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The relationship between economic growth and electricity consumption from renewable and non-renewable sources: A study of Turkey

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ABSTRACT

The main objective of this study is to analyze the short and long run estimates as well as the causality relationships between economic growth (GR), electricity consumption from renewable sources (RELC) and electricity consumption from non-renewable sources (NRELC) for Turkey in a multivariate model wherein capital (K) and labor (L) are included as additional variables. Using the autoregressive distributed lag (ARDL) approach to cointegration, the Johansen cointegration test and the Gregory–Hansen cointegration test with structural break, we show that GR, RELC, NRELC, K and L are cointegrated. Although NRELC has a long run positive effect on GR, the long run estimate of RELC is negative but insignificant at 5% level of significance. The Granger causality test based on the vector error correction model reveals the evidence of neutrality hypothesis between RELC and GR, and between NRELC and GR in Turkey in the short run. In addition, the Granger causality runs from RELC, NRELC, K and L to GR as well as from GR, RELC, K and L to NRELC in the long run, which supports the existence of growth hypothesis between RELC and GR, and feedback hypothesis between NRELC and GR in the long run. It is advised that policy makers in the Turkish government should continue to reduce the share of electricity consumption from renewable sources and encourage the usage of electricity from non-renewable sources to have sustainable long run growth rates. It is also essential to promote the investment projects to increase the efficiency of electricity generation from non-renewable sources.

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1. Introduction

Energy has served as an important source of economy for many decades. For instance, a variety of energy (i.e., natural gas, diesel, coal and electricity) is consumed to running vehicles, machines and devices, to producing goods, to fertilizing and irrigating lands, and harvesting crops, and to lighting up and heating apartments, buildings and factories. Since the use of energy is involved in each step of the process, producers' productivity and people's welfare within countries are likely to go down in the lack of energy. Thus, a large number of research studies have analyzed the relationship

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between energy consumption (EC) and economic growth (GR) for a variety of countries and regions to show whether or not EC has statistically significant impact on GR, vice versa, by constructing several different econometric models (Ozturk [1], Smyth and Narayan [2], Dogan [3]).

Recently, studies in the energy-growth literature focus on the omitted-variable bias problem which arises when one or more relevant explanatory variables are ignored in the estimated model makes the estimation results biased and inconsistent (Wooldridge [4]). The recent studies, by including several relevant additional variables (i.e., capital and labor) into a multivariate model in order to eliminate the potential omitted-variable bias problem, usually found different cause-effect (causality) relationship between EC and GR than those used the simple bivariate model (Dogan [5]). In detail, the simple bivariate model refers to a model at which economic growth is regressed solely on energy consumption, and a multivariate model refers to a model at which economic growth is regressed on energy consumption in addition to one or more relevant variables such as capital, labor, trade and energy prices. A brief comparison between the findings of studies used the bivariate and multivariate models are provided to understand the concept clearly. Soytas and Sari [6] found the evidence of no cause-effect relationship (no causality) between EC and GR for the USA and the UK using the bivariate model, whereas Soytas and Sari [7] supported that the changes in EC and GR simultaneously impacted each other (bidirectional causality) for the same countries in a multivariate analysis wherein capital and labor were included as additional variables. In addition, Ozturk and Acaravci [8] revealed that the changes in economic growth affected energy consumption, not vice versa, (unidirectional causality ran from economic growth to energy consumption) for Oman using GR and electricity consumption (ELC) in the bivariate model; however, Al-Mulali and Ozturk [9] supported that the changes in energy consumption impacted economic growth, not vice versa, (unidirectional causality ran from energy consumption to economic growth) for the same country employing GR, ELC, capital, labor, export and import in a multivariate framework. Furthermore, Wolde-Rufael [10] reported different causality directions for thirteen of seventeen countries in the multivariate model by accounting for capital and labor in addition to economic growth and energy consumption as opposed to Wolde-Rufael [11] that analyzed the linkage between EC and GR for the same 17 countries in the bivariate model. Moreover, Lutkepohl [12] noted that no-causality between the variables could be found in the bivariate framework owing to the relevant omitted variables. Lean and Smyth [13] argued that EC was not the only element impacting economic growth.

In addition to those dealing with the omitted-variable bias problem, a number of studies disaggregated energy into types (i.e., nuclear energy, natural gas, coal and electricity) and sources (i.e., renewable and non-renewable). The purpose behind the disaggregation is to find out whether the short and long run coefficient estimates, and the direction of causality for the listed energy types and sources differ from each other. This kind of diversity among research studies in the energy-growth literature makes sense as it brings out interesting outcomes for the policy makers and governments which should formulate different strategies and policies for each of energy types and sources in order to reach sustainable growth rates. For the sake of empirical clarification, let us consider the case of France. Lee [14] found one-way (unidirectional) causality running from GR to EC at the aggregate level; Lee and Chiu [15] exposed no causality between economic growth and nuclear energy consumption; Bildirici et al. [16] indicated that causality ran from economic growth to electricity consumption; Shahbaz et al. [17] revealed two-way (bidirectional) causal relationship between GR and natural gas consumption. As is clear from the mentioned-articles, policy makers in France are advised to encourage natural gas consumption for the sake of GR; however, they would presumably regulate an inconsistent energy policy if they were to rely on the results based on the aggregate data.

