Environmental Science and Pollution Research (2023) 30:58213–58225
https://doi.org/10.1007/s11356-023-26551-y

RESEARCH ARTICLE

Investigation of the relationship between renewable energy, natural gas, and coal consumption with economic growth in Turkey: evidence from augmented ARDL approach

Hakan Eygu[1] · **Fatih Soğukpınar**[1]

Received: 4 January 2023 / Accepted: 15 March 2023 / Published online: 28 March 2023

Abstract
Energy is an indispensable requirement for the sustainable development of countries. Turkey has been trying to increase the use of renewable sources in electricity energy production with the policies it has implemented recently. This study investigates the effect of disaggregate energy consumption on economic growth in Turkey via the Augmented ARDL. Robust results are obtained by Augmented ARDL in econometric analysis. In this context, it is to examine the impact of renewable energy, natural gas, and coal consumption. Considering the 2001 crisis in Turkey, we add a dummy variable to the cointegration equation. The paper employs the recently developed augmented ARDL approach in the presence of one structural break to investigate annual time series data during the period 1988–2018. The results obtained in this study showed that all variables were statistically significant eventually. Long-term estimation results suggest that among the energy sources examined in the study, on economic growth has a positive effect coal consumption, natural gas consumption, and renewable energy. Moreover, empirical results indicated that economic growth and energy consumption also contribute to environmental damage. On the contrary, natural gas both increases economic growth and is effective in increasing environmental quality. The fact that the positive effect of renewable energy sources on economic growth eventually is greater than natural gas is the most striking finding of the study. In line with these results, it can be said that Turkey can reduce its energy dependence by increasing the use of domestic and renewable energy sources and providing sustainable economic growth.

Keywords Renewable energy · Economic growth · Energy consumption · Cobb–Douglas production function · Augmented ARDL · Turkey

Introduction

Energy is an indispensable need for countries and is an important factor in both production and consumption processes. Any use of energy is the main factor behind economic growth (EG) and prosperity. These energy use sources can be renewable or non-renewable (Zafar et al. 2019). The increasing energy consumption due to developing technology and population growth, with industrialization and developing living standards, causes the demand for renewable energy (RE) and non-renewable energy (NRE) to increase day by day. The main purpose here is to ensure the country's further growth. However, economies reduce dependence on fossil resources. The evidence indicates to SDG7, which is expressed as clean energy (Caglar 2022). The EG and energy variables can provide important information for SDG7. Additionally, the consumption of renewable resources increased in 2018. In the same year, natural gas consumption decreased (IEA 2019). Besides, a report issued by the International Energy Agency warned that oil and coal prices could be volatile in some years because production and refining capacity are not enough to meet world energy needs.

Fossil energy resources, which meet a large part of the energy needs of countries, are being depleted rapidly. This has accelerated the search for alternative energy sources,

Responsible Editor: Arshian Sharif

✉ Hakan Eygu
hakaneygu@atauni.edu.tr; hakaneygu@gmail.com

Fatih Soğukpınar
sogukpinarfatih@hotmail.com

[1] Department of Econometrics, Faculty of Economics and Administrative Sciences, Ataturk University, Erzurum, Turkey

especially in foreign-dependent and developing countries. Turkey is among the developing countries and electricity consumption is increasingly growing in this country (Pata and Kahveci 2018). This dependency gradually increases and creates a great burden on the country's economy. Today, societies are faced with the problem of the continuity of electricity supply. Energy is one of the important formations needed in every field. Additionally, economic growth is expected to increase proportionally to energy consumption, because the level of growth and development of countries largely depends on its level of energy production. Despite the extensive literature, countries cannot achieve as much growth as they want. In this context, human capital based on energy consumption can affect economic growth. People who have reached high-income levels with an increase in economic level may be willing to prefer ecological food and renewable energy sources. At the same time, of the economy growth can provide encouraging people to work more efficiently in current conditions. In this context, Turkey takes important policies in energy consumption. However, the effect of Turkey on economic growth in terms of the energy resources it uses should also be investigated. In this direction, the energy sources used may reduce the environmental quality. This paper focuses on the renewable energy consumption, natural gas, and coal consumption in Turkey which contribute to economic growth. Moreover, it is thought that the results of this study will also contribute to developing countries.

In cases where energy production does not meet demand, it creates a negative impact on the economy. Accordingly, more and more investments are made in renewable energy sources in Turkey recently. Although it is observed that there is a rise in energy consumption in Turkey because of these investments, it still has a low share compared to non-renewable energy consumption. In this sense, Turkey has met its energy needs mostly from domestic and renewable resources to reduce its energy imports, alleviate the burden of this dependence on the country's economy, and ensure power quantity security. Recently, the number of studies among the energy resources consumed on a global scale belongs to fossil resources, which are almost at the point of depletion as reserves, with approximately 85%. The current global (reserve-production) ratio shows that oil, natural gas, and coal reserves in 2018 were responsible for 50, 51, and 132 years of current production, respectively. Recent studies (Coestar et al. 2018) have shown that RE leads to economic growth and that sufficient production capacity should be increased as a result. In this context, Turkey's energy consumption is gradually increasing.

As shown in Fig. 1, energy consumptions are continuously increasing in Turkey. More than 108.900 metric tons of carbon have been released into the atmosphere since 1990. According to the World Bank (2021), from 1960 to 2018, global emissions increased by 283%. Turkey has set targets for the future in order to use RE sources more intensively in energy production. Moreover, Turkey aims to achieve economic growth by reducing natural resource consumption. This study is important in terms of achieving the determined goals. In this context, it examines the impact of disaggregate energy consumption on economic growth in Turkey. It is thought that it will close the gap in the existing literature in terms of the model used and the separation of the selected variables.

This study, unlike the studies in the literature, aims to contribute to the existing literature on energy consumption by disaggregating it based on different variables (renewable, natural gas, and coal) using a multivariate model. There are several reasons why this study focuses on Turkey

