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Analyzing the linkage between renewable and non-renewable energy consumption and economic growth by considering structural break in time-series data

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ABSTRACT

Even though a number of studies investigate the energy-growth nexus, only a small number of the existing studies use estimation techniques with structural break. Furthermore, majority of the existing studies use aggregate energy consumption and thus fail to identify the effects of energy consumption by sources on economic growth. By taking into account the importance of structural break, this study analyzes the short run and the long run estimates as well as the causality relationship between economic growth, renewable and non-renewable energy consumption for Turkey in a multivariate model wherein capital and labor are included as additional variables. By including additional variables into the model, we also attempt to handle omitted-variable bias problem. This study finds that renewable energy consumption has an insignificant impact on economic growth while non-renewable energy consumption has a significant positive effect on it. The coefficients on capital and labor are statistically significant. Furthermore, we have enough evidence to support conservation hypothesis and feedback hypothesis between renewable energy consumption and economic growth in the short run and the long run, respectively, and feedback hypothesis between non-renewable energy consumption and economic growth both in the short run and the long run. Several policy implications are further discussed.

1. Introduction

The changes in the amount of energy consumption from renewable and non-renewable sources in Turkey were following an interesting path over the last several decades. By referring to graph 1, Turkey's renewable energy consumption per capita decreased from 210 kg of oil equivalent (kgoe) in 1961 to 49 kgoe in 2012; on the other hand, non-renewable energy consumption per capita increased from 173 kgoe in 1961 to 1513 kgoe in 2012. Furthermore, graph 2 shows that the share of renewable energy consumption per capita in energy mix was higher than 50% in 1961; whereas, its share became very small in 2012. On the other hand, the share of non-renewable energy consumption per capita in energy mix was higher than 50% after 1970s. In addition, the real gross domestic product (GDP) per capita increased from $2315 in 1961 to nearly $8500 in 2012. The enormous boosts in the real output and the dramatic changes in these energy consumption by sources over the past years have drawn our attention to this matter.

Indeed, a huge body of empirical studies have spent enough effort to carry out the dynamic long run relationship of energy consumption and economic growth (the real GDP) since the pioneering study by Kraft and Kraft [23] [3,7,10,11,13,28,29,36,37,40]. On the one hand, majority of the energy-growth nexus come from aggregate energy consumption and conventional non-renewable consumption such as coal, oil and natural gas. On the other hand, a much smaller body of works in the literature investigates the linkage among economic growth and energy consumption by sources (i.e. renewable energy consumption and non-renewable energy consumption). The focus on energy consumption by sources is an important progress in the literature. One purpose behind the investigation of energy consumption by sources may be to find out whether the short run and the long run relationship, and the direction of causality between economic growth and renewable energy differ from those between economic growth and non-renewable energy. This kind of diversity among research studies in the energy-growth literature is essential as the policy makers are advised to formulate different strategies and policies for each energy sources in order to reach sustainable growth rates. Take the

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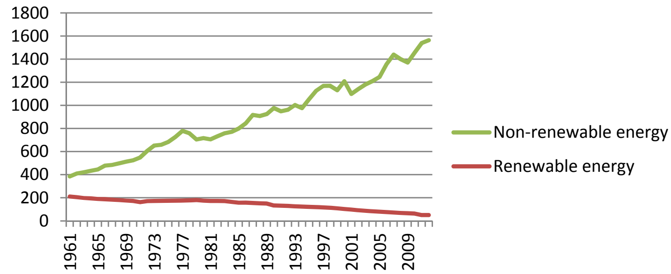
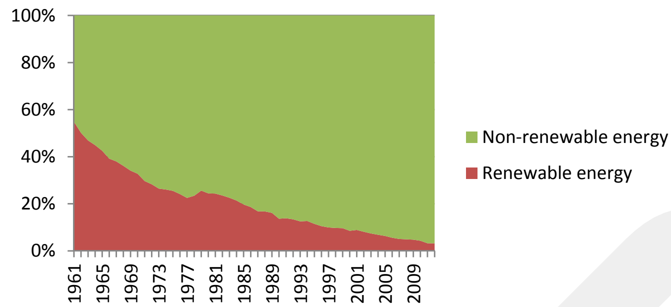


Graph 1. Turkey's renewable and non-renewable energy consumption (kg of oil equivalent).
Source: World Development Indicators (data.worldbank.org)



Graph 2. The share of renewable and non-renewable sources in Turkey's energy mix.
Source: World Development Indicators (data.worldbank.org)

case of Italy as an example, Soytas and Sari [38] support conservation hypothesis between economic growth and aggregate energy consumption while Vaona [42] finds feedback hypothesis between economic growth and non-renewable energy consumption, and neutrality hypothesis between economic growth and renewable energy consumption. According to results posted in these aforementioned studies, the Italian government is advised to encourage the use of non-renewable energy; however, it would presumably regulate an inconsistent energy policy if they were to rely on results based on the aggregate data.

In addition to the above-mentioned concern, studies that focus on the link between the real GDP and energy consumption by sources can even report conflicting results as explored in detailed in the literature review section. Thus, no consensus has been reached on the energy-growth nexus. These differences in empirical outcomes may happen due to the estimation techniques, time-period and variables used in econometric models [29]. More precisely, a number of studies by including several additional variables into a bivariate model in order to eliminate the potential omitted-variable bias problem show that the magnitude of coefficients and the causality directions found in a multivariate model can differ from those found in a simple bivariate model. In a panel study of 85 countries, Apergis and Tang [7] show that at least one type of Granger causality is found for 45 countries in the bivariate model; however, it is detected for 52 countries in the trivariate model and 71 countries in the multivariate model. Furthermore, Ozturk and Acaravci [30] reveal the presence of conservation hypothesis for Oman using economic growth and electricity consumption in the bivariate model; however, Al-Mulali and Ozturk [2] support growth hypothesis for the same country in the multivariate framework. Moreover, Dogan [11] finds that the magnitude of coefficient estimate of energy consumption become smaller after inserting capital and labor into the model as compare to that of Isik [17] which investigates the relationship between energy consumption and economic growth for Turkey in the bivariate model. Building on the Cobb-Douglas production function wherein capital and labor are fundamental elements for economic growth; therefore, we are also in favor of employing capital and labor in addition to energy consumption so as to eliminate the potential omitted-variable bias problem.