The descriptions of hypothesis commonly used in the energy-growth literature are given in Table 1 in advance to elaborating the findings of existing studies. As seen in Table 2, a lot of studies have investigated the relationship between economic growth and a type of disaggregated energy consumption; namely, electricity consumption, for various countries, regions and economic groups by using either the bivariate or multivariate framework. As Smyth and Narayan [2] claim that there is a trade-off between the usage of bivariate and multivariate models such that the bivariate model is likely to suffer from omitted-variable bias problem while a multivariate model can suffer from over-parameterization problem. Researchers are left to take their decision on which model they are willing to use constrained by the possible aforementioned concerns. Starting with the bivariate model in which economic growth is the response variable and aggregate electricity consumption is the predictor variable, Altinay and Karagol [18] supported the evidence of growth hypothesis in Turkey by employing the Dolado–Lutkepohl test and the Granger causality tests from 1950–2000. Aslan [19] showed the presence of neutrality hypothesis and feedback hypothesis in Turkey in the short run and long run, respectively, by applying the autoregressive distributed lag approach (ARDL) and the Granger causality tests to an annual data 1968–2008. Shiu and Lam [20] found the existence of growth hypothesis both in the short run and long run in China from 1971–2000 by employing the Granger causality tests. Ozturk and Acaravci [21] did not find a long run relation between economic growth and aggregate electricity consumption in a panel study of 15 transition economies by applying the Pedroni panel cointegration test to an annual data from 1990–2006. Yoo [22] revealed the existence of feedback hypothesis for Malaysia and Singapore, and conservation hypothesis for Indonesia and Thailand by using the Engle-Granger cointegration and the Granger causality tests for the years of 1971–2002. Squalli[23] focused on OPEC members and supported the evidence of growth hypothesis for Indonesia, Nigeria, United Arab Emirates and Venezuela, conservation hypothesis for Algeria, Iraq, Kuwait and Libya, and feedback hypothesis for Iran, Qatar and Saudi Arabia by applying the ARDL and the Granger causality tests to an annual from 1980–2003. Wolde-Rufael [24] analyzed 17 African countries by using the ARDL and the Granger causality tests for 1971–2001 period, and found the presence of conservation hypothesis for Cameroon, Ghana, Nigeria, Senegal, Zambia and Zimbabwe, growth hypothesis for Benin, Congo and Tunisia, and feedback hypothesis for Egypt, Gabon and Morocco.

Most studies have recently used a multivariate model at which economic growth is regressed on aggregate electricity

Table 1
Some useful definitions.

Neutrality hypothesis implies that there is no causal-effect relationship (no causality) between economic growth and energy consumption.
Growth hypothesis implies that unidirectional causality only runs from energy consumption to economic growth.
Conservation hypothesis implies that unidirectional causality only runs from economic growth to energy consumption.
Feedback hypothesis implies that bidirectional causality exists between energy consumption and economic growth.

Table 2
A survey of literature on energy-growth nexus.

Author	Time period	Country/ region	Methods	Variables	Results	Hypothesis
(A) Bivariate models						
Altinay and Karagol[18]	1950–2000	Turkey	Dolado–Lutkepohl test and Granger causality test	GR and ELC	ELC $\rightarrow$ GR	Growth hypothesis
Nazlioglu et al. [40]	1967–2007	Turkey	ARDL model and VECM Granger causality tests	GR and ELC	GR $\leftrightarrow$ ELC GR $\neq$ ELC	LA: feedback hypothesis NLA: neutrality hypothesis
Aslan [19]	1968–2008	Turkey	ARDL model and VECM Granger causality tests	GR and ELC	GR $\neq$ ELC GR $\leftrightarrow$ ELC	SR: neutrality hypothesis LR: feedback hypothesis
Aktas and Yilmaz[41]	1970–2004	Turkey	Granger causality tests	GR and ELC	GR $\leftrightarrow$ ELC GR $\rightarrow$ ELC	SR: feedback hypothesis LR: conservation hypothesis
Shiu and Lam [20]	1971–2000	China	Johansen cointegration and VECM Granger causality	GR and ELC	ELC $\rightarrow$ GR ELC $\rightarrow$ GR	SR: growth hypothesis LR: growth hypothesis
Ho and Siu [42]	1966–2002	Hong Kong	Johansen cointegration and VECM Granger causality	GR and ELC	ELC $\rightarrow$ GR	Growth hypothesis
Ozturk and Acaravci [21]	1990–2006	Transition economies	Pedroni panel cointegration and VECM Granger causality	GR and ELC	GR $\neq$ ELC	Neutrality hypothesis
Ozturk and Acaravci [8]	1971–2006	11 MENA countries	ARDL model and VECM Granger causality	GR and ELC	The variables are cointegrated only in Egypt, Israel, Oman and Saudi Arabia	SR: conservation hypothesis for Israel and Oman, and neutrality hypothesis for Egypt and Saudi Arabia LR: growth hypothesis for Egypt and Saudi Arabia, conservation hypothesis for Oman, and neutrality hypothesis for Israel
Yoo [22]	1971–2002	ASEAN	Johansen cointegration, Granger causality	GR and ELC	The variables are cointegrated in all ASEAN countries	Feedback hypothesis for Malaysia and Singapore, and conservation hypothesis for Indonesia and Thailand
Squalli [23]	1980–2003	OPEC members	ARDL Model and Toda–Yamamoto Granger causality	GR and ELC	The variables are cointegrated in all OPEC members	Growth hypothesis for Indonesia, Nigeria, United Arab Emirates and Venezuela, conservation hypothesis for Algeria, Iraq, Kuwait and Libya, and feedback hypothesis for Iran, Qatar and Saudi Arabia
Wolde-Rufael [24]	1971–2001	17 African countries	ARDL model and Granger causality	GR and ELC	The variables are cointegrated only in nine countries	Conservation hypothesis for Cameroon, Ghana, Nigeria, Senegal, Zambia and Zimbabwe, growth hypothesis for Benin, Congo and Tunisia, and feedback hypothesis for Egypt, Gabon and Morocco
Narayan et al. [43]	1970–2002	G-7 members	Structural vector autoregressive model	GR and ELC	Electricity conservation policies detract economic growth in all the G-7 countries but the US.	Conservation hypothesis for the US
	1960–2002	US, Canada, Italy, France, Japan, Germany, UK		GR and ELC		Growth hypothesis for Italy and feedback hypothesis for the rest.
Tang [44]	1972:1–2003:4	Malaysia	ARDL Model and Granger causality	GR and ELC	No cointegration is found between the variables. GR $\leftrightarrow$ ELC GR $\leftrightarrow$ ELC	SR: feedback hypothesis LR: feedback hypothesis
Yoo [45]	1970–2002	Korea	Johansson cointegration and VECM Granger causality	GR and ELC	GR $\leftrightarrow$ ELC	Feedback hypothesis
Wolde-Rufael [46]	1975–2010	15 Transition countries	Bootstrap panel Granger causality	GR and ELC	The results are mixed.	Feedback hypothesis for Ukraine, conservation hypothesis for Czech Republic, Latvia, Lithuania and the Russia, growth hypothesis for Belarus and Bulgaria, neutrality hypothesis for Albania, Macedonia, Moldova, Poland, Romania, Serbia, Slovak Republic and Slovenia
Kula[33]	1980–2008	19 OECD countries	Pedroni panel cointegration, DOLS and PECM Granger causality		The variables are cointegrated. GR $\rightarrow$ RELC	Conservation hypothesis