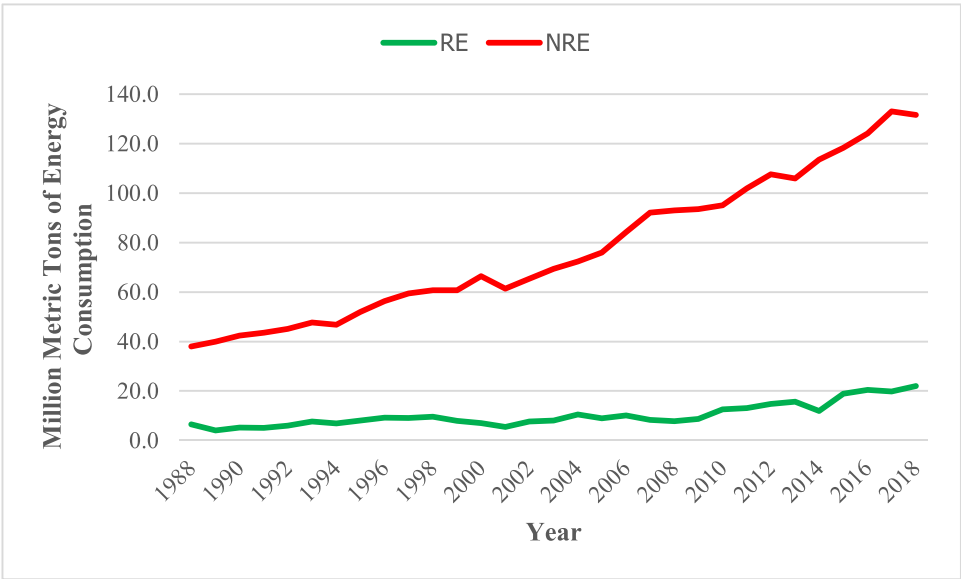

Fig. 1 Energy consumption in Turkey

for empirical analysis. Firstly, there has been a significant increase in economic growth and energy consumption in Turkey since the 1980s. The increase in economic growth and the tendency to natural gas in energy consumption is a matter of curiosity. The second, against this background, we wish to explore and answer the following research question: Does the renewable energy consumption, natural gas, and coal consumption in Turkey contribute to economic growth? By answering this question, it will help in developing countries in economic growth and energy consumption scenarios. Finally, although there are many studies on energy, economic growth, and electricity production in the domestic and foreign literature, it is important to conduct research via the Augmented ARDL (AARDL), different variables, and Cobb–Douglas production function in this field. The Augmented ARDL approach used in the analysis provides more robust results by considering the potential dependence in Turkey under consideration. The AARDL method is also used for robustness and to generate more comprehensive policy recommendations. As a result, Sam et al. (2019) showed that the Augmented ARDL is robust. In addition, in studies by Pata and Caglar (2021), the AARDL method used.

The rest of the article proceeds as follows: the "Literature review" section provides the literature review. The "Data set and methodology" section provides data set, modeling, and methods. The "Empirical results" section provides the empirical results. Then, the empirical findings are indicated and discussed in the "Empirical findings and discussions" section. In the last section, empirical findings are evaluated, and policies are presented for the Turkey.

Literature review

In this section, studies on economic growth in domestic and foreign literature are presented.

Economic growth and energy in the world

Some studies were conducted on different country groups using similar variables (Sebri and Ben-Salha 2014; Chen et al. 2020). When the rise in world primary energy consumption is analyzed according to resource types, it is seen that the demand for all renewable and non-renewable resources (Elahi et al. 2019) has increased. Zhoor et al. (2022) determined that polluting energy sources play a role in increasing economic growth. Apergis and Payne (2011) investigated productive activities in the energy sector and energy economic growth by speedily increasing productivity and generating enormous revenue as well as gross domestic product (GDP) variables. The study by Halicioglu and Ketenci (2018) evaluated the link between RE and NRE consumption and variables in the EU-15 countries between 1980 and 2015 using the function (Cobb–Douglas production) with the ARDL method. The investigation suggested that the consumption of RE and NRE varies among countries. In the analysis (Cobb–Douglas) conducted to determine the effect of RE consumption, it was concluded that a 1% rise in RE expenditure in China between 1978 and 2008 increased GDP by 0.12%. Similarly, another study (Inglesi-Lotz 2016) showed that electricity consumption in OECD industrial sectors is based on gray and vector autoregressive models. Azat et al. (2014) used the production function, to estimate the electricity consumption in energy consumption in G7 countries. The result of the study showed that production function holds importance for determining the cointegration among mutable. A meaningful relationship was found between energy use with growth (Tugcu and Topcu 2018). Khan et al. (2019) investigated of CO_2 increase in China. The results show that GDP income positively affects the emission level in China. Wan et al. (2022) found evidence of sustainable environment in China. The results show that economic growth is a core contributer to ecological emissions. Jian and Afshan (2022) made similar study for G10 countries for 2000–2018. These researchers used CS-ARDL as method. Their study supported the validity of the EKC hypothesis in G10 countries.

Some studies analyze renewable and non-renewable policies implemented in countries (Apergis and Payne 2010a, b) at certain periods. In this context, studies assessed the declaration of the electricity sector in Balkan countries (Koçak and Şarkgüneşi, 2017) and investigated Turkey's potential for RE research (Shakouri and Khoshnevis 2017) by showing the fastest increase; after 2010, it has almost doubled its annual average increase rate of 1.5% in the last decade (Dogan 2016; Tugcu et al. 2012). Furthermore, Tugcu et al. (2012) evaluated the economic growth, RE, and NRE. They used cointegration and causality tests in panel data (Pedroni 2001a, b; Perdroni, 2001) and showed that growth has a positive effect on energy decrease. Additionally, the increase in economic growth showed that emissions increased (Zafar et al. 2019). Sharif et al. (2019) examined the impact of economic growth, technological innovation, globalization, and renewable energy for Pakistan. According to the outputs of the study, renewable energy has a negative impact on carbon emission. Moreover, the costs may decrease. However, some scholars have explored the question of how environmental pollution can be controlled. Sun et al. (2021) focused on the effect eco-innovation and globalization on control environmental pollution. They examined the long-term relationship between CO_2 and GDP, environmental innovation, and globalization index in the USA by using the QARDL method. They showed that eco-innovation contributes to enhancing environmental quality. A similar study also showed that renewable energy consumption negatively

affects emissions for Pakistan in the short run (Chien et al. 2021). In another study, Chien et al. (2022) focused on the long-term relationship between CO_2 with solar energy and eco-innovation by using the QARDL method. Their study supported that the validity of the increase in GDP degrades the environment at higher quantiles. Sun et al. (2022) analyzed the effect of economic growth and urbanization on carbon emissions, using panel data analysis, for the period 1991–2019 in MENA countries. The authors found that economic growth and urbanization contribute to enhance CO_2. Zafar et al. (2022) found that economic growth increases environmental degradation. The results in similar studies reveal short-term asymmetric effects in the data. Moreover, Bélaïd and Youssef (2017) investigated the link between RE and NRE consumption with the economic development econometric method and established a significant relationship among related variables. A panel study involving African countries and investigating the effect of energy types on GDP found that between energy types and growth (Adams et al. 2018). Additionally, Dogan and Seker (2016) examined the resulting data was then used to estimate renewable and non-renewable various factors.

Economic growth and energy in Turkey

In this section, studies carried out in Turkey are given. In the study, an examination of the consumption areas of RE and NRE energy sources in Turkey with the Cobb–Douglas production function showed that 57.12% of the total energy was directly used (Dogan and Seker 2016; Erdal et al. 2008). Another study using the same method on energy consumption and on the areas where this energy is consumed showed that energy-related use has a direct effect on investments (Atmaca and Basar 2012). In another study, the natural gas consumption of Turkey between the years 2010 and 2018 was analyzed using machine learning techniques. The study Mert and Caglar (2020) showed the asymmetric impact of foreign direct investment and carbon emissions between the years 1974 and 2018. As in similar studies (Eygü, 2022), a positive relationship was determined between the variables. Some previous research indicates that Turkey will switch to 100% renewable energy by 2050 (Kilickaplan et al. 2017). However, they stated that there will be environmental degradation in this transition. Because of Turkey's growth policy, final energy consumption according to sources is increasing. In another study, Sharif et al. (2020) examined the impact of renewable and non-renewable energy consumption on ecological footprint for Turkey. According to the outputs of study, ecological footprint has a negative impact on selected variables.