Alongside the omitted-variable bias problem, one should also take into account the importance of structural break in the data. The economy very likely experiences energy supply shocks, jump in energy prices, institutional changes, and sudden changes in macroeconomic variables. By looking at the analyzed time-series data we believe that Turkey should also experience at least one change in the past. Acaravci [1]; and Saatci and Dumrul [33] which analyze the relationship between economic growth and energy consumption for Turkey confirm the presence of structural change in the data. Henceforth, ignoring the reality of structural break in time-series can cause misleading results and forecasting errors.

The current study makes two fundamental contributions to the existing pool of knowledge. First, since only a small number of the existing studies use estimation techniques with structural break, this study accounts for the presence of structural break in the data, and accordingly use the Zivot-Andrews unit root test with structural break in addition to the Augmented Dickey-Fuller (ADF) unit root test; the Gregory-Hansen cointegration test with structural break and the autoregressive distributed lag (ARDL) approach to cointegration with structural break in addition to the Johansen cointegration test; the Granger causality test in the Vector Error Correction Mechanism (VECM) with structural break. Second, since majority of the existing studies are based on aggregate energy consumption, this study focuses on energy consumption by sources. Overall, this is the first empirical study which analyzes the short run and the long run estimates as well as the causality relationship between economic growth, renewable energy consumption and non-renewable energy consumption for Turkey in a multivariate model wherein capital and labor are included as additional variables. By including relevant additional variables, we also attempt to eliminate potential omitted-variable bias problem. The remainder of this paper is organized as follows. The next section is literature review wherein methodology, variables, time-period, country/region used in the existing studies are further explored. Section 3 describes the data and the model. Section 4 provides the methodology and results. The last section concludes aims and findings of this study, and presents policy implications.

2. Literature review

Referring to a number of studies analyzing the energy-growth nexus, there are four typical hypotheses: growth, conservation, feedback and neutrality [7]. First, growth hypothesis implies that unidirectional causality runs from energy consumption to economic growth and not vice versa. In the case of growth hypothesis, energy consumption plays an important role in the economic growth, so an increase (decrease) in the use of energy leads to an increase (decrease) in the growth of an economy. Second, conservation hypothesis occurs when unidirectional causality runs from economic growth to energy consumption and not vice versa. This hypothesis means that the reduction in energy consumption do not have any effect on the growth of an economy. Third, feedback hypothesis implies that energy consumption and economic growth simultaneously Granger cause each other. In the presence of this hypothesis, such policies to promote energy consumption can stimulate the economic activities as well as a positive change in economic growth has a positive effect on energy consumption in an economy. Last, neutrality hypothesis refers to the absence of causal relationship between energy consumption and economic growth. Under this hypothesis, an increase or decrease in the use of energy does not affect economic growth and vice versa. Hence, no energy policy is effective.

In this paragraph, we elaborate studies which examine the relationship between economic growth and aggregate energy consumption and type of conventional energy sources such as natural gas. Soytas and Sari [38] examine the relationship between the real income and energy consumption for the case of G-7 and emerging countries over the period 1950–1992 in the bivariate model, and support growth hypothesis in Turkey, France, Germany and Japan, conservation hypothesis in Italy and Korea, and feedback hypothesis in Argentina by using the Granger causality test. In a similar study, Soytas and Sari [39] examine the relationship between the real income and energy consumption for G-7 countries by estimating the multivariate model wherein capital and labor are additional variables. According to the Granger causality test results for the years 1960–2004, bidirectional causality is supported between energy consumption and the real output in Canada both in the long run and in the short run whereas feedback hypothesis is found in France in the long run only. In Italy, Japan, the UK and Germany, bidirectional causality is supported in the long run, and conservation hypothesis is supported in the short run. Wolde-Rufael [43] examines the existence of long run relationship between energy consumption and economic growth for 19 African countries for the period 1971–2001. Results support bidirectional long run causality between energy consumption and economic growth in Zambia, unidirectional causality from energy consumption to economic growth in Cameroon, Morocco and Nigeria, and unidirectional causality from economic growth to energy consumption in Algeria, Egypt, and Ivory Coast. Halicioglu [16] examines the relationship between the real GDP (independent variable), energy consumption, exports, capital and labor in Turkey by using ARDL model for the period 1968–2008. Results indicate statistically significant and positive coefficients for energy consumption and capital only both in the long run and the short run. Ozturk and Acaravci [30] examine the relationship between electricity consumption and the real income in the bivariate model for 11 countries in the Middle East and North Africa (MENA) region by applying the ARDL approach to cointegration to the annual data from 1971 to 2006. Results reveal the presence of long run relationship between electricity consumption and the real GDP for Egypt, Oman, Israel and Saudi Arabia only, and support conservation hypothesis in Israel and Oman, and growth hypothesis in Egypt and Saudi Arabia. Apergis and Tang [7] analyze the energy-growth nexus in three different models (bivariate, trivariate and multivariate) by employing the TYDL (Toda-Yamamoto-Dolado-Lütkepohl) causality test using the data for 85 countries from 1975 to 2007. Results show the existence of at least one type of causality in 45 out of 85 countries for the case of bivariate model, 52 countries for the case of trivariate model, and 71 countries for the case of multivariate model. Al-Mulali and Ozturk [2] focus on the Gulf Cooperation Council countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates) for the relationship between the real GDP and electricity consumption from fossil fuels, capital, labor force, exports and imports by employing the ARDL model and TYDL causality test with the data covering period 1980–2012. Results show statistically significant and positive coefficients for exports and electricity consumption from fossil fuels in all the countries, and statistically significant and positive coefficients for imports in all countries except for Qatar, and statistically significant and positive estimates of capital in Bahrain, Oman and Saudi Arabia, and United Arab Emirates, and negative and statistically significant one for labor in Bahrain, Oman and Saudi Arabia. Nasreen and Anwar [25] examine the relationship between energy consumption, economic growth, trade openness and energy prices wherein energy consumption is the dependent variable. Authors apply panel unit root tests, panel cointegration tests and the VECM based causality test to the data for 15 Asian countries from 1980 to 2011. According to results, the existence of Granger causality is found between income, trade openness and oil prices to energy consumption both in the short run and the long run. Dogan [11] analyzes the relationship between natural gas consumption and economic growth for the case of Turkey over the years 1995–2012 by using the ARDL approach to cointegration and the VECM causality analysis. The estimated model includes natural gas consumption, capital and labor as the explanatory variables and the real GDP as the dependent variable. In the long run, results reveal a statistically significant and positive coefficient on capital, a statistically significant and negative coefficient on natural gas consumption, and a statistically insignificant coefficient on labor. Similar results are valid for the short run. Solarin and Shahbaz [37] estimate the multivariate model so as to carry out the dynamic relationship of the real GDP (dependent variable), natural gas consumption, foreign direct investment, capital and trade openness for the case of Malaysia by applying the ARDL approach to cointegration with structural break and the VECM causality test to the data from 1971 to 2012. The long run estimates suggest that all analyzed explanatory variables have positive and statistically significant effects on the real GDP both in the long run and the short run. In addition, the causality test indicates that feedback hypothesis exists in Malaysia.