				GR and RELC		
(B) Multivariate models						
Acaravci and Ozturk[25]	1968–2006	Turkey	ARDL model and VECM Granger causality tests	GR, ELC and L	ELC → GR	Growth hypothesis
Aslan[26]	1980–2008	Turkey	ARDL model, FMOLS, DOLS and VECM Granger causality	GR, ELC and L	GR ↔ ELC L ≠ ELC ELC → GR	SR: feedback hypothesis LR: growth hypothesis
Shahbaz and Lean [28]	1972–2009	Pakistan	ARDL model and Granger causality tests	GR, ELC, K and L	GR ↔ ELC GR ↔ ELC	SR: feedback hypothesis LR: feedback hypothesis
Belald and Abderrah-mani [29]	1971–2010	Algeria	Johansen cointegration test, Gregory–Hansen cointegration test and VECM Granger causality	GR, ELC and oil price	GR ↔ ELC GR ↔ ELC	SR: feedback hypothesis LR: feedback hypothesis
Odhiambo [47]	1971–2006	South Africa	Johansen cointegration and VECM Granger causality	GR, ELC and employment	GR ↔ ELC ELC → GR	SR: feedback hypothesis LR: feedback hypothesis
Narayan and Smyth [30]	1974–2002	Middle Eastern countries	Westerlund panel cointegration test, FMOLS and PECM Granger causality	GR, ELC and export	ELC → GR GR ↔ ELC	SR: growth hypothesis LR: feedback hypothesis
Gurgul and Lach [48]	2000:1–2009:4	Poland	Granger causality	GR, ELC and employment	GR → ELC	Conservation hypothesis
Al-Mulali and Ozturk [9]	1980–2012	6 Gulf Cooperation Countries	ARDL model and TYDL Granger causality	GR, ELC, K,L, export and import	The variables are cointegrated in all 6 countries.	Feedback hypothesis for Bahrain and United Arab Emirates, growth hypothesis for Oman and Qatar, neutrality hypothesis for Kuwait and Saudi Arabia
Karanfil and Li [49]	1980–2010	160 Countries	Pedroni panel cointegration test and PECM Granger causality	GR, ELC, urbanization and electricity net import	The variables are cointegrated. GR ↔ ELC GR ≠ Urbanization GR ≠ ELC import	Feedback hypothesis
Lean and Smyth [27]	1970–2008	Malaysia	ARDL model and TYDL Granger causality	GR, electricity production, EXP,CPI	GR → ELC EXP ≠ GR CPI ≠ GR	Conservation hypothesis
Apergis and Payne [31]	1985–2005	OECD	Heterogeneous panel cointegration and PECM Granger causality	GR,REC,K and L	GR ↔ REC GR ↔ REC	SR: feedback hypothesis LR: feedback hypothesis
Lin and Moubarak [50]	1977–2011	China	ARDL model, Johansen cointegration test and VECM Granger causality	GR, REC, CO2 Emission and L	GR ≠ REC GR ↔ REC	SR: neutrality hypothesis LR: feedback hypothesis
Fang [32]	1978–2008	China	OLS Model	GR,REC,K, L and R&D	REC → GR	Growth hypothesis
Inglesi-Lotz [51]	1990–2010	34 OECD members	Pedroni panel cointegration test, OLS with fixed effects	GR,REC,K, L and R&D	The variables are cointegrated. REC → GR	Growth hypothesis
Shahbaz et al. [52]	1972:1–2011:4	Pakistan	ARDL model, Johansen cointegration test and VECM Granger causality	GR, REC, K and L	The variables are cointegrated. GR ↔ REC GR ↔ K GR ↔ L	Feedback hypothesis
Apergis and Payne [53]	1980–2006	Central America	Pedroni panel cointegration, FMOLS and PECM Granger causality	GR, RELC, K and L	GR ↔ RELC GR ↔ ELC	SR: feedback hypothesis LR: feedback hypothesis
Apergis and Payne [34]	1992–2007	Eurasia	Pedroni panel cointegration, FMOLS and PECM Granger causality	GR, RELC, K and L	GR ↔ RELC GR ↔ RELC	SR: feedback hypothesis LR: feedback hypothesis
Apergis and Payne [37]	1990–2007	80 countries	Pedroni panel cointegration, FMOLS and PECM Granger causality	GR, RELC, NRELC, K and L	GR ↔ RELC GR ↔ RELC GR ↔ NRELC GR ↔ NRELC	SR: feedback hypothesis between GR and RELC LR: feedback hypothesis between GR and RELC SR: feedback hypothesis between GR and NRELC LR: feedback hypothesis between GR and NRELC
Apergis and Payne [35]	1990–2007	6 Central American Countries	Larsson panel cointegration and PECM Granger causality	GR, RELC, NRELC, K and L	RELC → GR GR ↔ RELC GR ↔ NRELC GR ↔ NRELC	SR: growth hypothesis between GR and RELC LR: feedback hypothesis between GR and RELC SR: feedback hypothesis between GR and NRELC LR: feedback hypothesis between GR and NRELC
Apergis and Payne [36]	1990–2007	16 Emerging Economies	Pedroni panel cointegration, FMOLS and PECM Granger causality	GR, RELC, NRELC, K and L	GR → RELC GR ↔ RELC GR ↔ NRELC	SR: conservation hypothesis between GR and RELC LR: feedback hypothesis between GR and RELC SR: feedback hypothesis between GR and NRELC

Table 2 (*continued*)