A comprehensive discussion has been made in the literature on the Cobb–Douglas production function related to energy consumption. In a study (Ocal and Aslan 2013) examining the relationship between RE and GDP in our country, outcomes obtained from the autoregressive models showed that RE expenditure negatively affected economic growth. The study of Ozkan et al. (2012) studied the link between energy production, energy imports, and GDP in Turkey for the period 1971–2010 using the same production function. The results showed significant differences between RE and NRE exploration. In the research considered, the effect of RE sources agricultural production is 18.12%, while the effect of non-renewable sources is 81.60%. Additionally, a bidirectional relationship was found between RE or NRE consumption GDP for Turkey. Similar previous studies are in parallel with the evidence in the literature (Lise and Montfort 2007; Sari et al. 2008).

Considering the development of total the energy consumption capacity in Turkey according to energy sources (see Fig. 2), the total energy consumption capacity was REC, NG, HE, and coal with an increase. Since 2010, this rate has been seen to be almost 100%. It has been determined that more than 45% of the energy consumed especially in the last 15 years is produced from natural gas and 5% from renewable resources.

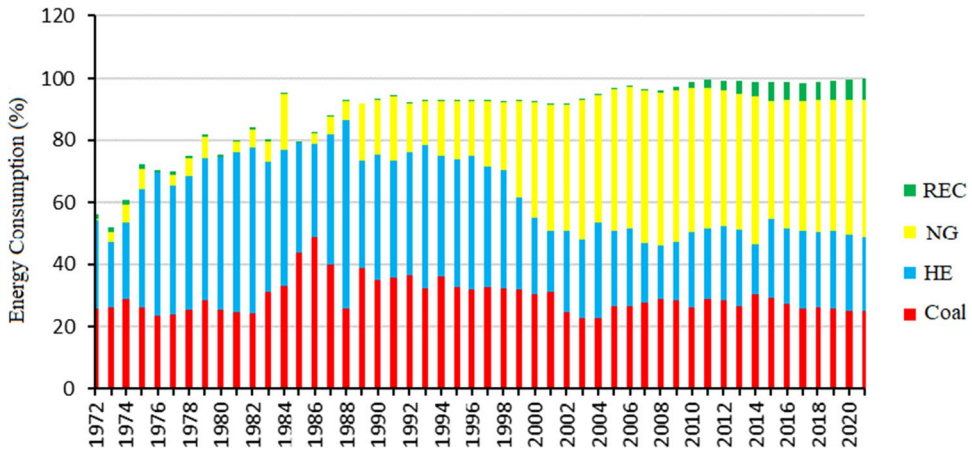

Fig. 2 Development of Turkish energy consumption by energy sources

As a result, Turkey has set future targets for the more intensive use of the country and RE resources in electrical energy production, the reliable and economical use of these resources, the increase of resource diversity, and the protection of the environment. Therefore, the relationship to be found between the variables with the method used in the study is important for the policies to be developed.

Data set and methodology

Data set

This study covers the period between 1988 and 2018. We obtained the 1988–2018 time series of economic growth (EG), capital (C), and labor (L) from the World Bank online database. However, we obtained the renewable energy consumption, natural gas (NGC), and coal consumption (CC) from Turkish Statistical Institute.

Within the framework provided by previous studies, the energy supply data used in electricity production in this study were used as a surrogate for energy consumption (Dogan 2015). The explanations for the variables are shown in Table 1.

The data are annual and the data of all variables in the econometric model are used in logarithmic form.

Econometric models

In this study, the investigated renewable energy consumption, natural gas, and coal consumption in Turkey contribute to economic growth. The models will be estimated by approaches based on cointegration techniques. Besides, when working with time series, stationarity should be examined first. Many recent studies have used energy consumption by adding it to the production function, according to the sources (Apergis and Payne 2012; Salim et al. 2014). This study considers capital (C) and labor (L) as individual factors and examines the relationship between energy consumption and economic growth using a modern approach. This research contributes to the existing literature by analyzing the impact of energy consumption on the Turkish economy by disaggregation based on resources (renewables, natural gas, and coal) by using a multivariate model. This model is the Cobb–Douglas (CD) production function. Generally, the model is,

$$T_j = \alpha_1 Y_{2j}^{\alpha_2} Y_{3j}^{\alpha_3} \dots Y_{lk}^{\alpha_k} f^{\varepsilon j};\ j = 1, 2, 3, \dots, m \tag{1}$$

where

T, is the output variable;

Y_1, Y_2, …,Y_i are the (l-1) input variables;

α_1, is the technical coefficient;

α_1, α_2, …, α_1 are the (l-1) regression coefficient showing flexibility (input);

ε, is the error term;

m, is the unobservable variable.

The model has been transformed into a multilinear model (2) and the obtained matrices are given below,

$$T^*_{mxl} = Y^*_{mxl}\alpha_{lx1} + \varepsilon_{mxl}, \tag{2}$$

where

$$T^* = \begin{bmatrix} T_1^* \\ T_2^* \\ M \\ T_m^* \end{bmatrix}, Y^* = \begin{bmatrix} 1 & Y_{21}^* & \Lambda & Y_{l1}^* \\ 1 & Y_{22}^* & \Lambda & Y_{l2}^* \\ M & M & \Lambda & M \\ 1 & Y_{2m}^* & \Lambda & Y_{lm}^* \end{bmatrix}_{mxl} and \varepsilon^* = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ M \\ \varepsilon_l \end{bmatrix}_{lx1}, \tag{3}$$

The LSE of α is gotten through

$$\hat{\alpha} = \left[Y*'\ Y*\right]^{-1} Y*'\ T*\ \ and\ \hat{\alpha} = antilog\left(\alpha_1^*\right) \tag{4}$$

Table 1 Their representation and construction

Variable names	Variable representation	Variable proxy	Source
Economic Growth	EG	GDP per capita (constant 2010 US$)	World Development Indicators
Capital	C	Gross fixed capital formation (constant 2010 US$)	World Development Indicators
Labor	L	Employment to population ratio, 15 +, total (%)	World Development Indicators
Renewable energy consumption	REC	Electricity production using renewable source	Turkish Statistical Institute
Natural gas consumption	NGC	Electricity production using renewable source	Turkish Statistical Institute
Coal consumption	CC	Electricity production using renewable source	Turkish Statistical Institute

Now the required one is,

$$\widehat{T}_j = \widehat{\alpha}_1 Y_{2j}^{\widehat{\alpha}_2} Y_{3j}^{\widehat{\alpha}_3} \dots Y_{lj}^{\widehat{\alpha}_l}; j = 1, 2, \dots, m. \quad (5)$$

Since disaggregated renewable energy sources data (solar, wind, geothermal, etc.) could not be obtained during the sample period, renewable energy sources were examined in the method. An expanded version of the method is given below.

$$EG_t = f(C_t, L_t, REC_t, NGC_t, CC_t) \quad (6)$$

The above-given function in which the constant term (β_0) and the error variate (ε_t) are included can be econometrically represented as follows.

$$LEG_t = \alpha_0 + \alpha_1 C_t + \alpha_2 L_t + \alpha_3 REC_t + \alpha_4 NGC_t + \alpha_5 CC_t + \varepsilon_t \quad (7)$$