From now on, we focus on studies which examine the relationship between economic growth and energy consumption by sources. Apergis and Payne [3] examine the relationship between renewable energy consumption, the real GDP (economic growth), capital and labor for 13 Eurasia countries (Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Moldova, Russia, Tajikistan, Ukraine and Uzbekistan) by applying the panel ADF unit root test, the Pedroni panel cointegration test, the fully modified ordinary least squares estimation (FMOLS) and the panel causality test to the panel data from 1992 to 2007. Results show that renewable energy consumption, capital and labor force are found to have positive and statistically significant impacts on economic growth in the long run, and there is evidence of feedback hypothesis between renewable energy consumption and the real GDP both in the short run and the long run. Apergis and Payne [4] examine the influence of renewable energy consumption on economic growth for twenty members of the Organization for Economic Cooperation and Development (OECD) with data covering years 1985–2005 in a multivariate model wherein capital and labor are included as additional variables. By using the panel ADF unit root test, the Pedroni panel cointegration test, the FMOLS and the Granger causality method, the authors show that renewable energy consumption, capital and labor have positive significant effects on economic growth, and bidirectional causality is supported between renewable energy consumption and the real GDP for the analyzed OECD members. Menegaki [24] estimates the multivariate model to carry out the dynamic relation of the real GDP (the dependent variable), renewable energy consumption, total energy consumption, greenhouse gas emissions and employment for the case of 27 European countries by applying the ARDL approach to cointegration with structural break and the VECM causality test to the data from 1997 to 2007. By using several panel unit root tests, the random effects model and the VECM based Granger causality test, the long run estimation results suggest statistically significant and positive coefficients on renewable energy consumption, greenhouse gas emissions and employment whereas the final energy consumption has a statistically significant coefficient of zero. In addition, neutrality hypothesis is valid between renewable energy consumption and economic growth. Vaona [42] examines the relationship between renewable energy consumption and the real output for the case of Italy by applying the Zivot-Andrews unit root test with structural break, the Lutkepohl test for cointegration and the Granger non-causality test (Box and Jenkins approach) to the data from 1861 to 2000. Results support bidirectional causality between the real GDP and renewable energy consumption. Apergis and Payne [6] analyze the long run dynamics of economic growth, renewable and non-renewable energy consumption, capital and labor for a set of 80 countries for the years 1990–2007 by employing several panel unit root tests, the Pedroni panel cointegration test and the panel causality test. Results show positive and statistically significant coefficients on all of the analyzed explanatory variables in the long run. In addition, their study supports the existence of feedback hypothesis between non-renewable energy consumption, renewable energy consumption and the real GDP both in the short run and the long run.

Tugcu et al. [41] investigate the relationship between energy consumption and real output by decomposing energy consumption into renewable and non-renewable energy consumption for G-7 countries covering the period 1980–2009. By using classical production function; in the long run, renewable energy consumption has no effect on the real GDP for Canada, France, Italy, Japan and the US, whereas it has a statistically significant and positive effect on economic growth for Germany and the UK. Non-renewable energy consumption has no effect on the real GDP for Canada, France, Italy and Japan, whereas it has a positive and statistically significant effect on the real output for Germany, the US and the UK. Ocal and Aslan [27] investigate the relationship of the real GDP (dependent variable) and renewable energy consumption for Turkey in a multivariate model wherein capital and labor are inserted. By applying the ADF unit root, the ARDL model and the VECM based Granger causality method to the data from 1990 to 2010, authors explore that the elasticity of economic growth with respect to renewable energy turns out to be negative whereas that the elasticities with respect to capital and labor are statistically significant and positive. In addition, their study supports the validity of conservation hypothesis between renewable energy consumption and the real output. Salim et al. [34] examine the relationship between the real GDP, renewable energy consumption, non-renewable energy consumption, capital and labor for twenty-nine OECD countries for the period 1980–2011 by employing several panel unit root tests, the Westerlund cointegration test with structural break, the common correlated effects mean group (CCEMG) estimator and the panel causality test. Results show that all of the explanatory variables have positive and statistically significant coefficients on economic growth. According to the panel Granger causality test results, feedback hypothesis is supported between economic growth and non-renewable energy consumption while growth hypothesis is valid between renewable energy consumption and economic growth in the short run, and bidirectional causality is detected between renewable energy consumption, non-renewable energy consumption and the real output in the long run. Omri et al. [28] investigate the causality from nuclear energy, renewable energy, capital and labor to the real GDP with data from 17 different countries for the period 1990–2011. According to the panel results only capital is found to have statistically significant impact on economic growth. There is also bidirectional causality between nuclear energy consumption and economic growth, and unidirectional causality running from economic growth to renewable energy consumption. Dogan [12] investigates the long run dynamics of economic growth and electricity consumption from renewable sources and electricity consumption from non-renewable sources for Turkey by augmenting capital and labor as explanatory variables in the model wherein the real GDP is the dependent variable. By applying several unit root tests with and without structural break, several cointegration tests with and without structural break, the ARDL estimator and the VECM based causality analysis; the author finds that electricity consumption from renewable sources has negative but insignificant effect on economic growth while electricity consumption from non-renewable sources positively and significantly impacts economic growth in the long run, and validates the evidence of growth hypothesis between renewable electricity consumption and the real output, and feedback hypothesis between non-renewable electricity consumption and the real GDP in the long run. Jebli and Youssef [19] investigate the long run dynamic of the real GDP (dependent variable), renewable energy, non-renewable energy, trade, capital and labor for a panel of 69 countries by using panel unit root tests, the Pedroni cointegration test, the FMOLS, the dynamic OLS and the panel causality test. Results show that all of the analyzed independent variables have positive and statistically significant impacts on economic growth. In addition, there is no causality between renewable energy and economic growth and between non-renewable energy and economic growth in the short run while there is bidirectional long run causality between renewable energy and the real GDP and one-way long run causality running from non-renewable energy to the real output.