Al-Mulali et al. [38]	1980–2010	18 Latin American Countries	Pedroni panel cointegration, DOLS and PECM Granger causality	GR, RELC, NRELC,K,L and Trade	GR ↔ NRELC GR ↔ RELC GR ↔ RELC NRELC → GR GR ↔ NRELC	LR: feedback hypothesis between GR and NRELC SR: feedback hypothesis between GR and RELC LR: feedback hypothesis between GR and RELC SR: growth hypothesis between GR and NRELC LR: feedback hypothesis between GR and NRELC

Note: SR and LR denote for the short and long run, respectively. LA and NLA represent linear and non-linear analyses, respectively. ELC → GR indicates that unidirectional causality runs from electricity consumption to economic growth. GR → ELC indicates that that unidirectional causality runs from economic growth to electricity consumption. GR ↔ ELC indicates that there is bidirectional causality between economic growth and electricity consumption. GR ≠ ELC indicates that there is no causality between economic growth and electricity consumption. *K* denotes capital and *L* denotes labor.

consumption (ELC) in addition to some additional explanatory variables such as capital, labor, trade, prices and employment. Acaravci and Ozturk [25] showed that ELC and employment had statistically significant impact on economic growth and growth hypothesis was valid in Turkey by employing the ARDL and the Granger causality tests for the years of 1968–2006. Aslan [26] indicated that labor force and ELC affected economic growth, and economic growth impacted both labor force and ELC at 5% level of significance in Turkey by applying the ARDL and the Granger causality tests to an annual data on GR, ELC and labor force from 1980–2008. Lean and Smyth [27] analyzed the relationship between GR, aggregate electricity production, export and consumer price index for Malaysia using the ARDL and the Granger causality tests for the period of 1970–2008, and exhibited that economic growth caused ELC; however, ELC did not cause GR and there was no relationship between economic growth and prices, and between economic growth and export. Shahbaz and Lean [28] showed that there was a long run relationship between GR, ELC, capital and labor in Pakistan over the period of 1972–2009 by using the Johansen cointegration test and the bounds testing for cointegration, and also found that a 1% increase in ELC, capital and labor increased economic growth by 0.31%, 0.12%, 0.30%, respectively, in the long run. In addition, Shahbaz and Lean [28] supported that ELC and GR as well as capital and GR simultaneously impacted each other and no causality relation between labor and GR in Pakistan by the employing vector error correction (VECM) Granger causality method. Belald and Abderrahmani [29] investigated the relationship between GR, ELC and oil price for Algeria by applying the Johansen cointegration test, the Gregory–Hansen cointegration test and the VECM Granger causality test to an annual data for the years of 1971–2010, and exhibited the presence of feedback hypothesis both in the short run and long run. Narayan and Smyth [30] examined the long run coefficient estimate and causality relationship between electricity consumption, economic growth and export for a panel study of 6 Middle Eastern countries over the period of 1974–2002, and found that a 1% increase in ELC and trade stimulated GR by 0.04% and 0.17% by employing the fully modified ordinary least squares (FMOLS). In addition, Narayan and Smyth [30] revealed that growth hypothesis and feedback hypothesis were valid in the short run and long run, respectively, and economic growth impacted export in the short run in the Middle Eastern countries as a whole by using the Granger causality tests based on the panel error correction model (PECM). Al-Mulali and Ozturk [9] investigated the tie between GR, ELC, capital, labor, export and import in the 6 Gulf Cooperation Council countries from 1980–2012, and showed that ELC, capital and export had statistically significant and positive impact on economic growth for almost all countries, and the effects of import and labor on GR were mixed at best by using the ARDL method. Moreover, Al-Mulali and Ozturk [9] indicated the evidence of feedback hypothesis for Bahrain and United Arab Emirates, growth hypothesis for Oman and Qatar, neutrality hypothesis for Kuwait and Saudi Arabia by using the Toda–Yamamoto–Dolado–Lutkepohl (TYDL) approach.

Several studies focused narrowly on the relationship between economic growth and renewable energy consumption as well as economic growth and renewable electricity consumption in either a bivariate model or a multivariate model. Apergis and Payne [31] analyzed the possible presence of long run relationship between GR, aggregate energy consumption from renewable sources (REC), capital and labor for a panel study of 20 OECD countries by applying the Pedroni panel cointegration test to an annual data for the years of 1985–2005, and found that a 1% increase in REC, capital and labor promoted GR by 0.76%, 0.70% and 0.24%, respectively, in the long run by running the FMOLS, and also found the evidence of feedback hypothesis between GR and REC

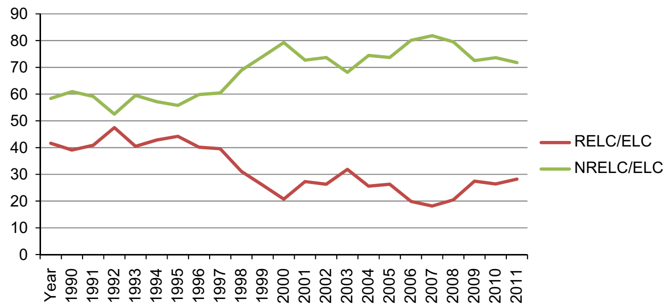

Fig. 1. The proportion of electricity production from renewable and non-renewable sources to the total electricity production in Turkey.

both in the long and short run by using the PECM Granger causality tests. Fang [32] investigated the tie between economic growth, renewable energy consumption, the share of renewable energy consumption, capital, labor and R&D expenses for the case of China over the period of 1978–2008, and exhibited that an increase in the share of renewable energy negatively impacted economic growth while a rise in REC, capital and R&D expenses positively impacted economic growth by employing the OLS method. Kula [33] examined the long run estimates and causality relationship between economic growth and renewable electricity consumption (RELC) for a panel study of 19 OECD countries for the years of 1980–2008 under the bivariate framework by using the Pedroni panel cointegration tests, the dynamic ordinary least squares (DOLS) and the PECM Granger causality tests, and showed that RELC had positive impact on GR and also found the evidence of conservation hypothesis between GR and RELC. Apergis and Payne [34] focused on the relationship of economic growth, renewable electricity consumption, capital and labor for a panel study of 13 countries within the Eurasia, and found that these variables were cointegrated by applying the Pedroni panel cointegration test to an annual data from 1992–2007, and revealed that a 1% increase in RELC, capital and labor stimulated economic growth by 0.19%, 0.22% and 0.55%, respectively, in the long run by running the FMOLS, and found the presence of feedback hypothesis between GR and RELC both in the short and long run.