Empirical results

As a methodology, we can list the things to be done in the study as follows. In this study, unit root properties of variables are investigated in the first stage of empirical analysis. The unit root test developed by Phillips and Perron (1988) was used. Time series are affected by structural shocks. This is why structural breaks are impotant to consider. After the unit root properties of the variables are determined, the extended ARDL approach is used to obtain the long- and short-term coefficients by considering Eq. (7). In this study, AARDL developed by Shin and Smith's (2001) determines the cointegration relationship between dependent and independent variables. Cai et al. (2018) and Caglar (2020) state that all F, t-test, and F_{all} tests should be used to confirm the difference between cointegration and non-cointegration degenerate cases. To better explain the AARDL, Eq. (7) is rewritten in an error correction form as follows:

$$\begin{aligned}\Delta LEG_t = {} & \gamma_0 + \gamma_1 D_t + \delta_1 LEG_{t-1} + \delta_2 LC_{t-1} \\ & + \delta_3 LL_{t-1} + \delta_4 LREC_{t-1} + \delta_5 LNGC_{t-1} + \delta_6 LCC_{t-1} \\ & + \vartheta_1 \sum_{i=1}^{c} \Delta LEG_{t-1} + \vartheta_2 \sum_{i=0}^{a} \Delta LC_{t-1} + \vartheta_3 \sum_{i=0}^{n} \Delta LL_{t-1} \\ & + \vartheta_4 \sum_{i=0}^{k} \Delta LREC_{t-1} + \vartheta_5 \sum_{i=0}^{l} \Delta LNGC_{t-1} + \vartheta_6 \sum_{i=0}^{r} \Delta LCC_{t-1} + v_t\end{aligned} \quad (8)$$

where Δ, γ_0, and v_t indicate the first difference operator, constant term, and i.i.d. residual term, respectively. D_t displays the break date obtained from the break unit root test. Use all three tests below to ensure that cointegration is valid in this test before:

1) The F-test should be done for all dependent and independent variables (F_{all}, known in the literature as the bound test).

H_0: $\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = 0$ (Critical values are obtained from Narayan (2005) study.)

2) t-test ($t_{depented}$) for lag dependent variable, hypothesis,

H_0: $\theta_1 = 0$.

(Critical values are obtained from Pesaran et al. (2001) study.)

3) F-test only for arguments ($F_{independent}$),

H_0: $\theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = 0$ (Critical values are obtained from Sam et al. (2019) study.)

If all three hypotheses shown above are rejected, we can talk about cointegration. In addition to these, two different degenerate states can occur in the ARDL model.

Degenerate Case 1: This is because the lag-dependent variable is significant ($\theta_1 \neq 0$). It also happens when the arguments are insignificant (H_0: $\theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = 0$).

Degenerate Case 2: The lag arguments are significant (H_0: $\theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq \theta_6 \neq 0$). It also happens when the lag-dependent variable is insignificant. Therefore, ARDL model will be used in cases where the dependent variable is stationary.

Unit root tests

As the first step of econometric analysis in time series, the stability of the series is tested. While making econometric estimations, first, the stationarity of the series should be checked. The use of the ARDL method in the exploration allows the analysis of variables with different degrees of stationarity. To use the ARDL method, it should be determined that any variable is not quadratic stationary. Therefore, first, it is necessary to investigate the unit root properties. Accordingly, the results are given in Table 2.

These results show that all series are not stationary at their levels. However, it shows that it is stationary in the first difference. With the 5% significance level, the H_0 hypothesis could not be rejected and it was determined that the series were stable at the level. These results that the ARDL bounds testing approach are suitable for this study. When the breaking dates are examined, a break in 2000 was found for economic growth. This date shows before the 2001 crisis year. While the GDP was 6.174 per capita in 1999, it decreased to 5.993 per capita in the period after 2000. The Perron test considers the lowest t-statistic. Therefore, it shows the year 2000 as the breaking time. According to the World Bank Report, GDP in 2001 was the lowest (annual − 5.75%) year in Turkey's history. The current study finds 2001 to the cointegration equation as a dummy variable, as there are policies to increase growth in Turkey. When the breaking dates are examined (1st

Table 2 Unit root tests results

Constant and trend model				
	Phillips Perron test		Single break Perron test	
Variables	Level	1st difference	Level	1st difference
LEG	−2.326	−7.554***	−3.211 [2000]	−4.089* [2007]
LC	−2.721	−6.074***	−3.171 [1993]	−7.094* [1981]
LL	−0.877	−5.678***	3.177 [2007]	6.287 [2000]
LREC	−3.026	−8.799***	−2.254 [2000]	5.568* [2002]
LNGC	−2.618	−9.312***	−3.054 [1998]	5.534* [2009]
LCC	−0.671**	−5.012***	−3.429 [1991]	−5.599* [1988]

***, **, *: $p<0.01$, $p<0.05$, $p<0.10$, respectively. [] shows the breaking years.

Table 3 Optimal lag length selection

Lag length	AIC	LM test
1	−18.02077	0.2983
2	−17.32371	0.3213
3	−18.20847[a]	0.3126[a]

AIC Akaike ınformation criteria; LM is the probability value for the Breusch-Godfrey Autocorrelation test statistic.

[a]The appropriate lag length.

length was chosen as 3. Moreover, the appropriate lag length was determined using the AIC (Table 3).

Based on the test results, after the optimal lag length was identified as 3, the most appropriate ARDL model (1, 1, 3, 1, 1, 1) was determined among the possible 3072 models according to the AIC criterion.

In this stage, the diagnostic of the tests are examined, and the results are given in Table 4.

The assumptions test results show that the model is free of autocorrelation, heteroscedasticity, functional problems, and normality problems. In addition to diagnostic tests, the fixity of the estimated model and the fixity of the short-term and long-term coefficients were determined (Brown et al. 1975) with the CUSUM and CUSUMSQ tests. This stability can be seen in Fig. 3.

As seen in Fig. 3, estimators are stable at the 5% significance level. Generally, it can be said that the obtained predictive values are fixity throughout the process.

After, whether there is a cointegration relationship between EG and independent variables was investigated according to the Augmented ARDL approach.

The null hypothesis (H_0: $\beta_1=\beta_2=\ldots=\beta_n$), which states that there is no long-term relationship, was examined against the research hypothesis (H_1: $\beta_1\neq\beta_2\neq\ldots\neq\beta_n$). The calculated three test statistic is upper than critical limits. When the calculated statistics is greater than the upper limit of the critical value, the null hypothesis is rejected and there is a cointegration relationship between the variables. The fact that all three test statistics are significant in the model indicates a cointegration relationship between EG and the independent variables. Because the calculated (6.635) statistic of the EG model is above the upper bounds critical values, the null hypothesis of no cointegration is rejected. It can be seen from Table 5 that the null hypothesis is rejected at the 1% signifivance level for the lagged dependent variable ($t_{dependent}=-5.414$) and the 5% significance level for the lagged independent variables ($F_{independent}=4.901$). Thus, it is confirmed that there is an exact cointegration relationship between renewable energy, natural gas

Table 4 Diagnositc test results

BG LM test[a]	BP Godfrey test[b]	JB test[c]	RR test[d]	Cusum[e]	CusumSQ[f]
1.3362 (0.3126)	0.6917 (0.7434)	1.6849 (0.4306)	0.3293 (0.5759)	Stable	Stable

[a]The Breusch–Godfrey LM test statistic for no serial correlation.