Overall, even though a number of studies in the energy-growth literature attempt to show the long run dynamics of economic growth and energy consumption, majority of the existing studies use aggregate energy consumption, and thus fail to identify the relationship between economic growth and energy consumption by sources (i.e. renewable and non-renewable energy). Furthermore, majority of studies that investigate the linkage between economic growth and energy consumption by sources are based on panel data, and thus produce identical coefficient parameters across countries within the panel. Therefore, single-country studies are of interest for researchers and policy makers so as to obtain more accurate and consistent results and policy implications for individual countries. In addition, a major criticism to the existing single-country studies in the related literature, we notice, is the selection of methodology. Because countries most likely experience unexpected shocks in energy markets and macroeconomic variables (structural change), the use of econometric methods without structural break may cause forecasting errors. To overcome the above-mentioned shortcomings of the literature, this study analyzes the relationship between economic growth and energy consumption by sources for Turkey by using estimation techniques with structural break.

3. Model and data

A large number of studies in the energy-growth literature have included energy consumption into the neo-classical Cobb-Douglas production function [11,29]. In addition, several recent studies integrate energy consumption by sources (renewable and non-renewable energy consumption) with the production function [3,5,6,12,27,28,34]. Following the relevant state-of-the-art, economic growth, renewable energy consumption, non-renewable energy consumption, capital and labor are considered as separate factors:

$$Y_t = f(RE_t, NRE_t, K_t, L_t) \quad (1)$$

The above function can be converted to an econometric model by including a constant (β_0) and error term (ε_t):

$$Y_t = \beta_0 + \beta_1 RE_t + \beta_2 NRE_t + \beta_3 K_t + \beta_4 L_t + \varepsilon_t \quad (2)$$

where Y denotes economic growth measured by the real gross domestic product (GDP) per capita; combustible renewable and waste (kg of oil equivalent) is used for renewable energy

Table 1
Definition of variables.

Variable	Definition	Source
GDP	Real gross domestic product	World Development Indicators
RE	Renewable energy consumption	World Development Indicators
NRE	Non-renewable energy consumption	World Development Indicators
K	Capital	World Development Indicators
L	Labor	Turkish Statistical Institute

consumption per capita (RE); the difference between total energy consumption (kg of oil equivalent) and combustible renewable and waste (kg of oil equivalent) is used for non-renewable energy consumption per capita (NRE); K is the gross capital formation as a percentage of GDP; L is the labor force per capita (Please refer to Table 1). All variables are in per capita values and converted into their natural logarithms to correct the heteroscedasticity of residuals and to interpret the estimates of β_i ($i = 1 \ldots 4$) as the elasticities of the dependent variable with respect to the explanatory variables. Annual time-series data on the real GDP, renewable energy consumption, non-renewable energy consumption, capital and population are drawn from the World Bank's "World Development Indicators",[1] and the data on labor force are taken from the Turkish Statistical Institute.[2] The data used are from 1988 to 2012. We should note that we use the longest available time-series data.

Table 2 reports the descriptive statistics for economic growth, renewable and non-renewable energy consumption, capital and labor. It shows that the differences between the minimum and maximum values of Y, RE, NRE, K and L are considerable big enough. By referring to the average values of these variables as well as standard deviations, there is enough variability in each time-series data.

4. Methodology and empirical results

4.1. Unit root tests

One of the main objectives of employing a unit root test is to check whether or not a time-series data is stationary. If variables are not stationary and not cointegrated, a researcher may estimate a spurious regression with a fairly high R^2 (goodness of fit) and significant parameter coefficients although the estimation results are lack of economic meaning. To avoid an econometric issue in the estimation process, the Augmented Dickey-Fuller unit root test (ADF) [9] and the Zivot-Andrews unit root test with structural break (ZA) (Zivot and Andrews [44]) are applied on the real income, renewable and non-renewable energy consumption, capital and labor. The lag lengths are selected based on the Akaike Information Criteria (AIC).

Table 3 reports that the analyzed variables are not stationary at their levels but become stationary at their first differences at 5% level of significance. Similarly, Table 4 reports that the time-series data except capital contain a unit root at their levels at 10% level of significance but become stationary at their first differences at 1% level of significance. Because time-series data are found to be non-stationary at their levels, there is a need to check whether or not they are cointegrated to obtain statistically and economically meaningful estimates.

Table 2
Descriptive statistics.

	Y	RE	NRE	K	L
Max	3.92	2.18	3.18	1.42	−0.41
Min	3.66	1.69	2.87	1.17	−0.48
Mean	3.79	1.98	3.02	1.32	−0.44
Std. Dev.	0.08	0.14	0.09	0.06	0.02
Skewness	0.23	−0.51	0.09	−0.75	−0.78

4.2. Cointegration tests

This study first applies the Johansen cointegration test [21,22] in order to test whether or not economic growth, renewable and non-renewable energy consumption, capital and labor are cointegrated. The Johansen multivariate cointegration test takes the following form:

$$\Delta Y_t = \mu + \sum_{i=1}^{k} \Gamma_i \Delta Y_{t-i} + \Pi\, Y_{t-1} + \varepsilon_t \quad (3)$$

where Y_t represents a 5×1 vector of the variables economic growth, renewable and non-renewable energy consumption, capital and labor; μ is a 5×1 vector of constant terms; the parameters Γ and Π stand for 5×5 matrix of coefficients; ε is a 5×1 vector of white noise error terms. This test is based on the maximum likelihood estimation and the trace-statistics (λ_{trace}), where the λ_{trace} statistic tests the null hypothesis of no cointegration (rank $(r) = 0$) against an alternative hypothesis of cointegration ($r > 0$).