Only a few studies have so far focused on the relationship between economic growth and disaggregated energy consumption by type and source together; namely, electricity consumption from renewable and non-renewable sources. Recent studies by Apergis and Payne [35], Apergis and Payne [36], Apergis and Payne [37] and Al-mulali et al. [38] investigated the relationship between economic growth, electricity consumption from renewable sources (RELC) and electricity consumption from non-renewable sources (NRELC) in a panel of 6 Central American countries, in a panel of 16 emerging market economies, in a panel study of 80 countries and in a panel of 18 Latin American countries, respectively, in a multivariate model to which some additional relevant independent variables are included. The analyses in the specified researches are constructed based on the investigation of the linkage between economic growth and disaggregated electricity consumption by sources for a group of countries. Apergis and Payne [35] focused on the possible existence of a long run relationship, long run coefficient estimates and causal relationship between GR, RELC, NRELC, capital and labor by applying the Larsson panel cointegration test, the PECM Granger causality tests to an annual data over the period of 1990–2007, and found that all variables but RELC had statistically significant and positive effects on economic growth, and also showed the presence of feedback hypothesis between RELC and GR as well as between NRELC and GR in the long run. In the study of Apergis and Payne [36], economic growth was regressed on RELC, NRECL, capital and labor from 1990–2007 in a multivariate model by using the FMOLS estimation approach and the PECM Granger causality tests. Apergis and Payne [36] found that the coefficient estimate of RELC was not statistically significant whereas the increase in NRELC, capital and labor significantly stimulated economic growth and also found that unidirectional causality ran from economic growth to RELC and there was bidirectional causality between GR and RELC in the short and long run, respectively, two-way causality between economic growth and NRELC was valid in both the short and long run. Apergis and Payne [37] found that the coefficients on RELC, NRELC, capital and labor were statistically significant and positive using the FMOLS, and also supported the evidence of bidirectional causality for both GR and RELC, and GR and NRELC in both the short and long run employing the PECM for the years of 1990–2007 in a multivariate model in which GR was regressed on capital and labor in addition to RELC, NRECL. Al-Mulali et al. [38] found that labor, capital, trade, RELC and NRECL positively impacted economic growth while RELC was more significant than NRELC, and also showed that bidirectional causality existed between RELC and GR as well as between NRELC and GR over the period of 1980–2010 in a multivariate framework wherein labor, capital and trade, RELC and NRELC were the independent variables. This type of empirical analyses also helps the policy makers and governments to rule proper energy policies for each source of electricity consumption.

The main contribution of this study to the existing body of knowledge is that this is the first study in the literature that investigates the relationship between economic growth, electricity consumption from renewable sources and electricity consumption from non-renewable sources for Turkey in a multivariate model wherein capital and labor are considered as additional variables. As given in detail in the above paragraphs and in Table 2, there are a lot of studies focusing on the relationship between economic growth and aggregate electricity consumption for a variety of countries and regions[1]; however, to the best of our knowledge, only four studies [35–38] have so far analyzed the relationship between economic growth and electricity consumption by sources. Moreover, their findings are mixed at best, and the studies [35–38] are based on multi-country panel data. As the investigation of this relationship is a significant research gap in the current energy-growth literature, further studies should focus on a single-country case. In short, the lack of consensus among the existing literature and the need of studies, especially for single-country cases, examining the relationship between economic growth and electricity consumption by sources mainly motivate this study to fulfill the gap in the energy-growth literature. Regarding the country selection, Turkey is an important country in terms of its impressive on regional and world affairs, and its role in the energy market. It is a candidate country for the European Union and one of the G-20 members. Turkey is the second populous country in Europe in 2012 after Germany and has the seventh largest GDP in the Europe in 2012 according to the “World Development Indicators”. The Ministry of Energy and Natural Resources of the Republic of Turkey has initiated a plan to build three nuclear power stations to produce electricity and become a net exporter of energy in the near future. In addition, Turkey is the sixth largest consumer of electricity at the aggregate level in the Europe in 2012 after France, Germany, the UK, Spain and Italy; the sixth largest consumer of electricity from renewable sources in the Europe in 2012 after Germany, Norway, Italy, Spain and France; the seventh largest consumer of electricity from non-renewable sources in the Europe in 2012 after Germany, France, the UK, Italy, Spain and Ukraine

[1] As shown in Table 2, only six research studies have focused on the linkage between economic growth and aggregate electricity consumption in Turkey; however, those did not consider the electricity consumption by sources in their analyses. In addition, five of which were based on the bivariate model.

Table 3
VIF test for multicollinearity.

	GR	RELC	NRELC	K	L
VIF	–	4.27	2.76	2.39	1.31
1/VIF	–	0.23	0.36	0.41	0.76
Mean VIF	2.68				

according to the U.S. Energy Information Administration. As shown in Fig. 1, the proportion of Turkey's electricity production from renewable sources was close to the proportion of its electricity generation from non-renewable sources in the early 1990s. On the other hand, 71% of Turkey's electricity generation came from non-renewable sources, while only 29% of its electricity production came from renewable sources in 2012. The large changes in the proportions over the years also encourage us to focus on the relationship between GR, RELC and NRELC.

By following the logic of recent works by Ohler and Fetters [39], and Lean and Smyth [27] we use the data on electricity generation as proxy for electricity consumption as different from all six previous works dedicated to Turkey, and all four studies examined the relationship between GR, RELC and NRELC. [27,39] noted that non-technical transmission and distribution (T&D) losses were often high in the developing countries. Turkey's T&D loss was nearly 14% in 2012 (The net value of Turkey's T&D loss was 32 billion kW h while its electricity generation was about 228 billion kW h in 2012). Because of the fact that all electricity production, excluding technical losses, is counted towards economic growth, it is not credible to rely on the electricity consumption data for analyzing the relationship between GR, RELC and NRELC as it likely provides misleading empirical results.