[b]The Breusch-Pagan-Godfrey test statistic for homoscedasticity.

[c]The Jarque–Bera statistic for normality.

[d]The Ramsey's reset test statistic for regression specification error.

[e,f]It determines the stability of the long-term coefficients of the model.

Difference), a break in 2007 was found for economic growth. In economics growth variable, there is year 2007 related to the financial crisis in the EU. This emerging crisis also negatively affected the Turkish economy.

Cointegration tests

In line with the purpose of the study, it is desired to examine the effect of energy consumption on economic growth. In this direction, it was decided to use the ARDL-bound testing approach (Pesaran et al. 2001) in the study. To run ARDL models, the maximum lag

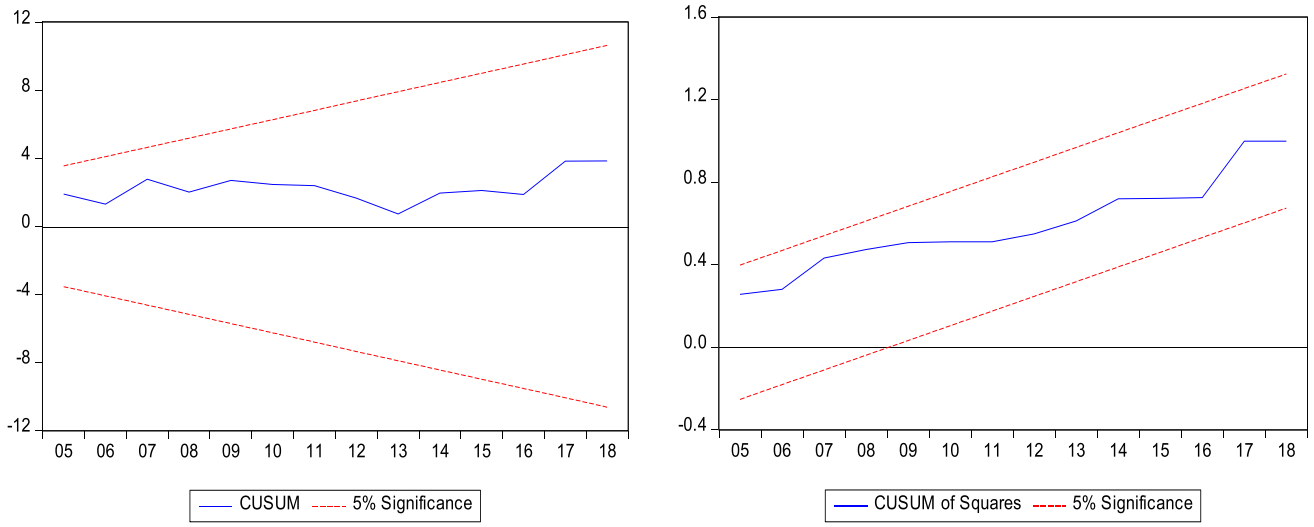

Fig. 3 The plot of CUSUM and CUSUMSQ tests for ARDL (1, 1, 3, 1, 1, 1)

Table 5 Augmented ARDL test results

Model	DU	Estimated model	Tests	Resource and critical values		
f(EG/C, L, REC, NGC, CC)	2001	(1, 1, 3, 1, 1, 1)	$F_{all} = 6.635$***	Narayan (2005)		
				%10	%5	%1
				3.76	4.44	6.04
			$t_{dependent} = -5.414$***	Pesaran et al. (2001)		
				%10	%5	%1
				−3.86	−4.19	−4.79
			$F_{independent} = 4.901$**	Sam et al. (2019)		
				%10	%5	%1
				3.67	4.40	6.15

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

consumption, coal consumption, and economic growth for Turkey. To sum up, the cointegration relationship exists for economic growth in AARDL method.

Long-run and short-run estimates

Moreover, long-and short-run estimates are presented, respectively, as can be seen in Tables 6 and 7.

Forecast results show that all variables examined in the analyzed period are statistically significant and have a positive effect on EG. An increase of 1% in L and C, which appear to have the greatest impact on economic growth, increases EG by 0.42% and 0.34%, respectively. In terms of the contribution of the energy sources examined in this study to EG, it was found that a 1% increase in CC and REC increased EG by 0.084% and 0.050%, respectively. While a 1% increase in NGC increased EG by 0.041% eventually, it decreased EG by 0.043% in the short run. An examination of the energy sources used for electricity production in Turkey in 2018 showed that coal had the largest share in total production with a rate of 37%. This rate is a record consumption rate for coal after 1989 in the sample period. Renewable

Table 6 Long-run estimation

Regressors	Coeff	Std. error	*p*-value
LC	0.343	0.022	0.000***
LL	0.420	0.092	0.000***
LREC	0.050	0.023	0.047**
LNGC	0.041	0.014	0.011**
LCC	0.084	0.035	0.031**
Constant	-3.130	0.548	0.000***

***, **, *: $p<0.01$, $p<0.05$, $p<0.10$, respectively.

Table 7 Short-run estimation

Regressors	Coeff	Std. error	*p*-value
ΔLC	0.331	0.013	0.000***
ΔLL	0.177	0.057	0.008***
ΔLREC	−0.019	0.012	0.143
ΔLNGC	−0.043	0.014	0.011**
ΔLCC	−0.044	0.021	0.056*
DU2001	−0.170	0.068	0.061**
ECT (−1)	−0.759	0.093	0.000***

***, **, *: $p<0.01$, $p<0.05$, $p<0.10$, respectively.

energy resources, which have made significant progress recently by virtue of incentive policies applied for their use in electricity production, took the second place with a rate of 32.4%. The rate of use of natural gas, a resource that Turkey is highly dependent on foreign sources, in electricity production was the lowest with a value of 31%. The contribution of natural gas power plants to electricity production in 2018 draws attention as it is the lowest contribution since 2000 (TSI). Considering this information, the long-term results are not quite surprising. To sum up, in the long run, coal consumption should be reduced. Production of renewable energy sources should be increased. In this case, economic growth will also be positively affected within the macroeconomic performance. Besides, the most influential variable on macroeconomic growth was determined by this method. In the final step, the error correction coefficient (ECT) is within acceptable limits. Short-term estimation is given in Table 7.

In terms of the short-term coefficients of the examined variables, the first striking difference compared to the long-term is that the impact of all energy sources on economic growth is negative, but only the short-term elasticity of economic growth compared to natural gas is significant at the 5% significance level. It was also observed that a 1% increase in NGC reduces EG by 0.043%. Another obvious difference is that the short-term elasticity of economic growth compared to RE is not significant even at the 10% significance level. However, a 1% increase in capital (C) stimulates economic growth by about 0.33%, while the labor (L) coefficient has a statistically significant and positive effect on economic growth in the short run and eventually. Moreover, the negative and statistically significant coefficient estimation of the delayed error correction term (ECT_{t-1}) confirms the existence of a long-term relationship between EG, C, L, REC, NGC, and CC. The coefficient (ECT_{t-1}) also indicates that the rate of convergence to the long-term equilibrium will be 75% in case of shock.