Results obtained from the Johansen cointegration test are reported in Table 5, showing that we can reject the null hypothesis of no cointegration in favor of the alternative hypothesis of one cointegrating vector because the value of trace statistic is greater than the related critical value. In addition, we have no evidence to reject the null hypothesis of one cointegrating vector versus the alternative hypothesis of two cointegrating vectors since the value of trace statistic is smaller than the related critical value. The appropriate lag length is once again chosen based on the AIC as it is better in small samples than other selection criterions. In light of these outcomes, we have enough evidence to conclude that these variables are cointegrated and there is only one cointegrating vector. One important drawback of the Johansen cointegration test in equation (3) is that it does not account for structural change in the time-series data. Henceforth, this study further employs the Gregory-Hansen cointegration test with one endogenously determined structural break [15]. It takes the following form:

$$Y_t = \beta_o + \beta_{1\varphi t} + \delta_1 T + \sum_{i=1}^{4} \alpha_{1i} X_{it} + \sum_{i=1}^{4} \alpha_{2i} \varphi_t X_{it} + \varepsilon_t \quad (4)$$

where Y_t is the dependent variable, X_{it} are the independent variables, ε_t is assumed to be I(0) error term, and φ_t is the dummy variable to pin down a structural break in the constant and trend.

[1] The data are available at http://data.worldbank.org.
[2] The data are available at www.turkstat.gov.tr.

Table 3
Results from the ADF unit root test.

Levels				First differences				
Variables	ADF-test statistics	Lag length	10%-critical value	Variables	ADF-test statistics	Lag length	1%-critical value	5%-critical value
Y	−2.47	0	−3.18	ΔY	−4.64**	0	−3.77	−3.13
RE	−0.18	1	−3.34	ΔRE	−4.79**	0	−3.77	−3.13
NRE	−2.44	0	−3.18	ΔNRE	−4.91**	0	−3.77	−3.13
K	−3.06	0	−3.18	ΔK	−6.32**	0	−3.77	−3.13
L	−1.17	0	−3.18	ΔL	−3.73*	0	−3.77	−3.13

Note: ** and * denote the statistical significance 1% and 5% level, respectively. Critical values are computed by stochastic simulations for the indicated lagged numbers using 1000 replications. An option of trend and intercept is used for the levels and an option of constant only is used for the first differences.

Table 4
Results from the Zivot-Andrews unit root test.

Levels					First differences				
Variables	ZA-test statistics	Lag length	Break date	10%-critical value	Variables	ZA-test statistics	Lag length	Break date	1%-critical value
Y	−3.69	0	1999	−4.58	ΔY	−5.97**	0	2003	−5.34
RE	−0.61	1	1994	−4.58	ΔRE	−6.93**	0	1993	−5.34
NRE	−4.53	0	2001	−4.48	ΔNRE	−6.07**	0	1998	−5.34
K	−5.02*	0	1999	−4.58	ΔK	−7.53**	0	2003	−5.34
L	−2.31	0	2003	−4.58	ΔL	−5.77**	0	2000	−5.34

Note: ** and * denote the statistical significance at 1% and 10% level, respectively.

$\varphi_t = \begin{cases} 1 \ldots if\ t > [n\tau] \\ 0 \ldots if\ t \leq [n\tau] \end{cases}$, $0<\tau<1$ and $t = 1,2,3 \ldots n$. The results obtained from the Gregory-Hansen cointegration test are posted in Table 6, indicating that we have enough evidence to reject the null hypothesis of no cointegration in favor of the alternative hypothesis of cointegration at 10% level of significance because the calculated test statistic is greater than the critical value. The year 2003 is the endogenously determined break date likely referring to economic downturn in Turkey occurred around 2001–2002 and the U.S. invasion of Iraq in 2003. These events are important for energy market and prices, and Turkey's economic activity.

Although results from the Johansen and the Gregory-Hansen cointegration tests are reliable, we also apply the ARDL approach to cointegration [31,32] to further confirm results shown in Tables 5 and 6. The ARDL framework is constructed based on the standard log-linear functional specification with the unrestricted error correction mechanism. By taking into the account the endogenously determined structural break detected through the Gregory-Hansen cointegration test, we estimate the following ARDL model:

$$\Delta Y_t = a + \gamma D_{2003} + \sum_{i=1}^{k}\alpha_i \Delta Y_{t-i} + \sum_{i=0}^{l}\beta_i \Delta RE_{t-i} + \sum_{i=0}^{m}\rho_i \Delta NRE_{t-i} + \sum_{i=0}^{n}\vartheta_i \Delta K_{t-i} + \sum_{i=0}^{p}\delta_i \Delta L_{t-i} + \varnothing_1 Y_{t-1} + \varnothing_2 RE_{t-1} + \varnothing_3 NRE_{t-1} + \varnothing_4 K_{t-1} + \varnothing_5 L_{t-1} + \varepsilon_t \quad (5)$$

where Δ is the first difference parameter; a is a constant parameter; D_{2003} is the dummy variable that takes the value of zero before the break date and the value of one after; α, β, ρ, ϑ and δ are the coefficients on economic growth, renewable energy consumption, renewable energy consumption, capital and labor, respectively; ε is a normally distributed error term; k, l, m, n and p are the right lag lengths chosen based on the AIC. The joint F-statistic is used to investigate the significance of possible existence of a long run relationship (cointegration) among Y, RE, NRE, K and L. The null hypothesis of no long run relationship, H_o: $\varnothing_1 = \varnothing_2 = \varnothing_3 = \varnothing_4 = \varnothing_5 = 0$, is tested against the alternative hypothesis, H_a: $\varnothing_1 \neq \varnothing_2 \neq \varnothing_3 \neq \varnothing_4 \neq \varnothing_5 \neq 0$. More precisely, the hypothesis of no cointegration cannot be rejected if a computed F-statistic is smaller than the lower critical bound (I(0)). If the computed F-statistic is greater than the upper critical bound (I(1)), the null hypothesis of no long run relationship can be rejected in favor of the alternative hypothesis. The result will be inconclusive if the computed F-statistic falls within the upper and lower critical bounds.