By using the ARDL approach to cointegration, the Johansen and the Gregory–Hansen cointegration tests, and the VECM Granger causality test, and in parallel with the idea of [35–38], the objective of this research article is to analyze the short and long run estimates as well as the causality relationships between GR, RELC and NRELC for Turkey in a multivariate model wherein capital and labor are included as additional relevant variables. The idea behind the inclusion of capital and labor into the model comes from the Cobb–Douglas production function. The rest of the paper is organized as follows. The next section explains the data and methodology, the third section reveals the empirical results, and the last section summarizes the findings of the paper.

2. Methodology and data

Most studies in the above Table 2 included electricity consumption as an additional factor into the Cobb–Douglas production function. Likewise all other available methods, the selection of Cobb–Douglas specification has also advantages and disadvantages. This specification requires several assumptions such as constant returns to scale; however, Cobb–Douglas function simplifies the estimation and exposition with those assumptions. The use of Cobb–Douglas production function is also certainly consistent with the energy-growth literature. Following the work of [35–38], we explore the relationship between RELC, NRELC and GR in a conventional neo-classical production function where RELC, NRELC, capital (K) and labor (L) are considered as separate factors

$$GR_t = f(RELC_t, NRELC_t, K_t, L_t) \quad (1)$$

The variables are presented in their natural logarithmic forms. The above production function can be shown in a mathematical form as

$$GR_t = K_t^{\alpha} L_t^{\beta} RELC_t^{\delta} NRELC_t^{\gamma}$$

where α, β, δ and γ are the elasticities of economic growth with respect to capital, labor, electricity consumption from renewable sources and electricity consumption from non-renewable sources. Moreover, the growth model yields the following log-linear form by adding constant (C) and error term (e):

$$GR_t = C + \alpha K_t + \beta L_t + \delta RELC_t + \gamma NRELC_t + e_t$$

where GR (economic growth) is the natural logarithmic value of real GDP per capita, RELC is the natural logarithmic value of per capita electricity generation from renewable sources (i.e., geothermal, wind, solar and biomass), NRELC is the natural logarithmic value of per capita electricity generation from non-renewable sources (i.e., coal and natural gas), K is the natural logarithmic value of per capita real gross capital formation and L is the natural logarithmic value of per capita labor force. The data on RELC and NRELC are drawn from the U.S. Energy Information Administration and the data on the GDP, capital, labor and population are obtained from the World Bank's "World Development Indicators" for the period of 1990–2012.[2] Note that we use the longest available data.

The simultaneous use of multiple variables in one regression may call for testing the possible presence of multicollinearity problem among economic growth, renewable electricity consumption, non-renewable electricity consumption, capital and labor. The presence of collinearity between the analyzed variables can lead to higher standard errors and (non-)significant coefficient estimates. Thus, the economic meaning and accuracy of the estimation results are questionable in the existence of the mentioned problem. To eliminate any doubt about multicollinearity problem, this study applies the Variance Inflation Factor (VIF) test for collinearity. The obtained results are reported in Table 3. Given that the critical value is 10 for the VIF test, we have no evidence to claim the presence of multicollinearity among the analyzed variables because the VIF for RELC, NRELC, K and L are 4.27, 2.76, 2.39 and 1.31, respectively, and fairly less than the critical value. As a result, we are not concerned about multicollinearity problem.

By the specification (1), our target is to address whether the analyzed variables have a long run relationship as well as the direction of causality between RELC, NRELC and GR, and the magnitude of coefficients on electricity consumption from renewable and non-renewable sources differ from each other in the short and long run. To do so, we perform ARDL approach to cointegration, the Johansen cointegration test, the Gregory–Hansen cointegration test and the Granger causality test based on the VECM. One will be skeptical about the economic meaning and consistency of estimation results if the time-series data are non-stationary and not cointegrated in their levels. On the other hand, the existence of non-stationarity does not cause a spurious regression problem as long as time-series data are cointegrated. In case that GR, RELC, NRELC, K and L have a long-run relationship, one can claim that at least one-way Granger causality should be present between the variables.

2.1. ARDL method and cointegration tests

The term cointegration basically refers to that one or more linear combinations of time-series data are stationary even though they are individually non-stationary. Put it differently related to this study, the variables GR, RELC, NRELC, K and L are found to be cointegrated if they are individually integrated of order one or mixed order of one and zero and some linear combination of them have lower order of integration. The possible existence of cointegration relation between GR, RELC, NRELC, K and L must be considered for the sake of correctness of the results. Therefore, the ARDL approach to cointegration (bounds testing for cointegration) due to Refs. [54,55] is used in this study. It provides consistent and unbiased long-run estimates even if the data are small and independent variables are endogenous. Each time-series can have different appropriate lag lengths. It allows us to simultaneously obtain

[2] The data are reported at www.eia.gov and at http://data.worldbank.org.

the long-run and short run elasticity estimates of the dependent variables with respect to the independent variables in one regression. It can be employed irrespective of whether the series are integrated in different orders unless the order of integration is greater than one. In other words, ARDL bounds test for cointegration provides efficient and consistent results when the variables are integrated in order zero, $I(0)$, and one, $I(1)$. We thus apply one of the most popular methods, the Augmented Dickey–Fuller unit root test (ADF), to confirm that the variables GR, RELC, NRELC, K and L are either $I(0)$ or $I(1)$. Dickey and Fuller [56] present the ADF as

$$\Delta X_t = \alpha + \beta X_{t-1} \sum_{i=1}^{n} \theta_i \Delta X_{t-i} + \rho T + \mu_t \tag{2}$$

where μ_t is a normally distributed white noise error term, T is a deterministic time trend, X_{t-1} is the lagged value of a time-series variable (i.e., GR), ΔX_{t-i} are the lagged values of the first differenced series, and α, β, θ, ρ are the estimated parameters. An appropriate lag length is selected based on the Akaike Information Criterion (AIC).