Empirical findings and discussions

In this section, we inspected the results of empirical applications between LEG, LC, LL, LREC, LNGC, and LCC with augmented ARDL approach developed by McNown et al. (2018) and Sam et al. (2019).

In the first phase of the econometric analysis, the unit root features of the variables are examined. We use both ordinary and single break unit root testing to achieve this aim. Table 2 depicts the findings of Phillips Perron and single-break Perron unit root tests. All variables contain unit root at the level, indicating variables are stationary at first differences, except CC in terms of Phillips Perron findings. According to Perron test outcomes, all variables contain unit root at level. Moreover, it is determined that the variables are stationary at first differences. Time series can be by affected random shocks (economic crisis, earthquake, etc.). Therefore, the unit root test with break is also used. The Perron test is more robust test than the Phillips Perron test. In Table 3, the lag length is given. Moreover, the appropriate lag length was determined using the AIC. Table 4 depicts the diagnostic test results show that the model is free of autocorrelation, heteroscedasticity, functional problems, and normality problems. Figure 3 illustrates a graph of CUSUM and CUSUMsq plot tests. According to the results of the test, it can be said that the model is valid. The graphs have illustrated in Fig. 3 that the estimators are stable at the 5% significance level.

According to Table 5, the significance of three different test statistics was tested by considering the augmented ARDL model. According to these results, the existence of cointegration was decided as the upper bound of the three test statistics was higher than the critical values. The findings summarized in Table 5 illustrate that the F-statistics (6.635) exceeds the critical value of 4.44 and is therefore statistically significant at 5% level of significance. Additionally, $F_{\text{independent}}$ and $t_{\text{deperndent}}$ tests are also significant at 5% vs 1% levels, inferring robust evidence of cointegration.

This robust evidence of cointegration leads us to check the long-run impact of EG. In Table 6, the estimates depict that there is Cobb–Douglas production function in Turkey because the coefficient of C and L is positive. Further, REC, NGC, and CC have a positive and statistically significant effect on economic growth.

Proceeding to the main finding, renewable energy consumption (REC), the additional variable in our CD production function, has a significant coefficient and the sign of the coefficient is positive. Going into more detail, a 5% increase in REC will alleviate EG by 0.050%. The coefficient of natural gas (NGC), included to capture the effect of the natural gas in the Cobb–Douglas production function, is also significant indicating that NGC promotes EG. Apart from this, coal consumption (CC) is positive and significant. These results show that it increases economic growth. Lastly, the dummy variable (DU2001) decreases EG.

There is empirical evidence for an increase in economic growth in terms of the variable used. Oryani et al. (2021) confirmed the existence of a long-run relationship between

economic growth and the variables studied. Further, Nawaz et al. (2019) also determined that capital, labor, and natural resources positively affect economic growth. The results are similar to our study. Similarly, another study found (Okumus et al. 2021) a positive and statistically significant relationship between renewable energy consumption, labor, capital, and economic growth in the long and short runs. Azad et al. (2014) used the production function, to estimate the electricity consumption in energy consumption in G7 countries. This study showed that C, L, and energy consumption positively affect growth in Austria. Lastly, in the causal outcomes, another study (Bilgili and Bağlıtaş 2022) found a positive and statistically significant relationship between energy consumption, labor, capital, and economic growth in the long and short runs in OECD. In addition, long-run causality results indicate that economic growth causes carbon emissions in MENA countries (Sun et al. 2022) and our findings are compatible with this results. These findings show that the production function is valid between economic growth and renewable energy, natural gas, and coal production in Turkey.

Conclusions and policy recommendations

This paper investigates the effect of disaggregate energy consumption on economic growth in Turkey via the Augmented ARDL. In this context, it is to examine the impact of renewable energy, natural gas, and coal consumption. To this end, the effects of renewable energy, natural gas, and coal consuption on economic growth are investigated using the recently developed AARDL approach with single-break unit root test. In this direction, using annual data for the period 1988–2018, long- and short-run relationship were examined with AARDL cointegration approach.

Turkey is among the developing countries and is highly dependent on foreign energy due to its limited energy resources. This dependency, which is increasing day by day, creates a great burden on the country's economy. To reduce this burden, Turkey, which is considered among the rich countries in terms of renewable energy resources, should use these resources effectively. Thus, as of 2021, the government has started to make great amounts of investments in this field to reduce foreign dependency.

This study, unlike the studies in the literature, aims to contribute to the existing literature on energy consumption by decomposing it based on different variables (renewable, natural gas, and coal) using a multivariate model. In this study, the relationship among the variables examined the CD production function established by econometric analysis. The results showed that there is a long-term relationship between economic growth, renewable energy consumption, natural gas consumption, coal consumption, capital, and labor. Additionally, it was seen that the capital and labor variables included in our model had a significant, positive effect on economic growth in both the short and long terms, and had a greater effect than energy sources. The results of this study will contribute to the decision-makers in the energy sector in Turkey in terms of reducing foreign dependency, ensuring resource diversity, and making energy supply cost-effective. Additionally, these results are important both for the developed countries to maintain their current situation and for the developing countries to see the contribution of the selected variables to economic growth. Future studies should investigate the effects of disaggregated RE sources (hydroelectric, wind, solar, geothermal, and biomass) on GDP eventually, if a sufficient sample size is obtained in terms of data availability.

To apply the AARDL method, the analyzed series should not be $I(2)$. The findings of the Phillips Perron unit root test also indicate that EG, C, L, REC, NGC, and CC are stationary at their first differences. This result is consistent with the findings in Dogan (2015), and Nazlioglu et al. (2014). According to the results of the single break unit root test, all series do not contain unit root at their first differences except L. A cointegration relationship is found for EG model. The estimation results presented in this article have determined the existence of a long-run relationship between economic growth, renewable energy consumption, natural gas consumption, coal consumption, capital, and labor. In the short run, renewable energy has no impact on economic growth, while the 2001 global crisis reduces economic growth. To sum up, in terms of the short-term coefficients of the examined variables, the first striking difference compared to the long-term is that the impact of all energy sources on economic growth is negative.

The results obtained from the study contain important clues and implications for policymakers. The energy consumed in every imaginable area is an indispensable requirement for a country's economic development to achieve a sustainable structure. The increase in production affects energy. With the increase in production and consequently energy demand, economic growth occurs in countries rich in resource potential, while countries that do not have sufficient capacity remain foreign-dependent in energy and therefore economic growth slows down in these countries. The energy field is one of the growth indicators for a developing Turkey. Therefore, most of the energy provided in this area is obtained from fossil sources. Turkey has limited underground wealth in terms of fossil resources and natural gas. The large gradual rise in energy imports causes significant economic problems eventually. This makes it inevitable for Turkey to follow an accurate and effective energy policy, considering the increasing energy demand, limited resource potential, and energy supply security.

The findings of this study show that the consumption of both RE and NRE resources (coal and natural

gas) impacts economic growth eventually. This effect is important for Turkey, which reduces its dependence on foreign energy because it is a negative factor in obtaining goals and in terms of the country's economy. Natural gas, another non-renewable resource in the study, was found to have a positive effect on growth eventually. Nonetheless, approximately 99% of all natural gas consumed in Turkey is imported. This means that Turkey's national income is transferred to energy-rich countries every year, which is a negative result for the country's economy. As a matter of fact, this finding regarding natural gas emerged in the short-term results of the study.

