy.

The empirical outcomes of this study also affirm that OP has a negative impact on the use of renewable energy in Turkey through the channel of real income. Turkey is one of the major producers of construction materials, electronics, automobiles, electronic devices, and other equipment in the world, which makes the relationship between OP and energy consumption in Turkey even more obvious. In this context, more than 70% of Turkey's energy needs are met by imports. A significant increase in OP may lead Turkey to postpone the purchase of equipment that consumes oil, gas, and coal. As a result, demand for equipment, capital goods, and durable goods will fall. This, in turn, may lead to a decline in real income and energy consumption. With this decline in real income, investment in renewable energy will also be curtailed and, with it, environmentally friendly energy consumption. Therefore, Turkey should consider the spillover effect of US monetary policy when designing its energy policy and make efforts to minimize the negative impact of external shocks on the energy sector.

Conclusion

Energy is essential for the needs of industry, agriculture, transportation, and housing. In recent decades, energy consumption has increased significantly and is expected to increase further in the future. As an emerging country, Turkey's energy consumption from fossil fuels has increased rapidly. However, fossil fuel consumption has negative impacts on the environment. For this reason, Turkey should use and evaluate renewable energy resources to achieve sustainable energy development.

Turkey is among the largest recipients of FDI in West Asia, accounting for more than 20% of total FDI in West Asia during 2002–2012. As an open economy, Turkey maintains close ties with foreign countries, leading to external vulnerabilities and energy security issues. Despite the significant improvement in economic growth in recent years, external economic shocks and economic instability have significantly affected the Turkish economy. External shocks can also affect renewable energy investment and consumption in Turkey. In this context, the main objective of this study is to investigate the impact of external shocks, namely the US interest rate and OP, on renewable energy consumption in Turkey. For this purpose, the newly developed bootstrap ARDL approach is applied in the study.

The findings of the empirical models have shown that an increase in the US interest rate negatively affects the level of renewable energy consumption in Turkey. Thus, the findings of this research affirm a significant spillover effect of the US interest rate on renewable energy consumption in Turkey through different channels such as real income and local interest rate. These findings can be attributed to several factors: excessive external debt in Turkey, unstable economic policies that negatively affect the level of foreign capital, and low international reserves. Over the last years, Turkey has suffered from an external shock, which manifested itself in a decline in the exchange rate and a reduction in the value of assets. All these factors enhance the spillover influence of the US interest rate on renewable energy consumption in Turkey.

Moreover, the results suggest that OP has a negative impact on the level of renewable energy consumption. Nevertheless, a significant increase in OP may influence the options of consumers in oil-importing countries such as Turkey by switching to the use of renewable energy sources. However, this is not true for the results of this study. Turkey is a country that relies on fossil fuels for its production. The increase in OP imported by Turkey can cause inflationary and cost pressures that lead to a decrease in production and exports. This situation, which is unfavorable for economic growth, may lead to delays in renewable energy investments. The most important conclusion from this research is that oil

price is an external factor that cannot be influenced by local economic policies. Therefore, as an oil-importing country, Turkey needs to adopt new policies to reduce oil demand, which would help reduce the inflationary impact of oil prices on the Turkish economy. The policymakers in Turkey should develop alternative ways to meet their energy needs.

In this sense, the study suggests that policymakers should develop strategies to respond to external economic shocks, particularly the US interest rate and OP. To minimize the negative effects of OP, the Turkish government can support the use of renewable energy resources in industry and services through tax cuts and low-interest rates. In addition, in order to minimize the negative impact of the increase in US interest rates and pressure on the exchange rate on renewable energy consumption in the period COVID-19, the Turkish government needs to reduce its dependence on foreign countries for technology. To this end, the production of domestic renewable energy technologies should be supported through tax exemptions and subsidies.

This study offers some research opportunities. Future empirical studies could incorporate and test the impact of external shocks on renewable energy utilization by using different time series and panel data models for different countries.

Author contribution **AS:** conceptualization, methodology, formal analysis, writing original draft. **UKP:** data curation, writing original draft, writing—review and editing, investigation.

Data availability The sources of data have been duly mentioned in the study.

Declarations

Ethics approval This article does not contain any studies with human participants performed by any of the authors.

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