To consider the possible existence of structural break in time series and strengthen the inference of this study, we shall adopt the Zivot–Andrews (ZA) unit root test with one break in which the structural break is endogenously determined from the data (Zivot and Andrews [57]). The regression of ZA unit root test is written by

$$\Delta y_t = \alpha + \beta y_{t-1} + + \rho T + \delta \mathrm{DM}_t + \Phi \mathrm{DT}_t + \sum_{i=1}^{n} \theta_i \Delta y_{t-i} + \varepsilon_t \tag{3}$$

where ε_t is a white noise residual, DM is a dummy variable for one-time change in intercept and DT is a dummy variable for a break in trend. These dummy variables are determined by the following method in which BD is the break-date.

$$\mathrm{DM} = \begin{cases} 1\ldots\text{if} \quad t > \mathrm{BD} \\ 0\ldots\text{otherwise} \end{cases}, \text{and} \quad \mathrm{DM} = \begin{cases} t-\mathrm{BD}\ldots\text{if} \quad t > \mathrm{BD} \\ 0\ldots\ldots\ldots \text{ otherwise} \end{cases}$$

The null hypothesis of non-stationarity is tested against the alternative hypothesis of trend stationary through H_0: $\beta = 0$ and H_a: $\beta < 0$. Because the time period is not too long, the application of a unit root test with one structural break only should sufficient. An appropriate lag length is selected based on the AIC.

After we detect whether the variables have a unit root, the first next step is to set up the ARDL model based on the standard log-linear functional specification with an unrestricted error correction mechanism (UECM). The UECM integrates the short-run dynamics with the long-run equilibrium without losing any long-run information. The UECM for Eq. 1 is written by

$$\begin{aligned} \Delta \mathrm{GR}_t = c_1 &+ \sum_{i=1}^{j1} a_{1i} \Delta \mathrm{GR}_{t-i} + \sum_{i=0}^{k1} \beta_{1i} \Delta \mathrm{RELC}_{t-i} + \sum_{i=0}^{l1} \theta_{1i} \Delta \mathrm{NRELC}_{t-i} + \sum_{i=0}^{m1} \gamma_{1i} \Delta K_{t-i} \\ &+ \sum_{i=0}^{n1} \delta_{1i} \Delta L_{t-i} + \varnothing_1 \mathrm{GR}_{t-1} + \varnothing_2 \mathrm{RELC}_{t-1} \\ &+ \varnothing_3 \mathrm{NRELC}_{t-1} + \varnothing_4 K_{t-1} + \varnothing_5 L_{t-1} + \varepsilon_{1t} \end{aligned} \tag{4}$$

where Δ is the first difference operator; α, β, θ, γ and δ are the coefficient estimates on the related variables; ε is a white noise error term; j, k, l, m and n are the optimal lag lengths selected based on the AIC. The possible presence of a cointegration between economic growth, electricity consumption from renewable and non-renewable sources, capital and labor in Eq. 4 is examined based the joint F-statistics. The null hypothesis of no cointegration, H_0:$\varnothing_1 = \varnothing_2 = \varnothing_3 = \varnothing_4 = \varnothing_5 = 0$, is tested against the alternative hypothesis, H_a:$\varnothing_1 \neq \varnothing_2 \neq \varnothing_3 \neq \varnothing_4 \neq \varnothing_5 \neq 0$. Because the distribution of test statistics under the null is non-standard, Pesaran et al. [55] produce critical value bounds for the F-test. If calculated F-statistics fall below the lower critical bound, $I(0)$, the null hypothesis cannot be rejected; in contrary, if calculated F-statistics exceed the upper critical bound, $I(1)$, the null will be rejected in favor of the alternative hypothesis and thus the series are said to be cointegrated.

The second next step is to present the Johansen cointegration test to confirm the verdict of the bounds testing for cointegration. The Johansen multivariate cointegration test takes the following form by following [58–59]:

$$\Delta Y_t = \mu + \sum_{i=1}^{k} \Gamma_i \Delta Y_{t-i} + \Pi\, Y_{t-1} + \varepsilon_t \tag{5}$$

where Y_t represents a 5×1 vector of the variables economic growth, electricity consumption from renewable and non-renewable sources, 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 maximum likelihood estimation and 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 ($r > 0$).

The third and last stage is to apply the Gregory–Hansen cointegration test with endogenously determined structural break so as to approve the findings of the ARDL approach to cointegration test and the Johansen cointegration test. Since it allows for possible structural breaks in the series, this test is also robust and good option for testing cointegration among the analyzed variables. Gregory and Hansen [60] define the cointegration test as in Eq. 6 in which a break in the constant, the slope and the trend are specified

$$Y_t = \beta_o + \beta_1 \varphi_t + \delta_1 T + \delta_2 \varphi_t T + \sum_{i=1}^{4} \alpha_{1i} X_{it} + \sum_{i=1}^{4} \alpha_{2i} \varphi_t X_{it} + \varepsilon_t \tag{6}$$

where Y_t is the dependent variable, X_t is the independent variables, ε_t is assumed to be $I(0)$ error term, and φ_t is the dummy variable to pin down structural break in the constant, the slope and the trend. The dummy variable is defined as:

$$\varphi_t = \begin{cases} 1\ldots\text{if} \quad t > [n\tau] \\ 0\ldots\text{if} \quad t \le [n\tau] \end{cases}, \; 0 < \tau < 1 \text{ and } t = 1,2,3\ldots n.$$

In case that GR, RELC, NRELC, K and L have a long run relationship, the long-run effects of RELC, NRELC, K and L are posed by the estimates of $\varnothing_2$, $\varnothing_3$, $\varnothing_4$ and $\varnothing_5$ after a normalization process by the estimate of $\varnothing_1$ in Eq. (4).[3] In detail, the long-run effect of RELC on GR is obtained by $-(\varnothing_2/\varnothing_1)$, that of NRELC on GR is obtained by $-(\varnothing_3/\varnothing_1)$, that of K on GR is obtained by $-(\varnothing_4/\varnothing_1)$, and that of L on GR is obtained by $-(\varnothing_5/\varnothing_1)$. In addition, the short-run effects of each variable are posed by the coefficient estimates of the first-differenced series in Eqs. (7)–(11). For instance, the short-run effects of RELC and NRELC on GR are judged by the estimates of ϑ_{1i} and q_{1i}.