According to the long-term results of the study, it can be said that growth is possible with renewable energy sources as a production factor. However, these sources did not appear to have any impact on EG in the short run because they have not yet been used effectively and efficiently. Turkey, which has an important position on a global scale, especially in terms of solar, wind, geothermal, and biomass resources, has installed power and production at a level well below the potential of these resources. Remarkably, the effect of renewable resources on growth eventually is greater than the impact of natural gas, which Turkey is highly dependent on foreign sources as a resource. Accordingly, Turkey should take this long-term effect into account and include more renewable energy sources in its production, in line with its aims regarding sustainable growth. Moreover, with its incentive and support policies in the field of renewable energy, Turkey should provide consumers with a purchase guarantee for surplus production and meet their own electricity needs. Policymakers should consider economic growth policies at the same time while producing energy policies.

The study disaggregated the effects of energy consumption on the Turkish economy based on resources (renewables, natural gas, and coal) with a multivariate model. The findings were evaluated not only around a specific variable but also in terms of several different variables. In this respect, considering the current economic and technological conditions in Turkey, it does not seem possible to completely abandon the use of imported energy sources in the near future. However, it can be said that the more intensive use of domestic and renewable energy resources in the production process, the reliable and cost-efficient use of these resources, and the increase in resource diversity can reduce Turkey's dependence on foreign energy and provide long-term sustainable growth for the country. Future studies can repeat this study by making investigations for developing countries or European Union countries using panel data.

Finally, this study provides new research opportunities. Our paper focuses on mostly economic growth and energy sources. However, if there are enough data set for future studies, we recommend using the AARDL method to focus of renewable energy in countries.

Author contribution Hakan Eygu: conceptualization; methodology; formal analysis; ınvestigation; resources; writing—original draft; writing—review and editing; visualization.

Fatih Soğukpınar: methodology, formal analysis, writing—review and editing.

Declarations

Ethical approval Ethical approval is not required as this study uses data shared with the public.

Data availability Data can be shared with third parties at any time.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Adams S, Klobodu EKM, Apio A (2018) Renewable and non-renewable energy, regime type and economic growth. Renewable Energy 125:755–767. https://doi.org/10.1016/j.renene.2018.02.135

Ahmed Z, Caglar AE, Murshed M (2022) A path towards environmental sustainability: the role of clean energy and democracy in ecological footprint of Pakistan. J Clean Prod 358:132007. https://doi.org/10.1016/j.jclepro.2022.132007

Apergis N, Payne JE (2010a) Renewable energy consumption and economic growth: evidence from a panel of OECD countries. Energy Policy 38(1):656–660. https://doi.org/10.1016/j.eneco.2010.06.001

Apergis N, Payne JE (2010b) Renewable energy consumption and growth in Eurasia. Energy Economics 32(6):1392–1397. https://doi.org/10.1016/j.eneco.2010.06.001

Apergis N, Payne JE (2012) Renewable and non-renewable energy consumption-growth nexus: evidence from a panel error correction model. Energy Economics 34(3):733–738. https://doi.org/10.1016/j.eneco.2011.04.007

Atmaca E, Basar HB (2012) Evaluation of power plants in Turkey using analytic network process (ANP). Energy 44(1):555–563. https://doi.org/10.1016/j.energy.2012.05.046

Azad AK, Rasul MG, Khan MMK, Omri A, Bhuiya MMK, Hazrat MA (2014) Modelling of renewable energy economy in Australia. Energy Procedia 61:1902–1906. https://doi.org/10.1016/j.egypro.2014.12.238

Bélaïd F, Youssef M (2017) Environmental degradation, renewable and non-renewable electricity consumption, and economic growth: assessing the evidence from Algeria. Energy Policy 102:277–287. https://doi.org/10.1016/j.enpol.2016.12.012

Brown RL, Durbin J, Evans JM (1975) Techniques for testing the constancy of regression relationships over time. J Royal Stat Soc. Series B (Methodological) 37(2):149–163. https://doi.org/10.1111/j.2517-6161.1975.tb01532.x

Caglar AE (2022) Can nuclear energy technology budgets pave the way for a transition toward low-carbon economy: ınsights from the United Kingdom. Sustain Dev 31(1):98–210. https://doi.org/10.1002/sd.2383

Chen C, Pinar M, Stengos T (2020) Renewable energy consumption and economic growth nexus: evidence from a threshold model. Energy Policy 139:111295. https://doi.org/10.1016/j.enpol.2020.111295

Chien F, Ajaz T, Andlib Z, Chau KY, Ahmad P, Sharif A (2021) The role of technology innovation, renewable energy and globalization in reducing environmental degradation in Pakistan: a step towards sustainable environment. Renewable Energy 177:308–317. https://doi.org/10.1016/j.renene.2021.05.101

Chien F, Hsu CC, Andlib Z, Shah MI, Ajaz T, Genie MG (2022) The role of solar energy and eco-innovation in reducing environmental degradation in China: evidence from QARDL approach. Integr Environ Assess Manag 18(2):555–571

Coester A, Hofkes MW, Papyrakis E (2018) An optimal mix of conventional power systems in the presence of renewable energy: a new design for the German electricity market. Energy Policy 116:312–322. https://doi.org/10.1016/j.enpol.2018.02.020

Dogan E (2016) Analyzing the linkage between renewable and non-renewable energy consumption and economic growth by considering structural break in time-series data. Renewable Energy 99:1126–1136. https://doi.org/10.1016/j.renene.2016.07.078

Dogan E, Seker F (2016) The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renew Sustain Energy 60:1074–1085. https://doi.org/10.1016/j.rser.2016.02.006

Dogan E (2015) The relationship between economic growth and electricity consumption from renewable and non-renewable sources: a study of Turkey. Renew Sustain Energy Rev 52:534–546. https://doi.org/10.1016/j.rser.2015.07.130

Elahi E, Weijun C, Jha SK, Zhang H (2019) Estimation of realistic renewable and non-renewable energy use targets for livestock production systems utilising an artificial neural network method: a step towards livestock sustainability. Energy 183:191–204. https://doi.org/10.1016/j.energy.2019.06.084

Erdal G, Erdal H, Esengün K. (2008) The causality between energy consumption and economic growth in Turkey. Energy Policy, 36(10):838–3842, (2008). https://doi.org/10.1016/j.enpol.2008.07.012

Eygü H (2022) Panel data analysis in investigation the economic growth of Turkic states. Intl J New Appr Soc Stud 6(1):36–46. https://doi.org/10.38015/sbyy.1075022

Halicioglu F, Ketenci N (2018) Output, renewable and non-renewable energy production, and international trade: evidence from EU-15 countries. Energy 159:995–1002. https://doi.org/10.1016/j.energy.2018.06.197

Inglesi-Lotz R (2016) The impact of renewable energy consumption to economic growth: a panel data application. Energy Economics 53:58–63. https://doi.org/10.1016/j.eneco.2015.01.003

IEA (2019) International Energy Agency. Retrieved from https://www.iea.org/data-and-statistics. [accessed 15 August 2022]