Table 7 reports the F-statistic obtained from the bounds testing for cointegration as well as the corresponding critical value bounds. The critical value bounds in Table 7 are computed by stochastic simulations using 20,000 replications because the actual critical values for different sample sizes can differ from the critical values posted in Pesaran et al. [32]. Because the computed F-statistic is greater than the upper critical value, we have enough evidence to reject the null hypothesis of no cointegration in favor of cointegration among the analyzed variables. In light of the outcomes from the three cointegration tests, we can confidently conclude that a long run relationship exists among economic growth, renewable energy consumption, non-renewable energy consumption, capital and labor for the case of Turkey.

4.3. Long run and short run estimates

After it is confirmed that there is a long run relationship between Y, RE, NRE, K and L, the short run elasticities of each explanatory variable are exposed by the coefficients on the first-differences in equation (6). Take renewable and non-renewable energy consumption for example, the short run elasticities of Y with respect to RE and NRE are exposed by the estimates of ζ_{2i} and ζ_{3i}, respectively.

$$\Delta Y_t = c + \gamma D_{2003} + \sum_{i=1}^{p} \zeta_{1i}\Delta GR_{t-i} + \sum_{i=0}^{q} \zeta_{2i}\Delta RE_{t-i} + \sum_{i=0}^{r} \zeta_{3i}\Delta NRE_{t-i} + \sum_{i=0}^{s} \zeta_{4i}\Delta K_{t-i} + \sum_{i=0}^{w} \zeta_{5i}\Delta L_{t-i} + \Phi ECT_{t-1} + \omega_t \quad (6)$$

Table 5
Results from the Johansen cointegration test.

Null hypothesis	Trace statistic	Critical value
$r = 0$	81.92[a]	68.52
$r \le 1$	46.31	47.21
$r \le 2$	17.97	29.68
$r \le 3$	5.86	15.41
$r \le 4$	0.10	3.76

Note.
[a] Denote the statistical significance at 5% level. The estimated model is *f*(Y/RE, NRE, K, L). The lag length is selected based on the AIC.

where Δ is the first difference operator; c is a constant parameter; ζ_i ($i = 1...,5$) are the coefficient parameters; ω is a white noise error term; p, q, r, s and w are the right lag lengths selected based on the AIC; ECT_{t-1} is the error correction term attained from the long run equilibrium relationship; Φ stands for the speed of adjustment to the long run equilibrium. Furthermore, the long run elasticities of Y with respect to renewable energy consumption, non-renewable energy consumption, capital and labor are exposed by $\varnothing_2$, $\varnothing_3$, $\varnothing_4$ and $\varnothing_5$, respectively, in conjunction with a normalization process by the estimate of $\varnothing_1$ in equation (5).

The estimation results in Table 8 show that economic growth is positively linked to non-renewable energy consumption and capital, whereas labor detracts the real output and the effect of renewable energy is negative but statistically insignificant in the long run. More precisely, a 1% increase in NRE and K boosts Y by around 0.75% and 0.10%, respectively. In addition, a 1% increase in L reduces Y by about 0.18%. While we look at the short run coefficient on the analyzed variables, the first noticeable similarity is that the short run elasticities of economic growth with respect to renewable energy is insignificant at 10% level of significance. The other obvious change is that the effect of non-renewable energy consumption on economic growth is relatively smaller in the short run. In detail, a 1% increase in energy consumption from non-renewable sources stimulates the real GDP by 0.54%, and a 1% rise in capital promotes economic growth by nearly 0.14% at 1% level of significance. On the other hand, the coefficient on labor is statistically significant and negative as it is the same in the long run.

Results found in this study are in line with those of the existing studies. A statistically insignificant coefficient for renewable energy consumption found in the current study is consistent with that of Ref. [5,12,41]; and [28]. In addition, a statistically significant and positive coefficient for non-renewable energy is in line with Ref. [5,6,19,34]; and [12]. The short run and the long run estimates of renewable and non-renewable energy consumption imply that the Turkish government should keep on using non-renewable energy consumption as increases in NRE stimulate the real output of Turkey; on the other hand, Turkey's energy dependence is quite high because almost 90% of energy used in Turkey is imported from energy exporting countries. By noting that renewable energy consumption has no effect on economic growth, the Turkish government should also aim to increase the share of renewable energy in the total energy consumption so as to be able to upgrade its energy independence.

In addition, the negative and statistically significant coefficient estimate of the lagged error correction term (ECT_{t-1}) validates the existence of a long run relationship between Y, RE, NRE, K and L. The coefficient on ECT_{t-1} also implies that deviations from the long run equilibrium are corrected by 95% in each year. In addition, the

Table 6
Results from the Gregory-Hansen cointegration test.

Estimated model	Break date	ADF-statistic	Critical value
f(Y/RE,NRE, K, L)	2003	−5.74[a]	−5.59

Note.
[a] Denote the statistical significance at 10% level. The regression includes an endogenously determined break in the constant and trend. The lag length is selected based on the AIC.

Table 7
Results from the ARDL approach to cointegration.

Estimated model	F-statistic	Critical values	
		I(0)	I(1)
f(Y/RE,NRE, K, L)	8.56[a]	4.33	5.63

Note.
[a] Denote the statistical significance at 5% level. The critical value bounds are computed by stochastic simulations using 20,000 replications.

Table 8
Results from the long run and the short run estimates.

Regressors	Coeff.	Std. Error	T-ratio	Prob.
Long run results				
RE	−0.04	0.03	−1.19	0.25
NRE	0.75***	0.04	17.59	0.00
K	0.10***	0.03	2.89	0.01
L	−0.18*	0.09	−1.96	0.07
Cons	1.38***	0.18	7.54	0.00
D_{2003}	0.01**	0.01	2.19	0.05
Short run results				
ΔRE	0.03	0.05	0.71	0.48
ΔNRE	0.54***	0.06	8.28	0.00
ΔK	0.14***	0.02	6.01	0.00
ΔL	−0.17*	0.09	−1.81	0.09
ECT(-1)	−0.95***	0.14	−3.92	0.00
F-statistic	83.54***			0.00
R^2	0.96			

Note: ***, **, * denote the statistical significance at 1%, 5% and 10% level.
The model ARDL (2,1,2,1,0) is selected based on the AIC.