Jian X and Afshan S (2022) Dynamic effect of green financing and green technology innovation on carbon neutrality in G10 countries: fresh insights from CS-ARDL approach. Econ Res-Ekonomska Istraživanja 1–18. https://doi.org/10.1080/1331677X.2022.2130389

Khan SAR, Sharif A, Golpîra H, Kumar A (2019) A green ideology in Asian emerging economies: from environmental policy and sustainable development. Sustain Dev 27(6):1063–1075. https://doi.org/10.1002/ieam.4500

Kilickaplan A, Bogdanov D, Peker O, Caldera U, Aghahosseini A, Breyer C (2017) An energy transition pathway for Turkey to achieve 100% renewable energy powered electricity, desalination and non-energetic industrial gas demand sectors by 2050. Sol Energy 158:218–235. https://doi.org/10.1016/j.solener.2017.09.030

Koçak E, Şarkgüneşi A (2017) The renewable energy and economic growth nexus in Black Sea and Balkan countries. Energy Policy 100:51–57. https://doi.org/10.1016/j.enpol.2016.10.007

Lise W, Van Montfort K (2007) Energy consumption and GDP in Turkey: ıs there a co-integration relationship? Energy Economics 29(6):1166–1178. https://doi.org/10.1016/j.eneco.2006.08.010

Mert M, Caglar AE (2020) Testing pollution haven and pollution halo hypotheses for Turkey: a new perspective. Environ Sci Pollut Res 27(26):32933–32943. https://doi.org/10.1007/s11356-020-09469-7

Narayan PK (2005) The Saving and investment nexus for China: evidence from cointegration tests. Appl Econ 37(17):1979–1990. https://doi.org/10.1080/00036840500278103

Nazlioglu S, Kayhan S, Adiguzel U (2014) Electricity consumption and economic growth in Turkey: cointegration, linear and nonlinear granger causality. Energy Sources Part B 9(4):315–324. https://doi.org/10.1080/15567249.2010.495970

Ocal O, Aslan A (2013) Renewable energy consumption–economic growth nexus in Turkey. Renew Sustain Energy 28:494–499. https://doi.org/10.1016/j.rser.2013.08.036

Ozkan A, Kinney K, Katz L, Berberoglu H (2012) Reduction of water and energy requirement of algae cultivation using an algae biofilm photobioreactor. Biores Technol 114:542–548. https://doi.org/10.1016/j.biortech.2012.03.055

Pata UK, Kahveci S (2018) A multivariate causality analysis between electricity consumption and economic growth in Turkey. Environ Dev Sustain 20(6):2857–2870. https://doi.org/10.1007/s10668-017-0020-z

Pata UK, and Caglar AE (2021) Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: evidence from augmented ARDL approach with a structural break. Energy 216: 119220. https://doi.org/10.1016/j.energy.2020.119220

Pedroni P (2001a) Fully modified OLS for heterogeneous cointegrated panels. In Nonstationary panels, panel cointegration, and dynamic panels. Emerald Group Publishing Limited

Pedroni P (2001b) Purchasing power parity tests in cointegrated panels. Rev Econ Stat 83(4):727–731. https://doi.org/10.1162/003465301753237803

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Econ 16(3):289–326. https://doi.org/10.1002/jae.616

Phillips PC, Perron P (1988) Testing for a unit root in time series regression. Biometrika 75(2):335–346. https://doi.org/10.1093/biomet/75.2.335

Salim RA, Hassan K, Shafiei S (2014) Renewable and non-renewable energy consumption and economic activities: further evidence-from OECD countries. Energy Economics 44:350–360. https://doi.org/10.1016/j.eneco.2014.05.001

Sari R, Ewing BT, Soytas U (2008) The relationship between disaggregate energy consumption and industrial production in the United States: an ARDL approach. Energy Economics 30(5):2302–2313. https://doi.org/10.1016/j.eneco.2007.10.002

Sam CY, McNown R, Goh SK (2019) An augmented autoregressive distributed lag boundstest for cointegration. Econ Model 80:130–141. https://doi.org/10.1016/j.econmod.2018.11.001

Sebri M, Ben-Salha O (2014) On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: fresh evidence from BRICS countries. Renew Sustain Energy Rev 39:14–23. https://doi.org/10.1016/j.rser.2014.07.033

Shakouri B and Khoshnevis Yazdi S (2017) Causality between renewable energy, energy consumption, and economic growth. Energy Sources. Part B: Economics, Planning and Policy 12(9):838–845. 10.1080/ 15567249.2017.1312640

Sharif A, Raza SA, Ozturk I, Afshan S (2019) The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: a global study with the application of heterogeneous panel estimations. Renewable Energy 133:685–691. https://doi.org/10.1016/j.renene.2018.10.052

Sharif A, Baris-Tuzemen O, Uzuner G, Ozturk I, Sinha A (2020) Revisiting the role of renewable and non-renewable energy consumption on Turkey's ecological footprint: Evidence from Quantile ARDL approach. Sustain Cities Soc 57:102138. https://doi.org/10.1016/j.scs.2020.102138

Shin Y, Smith RJ (2001) Bounds testing approaches to the analysıs 326:289–326. https://doi.org/10.1002/jae.616

Sun Y, Yesilada F, Andlib Z, Ajaz T (2021) The role of eco-innovation and globalization towards carbon neutrality in the USA. J Environ Manag 299:113568. https://doi.org/10.1016/j.jenvman.2021.113568

Sun Y, Li H, Andlib Z, Genie MG (2022) How do renewable energy and urbanization cause carbon emissions? Evidence from advanced panel estimation techniques. Renewable Energy 185:996–1005

Tugcu CT, Topcu M (2018) Total, renewable and non-renewable energy consumption and economic growth: revisiting the issue with an asymmetric point of view. Energy 152:64–74. https://doi.org/10.1016/j.energy.2018.03.128

Tugcu CT, Ozturk I, Aslan A (2012) Renewable and non-renewable energy consumption and economic growth relationship revisited: evidence from G7 countries. Energy Economics 34(6):1942–1950. https://doi.org/10.1016/j.eneco.2012.08.021

TSI, Turkish Statistical Institute, https://data.tuik.gov.tr/Kategori/GetKategori?p=Cevre-ve-Enerji-103 (Accessed 15.10 2020)

Wan Q, Miao X, Afshan S (2022) Dynamic effects of natural resource abundance, green financing, and government environmental concerns toward the sustainable environment in China. Resour Policy 79:102954. https://doi.org/10.1016/j.resourpol.2022.102954

WB, World Bank and BP https://databank.worldbank.org/reports.aspx?source=2&series=NV.IND.TOTL.CD&country=# (Accessed 10.09 2020)

Zafar MW, Shahbaz M, Hou F, Sinha A (2019) From nonrenewable to renewable energy and its impact on economic growth: the role of research & development expenditures in Asia-Pacific Economic Cooperation countries. J Clean Prod 212:1166–1178. https://doi.org/10.1016/j.jclepro.2018.12.081

Zafar MW, Saleem MM, Destek MA, Caglar AE (2022) The dynamic linkage between remittances, export diversification, education, renewable energy consumption, economic growth, and CO2 emissions in top remittance-receiving countries. Sustain Dev 30(1):165–175. https://doi.org/10.1002/sd.2236