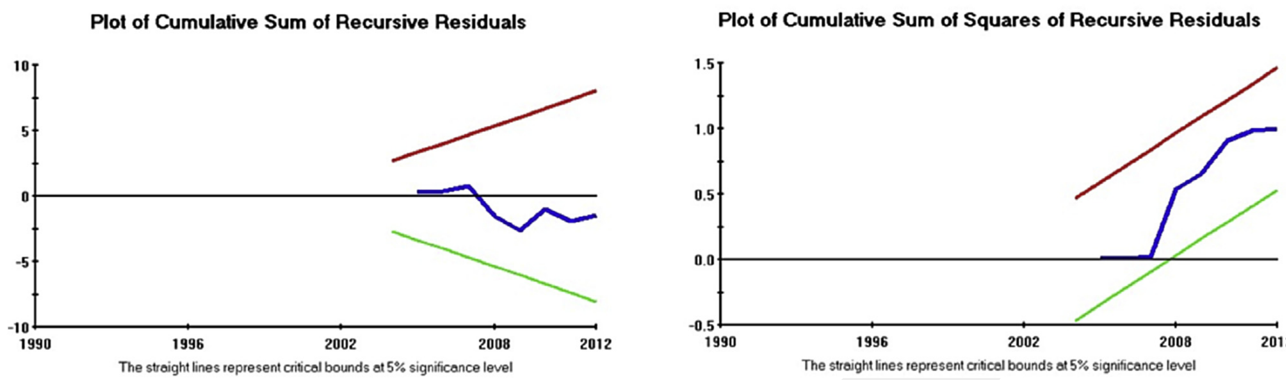


Fig. 1. CUSUM and CUSUMQ stability tests.

goodness of fit of the specification ($R^2 = 0.96$) is very close to one that is preferred in econometric analysis as the adjustment of the model in equation (5) is fairly perfect. The statistically significant F-statistic confirms the joint significance of explanatory variables in the ARDL model. The last identification related to the goodness of fit of the model is stability tests. For this purpose, the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMQ) of recursive residuals are performed [8]. Many studies apply these stability tests in order to show the stability of the estimated model and the stability of the short run and the long run coefficients [18]. Fig. 1 shows the plots of the CUSUM and the CUSUMQ test statistics from the estimated ARDL model with dummy variable (structural break) for Turkey over the period 1988–2012. The estimated model and parameters are stable over time since the plots fall within the 5% boundaries, indicating that the residuals are within the critical bounds of the 5% significance level. Overall, we can conclude that the estimated model and coefficient estimates are structurally stable over the time-period that this study uses.

4.4. Causality analysis

In conjunction with the result of a long run relationship among economic growth, renewable and non-renewable energy consumption, capital and labor, it is our aim to apply the Granger causality test to guide Turkish government to rule proper energy policies so as to reach higher economic growth rates. Because Y, RE, NRE, K and L are found to be cointegrated, the VECM Granger causality test can be employed to elaborate the directions of the short run and the long run causality between the analyzed variables. Following Engle and Granger [14]; we estimate the VECM Granger causality test using equations (7)–(11):

$$\Delta Y_t = c + \gamma D_{2003} + \sum_{i=1}^{p} \zeta_{1i}\Delta GR_{t-i} + \sum_{i=0}^{q} \zeta_{2i}\Delta RE_{t-i} + \sum_{i=0}^{r} \zeta_{3i}\Delta NRE_{t-i} + \sum_{i=0}^{s} \zeta_{4i}\Delta K_{t-i} + \sum_{i=0}^{w} \zeta_{5i}\Delta L_{t-i} + \Phi_1 ECT_{t-1} + \omega_t \tag{7}$$

$$\Delta RE_t = c + \gamma D_{1992} + \sum_{i=0}^{p} \zeta_{1i}\Delta GR_{t-i} + \sum_{i=1}^{q} \zeta_{2i}\Delta RE_{t-i} + \sum_{i=0}^{r} \zeta_{3i}\Delta NRE_{t-i} + \sum_{i=0}^{s} \zeta_{4i}\Delta K_{t-i} + \sum_{i=0}^{w} \zeta_{5i}\Delta L_{t-i} + \Phi_2 ECT_{t-1} + \omega_t \tag{8}$$

$$\Delta NRE_t = c + \gamma D_{1994} + \sum_{i=0}^{p} \zeta_{1i}\Delta GR_{t-i} + \sum_{i=0}^{q} \zeta_{2i}\Delta RE_{t-i} + \sum_{i=1}^{r} \zeta_{3i}\Delta NRE_{t-i} + \sum_{i=0}^{s} \zeta_{4i}\Delta K_{t-i} + \sum_{i=0}^{w} \zeta_{5i}\Delta L_{t-i} + \Phi_3 ECT_{t-1} + \omega_t \tag{9}$$

$$\Delta K_t = c + \gamma D_{1992} + \sum_{i=0}^{p} \zeta_{1i}\Delta GR_{t-i} + \sum_{i=0}^{q} \zeta_{2i}\Delta RE_{t-i} + \sum_{i=0}^{r} \zeta_{3i}\Delta NRE_{t-i} + \sum_{i=1}^{s} \zeta_{4i}\Delta K_{t-i} + \sum_{i=0}^{w} \zeta_{5i}\Delta L_{t-i} + \Phi_4 ECT_{t-1} + \omega_t \tag{10}$$

$$\Delta L_t = c + \gamma D_{2001} + \sum_{i=1}^{p} \zeta_{1i}\Delta GR_{t-i} + \sum_{i=0}^{q} \zeta_{2i}\Delta RE_{t-i} + \sum_{i=0}^{r} \zeta_{3i}\Delta NRE_{t-i} + \sum_{i=0}^{s} \zeta_{4i}\Delta K_{t-i} + \sum_{i=1}^{w} \zeta_{5i}\Delta L_{t-i} + \Phi_5 ECT_{t-1} + \omega_t \quad (11)$$

Table 9
Results from the VECM Granger causality test.

Dependent variable	Short run causality					Long run causality
	ΔY	ΔRE	ΔNRE	ΔK	ΔL	ECT(-1)
ΔY	–	0.51 (0.47)	78.44*** (0.00)	36.07*** (0.00)	3.28* (0.07)	46.01*** (0.00)
ΔRE	6.25** (0.04)	–	0.19 (0.66)	17.47*** (0.00)	1.64 (0.19)	8.37*** (0.00)
ΔNRE	61.42*** (0.00)	2.96 (0.22)	–	14.10*** (0.00)	10.34*** (0.00)	27.24*** (0.00)
ΔK	55.34*** (0.00)	2.77 (0.25)	24.18*** (0.00)	–	13.78*** (0.00)	19.63*** (0.00)
ΔL	13.77*** (0.00)	9.17*** (0.00)	9.18*** (0.01)	11.27*** (0.00)	–	10.02*** (0.00)

Note: ***, ** and * denote the significant at 1%, 5% and 10% levels, respectively. Associated p-values are given in parenthesis.

where the dummy variables for structural break dates are taken from the Gregory-Hansen cointegration test with one endogenously determined structural break.[3] For example, D_{1992} is the dummy variable for equation (8) takes the value of zero before the break date (year 1992) and the value of one after. By referring to equations (7)–(11), the short run causalities are conducted based on the statistical significance of the partial Wald-statistics associated with the right hand variables. In a similar way, the long run causalities are conducted based on the statistical significance of the Wald-statistics of the ECT_{t-1}. In detail, the short run Granger causality is conducted testing the significance of the sum of the lagged differences of the right hand-side variables based on the Wald-test statistics. For example, the possible presence of the short run causality from RE to Y is investigated by testing the null hypothesis of no-causality, H_0: $\xi_{12c} = 0$, against the alternative hypothesis, H_a: $\xi_{12c} \neq 0$. In addition, the possible presence of the long run Granger causality is conducted testing the significance of ECM_{t-1} based on the Wald-test statistics. For example, the long run causality to economic growth from renewable and non-renewable energy consumption, capital and trade is investigated by testing the null hypothesis of no-causality, H_0: $\Phi_1 = 0$, against the alternative hypothesis, H_a: $\Phi_1 \neq 0$.

Results from the VECM Granger causality test are posted in Table 9 in which p-values produced according to the Wald-test are given in parentheses. Starting with the short run, there is a bidirectional causality between economic growth and non-renewable energy consumption, between the real output and capital, between the real GDP and labor, between capital and non-renewable energy consumption, between labor and non-renewable energy consumption, and between capital and labor. In addition, unidirectional causality is found running from economic growth to renewable energy consumption, from renewable energy consumption to labor, and from capital to renewable energy consumption. As a short summary of the short run analysis, this study explores the existence of feedback hypothesis between Y and NRE, and conservation hypothesis between Y and RE in the short run for the case of Turkey. Considering the long run, renewable energy consumption, non-renewable energy consumption, capital and labor Granger causes economic growth. In addition, the Granger causality runs from Y, RE, K and L to NRE. As similar to that, the Granger causality runs from Y, NRE, K and L to RE. Furthermore, the real GDP, RE, NRE and labor Granger causes K. Last, economic growth, energy consumption from renewable and non-renewable sources and capital Granger causes labor. According to the long run outputs, we can claim the presence of feedback hypothesis between economic growth and non-renewable energy consumption, and between economic growth and renewable energy consumption in the long run. The overall results found in this section are consistent with those of several studies [3–6,12,19,27,28,34,42].

5. Conclusions and policy implications

A small number of studies in the energy-growth literature have analyzed the linkage between economic growth (the real GDP) and energy consumption by sources (i.e. renewable and non-renewable energy consumption). In addition to this concern, majority of the existing studies use estimation techniques without structural break. Moreover, the enormous boost in the Turkey's real output and the dramatic changes in renewable and non-renewable energy consumption over the past years attract our attention to this subject. These concerns are the main motivations of this empirical study. Therefore, the objective of this study is to analyze the short run and the long run estimates as well as the causality relationships between economic growth, renewable energy consumption and non-renewable energy consumption for Turkey in a multivariate model wherein capital and labor are included as additional variables.

By taking into the account the importance of the existence of structural break in the time-series data, this study employs several appropriate econometric techniques. The ADF test and

[3] Although the Gregory-Hansen cointegration test is also applied for models *f*(RE/Y,NRE, K, L), *f*(NRE/Y, RE, K, L), *f*(K/Y, RE,NRE, L) and *f*(L/Y, RE,NRE, K), related results are not posted in this paper for the sake of brevity but are available upon request.

the Zivot-Andrews unit root test with structural break report that the analyzed variables become stationary in their first differences. Then, the Johansen cointegration test, the Hansen-Gregory cointegration test with structural break and the bounds testing for cointegration with structural break are employed to determine whether this empirical analysis should be pursued further. In lack of cointegration, estimation results that we obtain may be suspect and in error. Once these cointegration tests confirm the existence of long run relationship between economic growth, renewable and non-renewable energy consumption, capital and labor, the short run and the long run elasticities of the real output with respect to renewable and non-renewable energy consumption, capital and labor are estimated through the ARDL method. It is found that renewable energy consumption has no significant impact on economic growth while non-renewable energy consumption and capital stimulates the real GDP, and labor reduces it both in the short run and the long run. According to results obtained from the VECM Granger causality test with structural break, we find that there is bidirectional Granger causality between non-renewable energy consumption and economic growth both in the short run and the long run. In addition, there is one-way causality running from economic growth to renewable energy consumption in the short run, and bidirectional causality between them in the long run.

In regards to policy implications, the overall results imply that Turkish policy makers are advised to keep the balance of renewable energy consumption and non-renewable energy consumption in energy mix because of listed reasons. First of all, it is worth-noting that non-renewable energy consumption is one main contributor to economic growth. Although increases in non-renewable energy consumption stimulate economic growth, Turkey is an energy dependent country wherein nearly 90% of energy used in Turkey is imported from other countries. The Turkish government should not only support universities and institutions to increase energy efficiency but also invest in renewable energy sector in order to increase its energy independence. Indeed, the National Renewable Energy Action Plan for Turkey [26] carried out by the Ministry of Energy and National Sources reports that the projected share of renewable energy is not less than 20% by 2023 while its share was about 13% in 2012. Furthermore, energy efficiency is projected to be 20% above 2012 levels by 2023. From an environmental point of view, non-renewable energy is not an environmental-friendly source while renewable energy is [20,35]. Considering that climate change and environmental quality are of recent fundamental concerns for a lot of countries including Turkey (Kyoto agreement is a good example for a proof), increase of investments in renewable energy sector is an important target as a policy implication.

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