2.2. Causality analysis

Granger [61] argues that there should be at least one-way causality if two or more variables are cointegrated. Although the ARDL approach to cointegration, the Johansen and the Gregory–Hansen cointegration tests explore whether the time-series data are cointegrated, they do not reveal the causality directions between GR, RELC, NRELC, K and L. For this purpose, we follow Granger causality in the VECM framework proposed by [62]

$$\begin{aligned} \Delta \mathrm{GR}_t = c_2 &+ \sum_{i=1}^{p1} \zeta_{1i} \Delta \mathrm{GR}_{t-i} + \sum_{i=0}^{q1} \vartheta_{1i} \Delta \mathrm{RELC}_{t-i} \\ &+ \sum_{i=0}^{r1} q_{1i} \Delta \mathrm{NRELC}_{t-i} + \sum_{i=0}^{s1} \xi_{1i} \Delta K_{t-i} \\ &+ \sum_{i=0}^{v1} \psi_{1i} \Delta L_{t-i} + \Phi_1 \mathrm{ECM}_{t-1} + \omega_{1t} \end{aligned} \tag{7}$$

[3] The Microfit 5.0 statistical package is used to obtain the estimated coefficients in the ARDL approach. For a detailed explanation about normalization, please see MIFT5.0 manual prepared by [63].

$$\Delta \mathrm{RELC}_t = c_3 + \sum_{i=0}^{p2} \zeta_{2i} \Delta \mathrm{GR}_{t-i} + \sum_{i=1}^{q2} \vartheta_{2i} \Delta \mathrm{RELC}_{t-i} + \sum_{i=0}^{r2} q_{2i} \Delta \mathrm{NRELC}_{t-i} + \sum_{i=0}^{s2} \xi_{2i} \Delta \mathrm{K}_{t-i} + \sum_{i=0}^{v2} \psi_{2i} \Delta L_{t-i} + \Phi_2 \mathrm{ECM}_{t-1} + \omega_{2t} \quad (8)$$

$$\Delta \mathrm{NRELC}_t = c_4 + \sum_{i=0}^{p3} \zeta_{3i} \Delta \mathrm{GR}_{t-i} + \sum_{i=0}^{q3} \vartheta_{3i} \Delta \mathrm{RELC}_{t-i} + \sum_{i=1}^{r3} q_{3i} \Delta \mathrm{NRELC}_{t-i} + \sum_{i=0}^{s3} \xi_{3i} \Delta K_{t-i} + \sum_{i=0}^{v3} \psi_{3i} \Delta L_{t-i} + \Phi_3 \mathrm{ECM}_{t-1} + \omega_{3t} \quad (9)$$

$$\Delta K_t = c_5 + \sum_{i=0}^{p4} \zeta_{4i} \Delta \mathrm{GR}_{t-i} + \sum_{i=0}^{q4} \vartheta_{4i} \Delta \mathrm{RELC}_{t-i} + \sum_{i=0}^{r4} q_{4i} \Delta \mathrm{NRELC}_{t-i} + \sum_{i=1}^{s4} \xi_{4i} \Delta K_{t-i} + \sum_{i=0}^{v4} \psi_{4i} \Delta L_{t-i} + \Phi_4 \mathrm{ECM}_{t-1} + \omega_{4t} \quad (10)$$

$$\Delta L_t = c_6 + \sum_{i=0}^{p5} \zeta_{5i} \Delta \mathrm{GR}_{t-i} + \sum_{i=0}^{q5} \vartheta_{5i} \Delta \mathrm{RELC}_{t-i} + \sum_{i=0}^{r5} q_{5i} \Delta \mathrm{NRELC}_{t-i} + \sum_{i=0}^{s5} \xi_{5i} \Delta K_{t-i} + \sum_{i=1}^{v5} \psi_{5i} \Delta L_{t-i} + \Phi_5 \mathrm{ECM}_{t-1} + \omega_{5t} \quad (11)$$

where Δ is the first difference operator; ζ, ϑ,q, ξ and ψ are the coefficient parameters; ω is a white noise error term; p, q, r, s and v are the optimal lag lengths selected based on the AIC; ECM_{t-1} is the lagged error correction mechanism attained from the long-run

Table 4
ADF unit root test results.

Levels				First differences			
Variables	ADF-test statistics	Lag length	5% critical values	Variables	ADF-test statistics	Lag length	5% critical values
GR	−2.27	1	−3.91	ΔGR	−3.10*	0	−1.94
RELC	−3.32	2	−3.64	ΔRELC	−4.02*	2	−1.84
NRELC	−1.56	0	−3.76	ΔNRELC	−2.37*	0	−1.94
K	−0.65	0	−3.76	ΔK	−4.10*	0	−1.94
L	−1.39	1	−3.91	ΔL	−2.11*	1	−2.01

* Denotes significance at 5% level.

Table 6
Bounds testing for cointegration.

			5% critical values	
Estimated model	Lag length	*F*-statistic	*I*(0)	*I*(1)
f(GR/RELC, NRELC, *K*, *L*)	(2,0,1,1,2)	5.53	3.81	5.33

Table 7
Johansen cointegration test results.

Maximum rank	Trace statistic	5% Critical value
$r=0$	104.4	68.52
$r=1*$	32.48	47.21
$r=2$	31.14	29.68
$r=3$	9.26	15.41
$r=4$	0.30	3.76

Note: The star shows the number of cointegrating vectors at 5% level of significance.

Table 8
Gregory–Hansen cointegration test results.

Estimated model	Break date	ADF-statistic	1% critical value
f(GR/RELC, NRELC, *K*, *L*)	1995	7.89	7.31

Note: The regression includes a break in the constant, the slope and the trend.

Table 9
Long and short-run estimates.

Long-run analysis Variables	Coeff.	Std. error	*T*-ratio	Prob.
NRELC	0.22**	0.03	18.64	0.00
RELC	−0.04	0.03	−1.35	0.20
K	0.31**	0.02	12.92	0.00
L	0.35*	0.12	2.72	0.02
Constant	2.96**	0.09	32.01	0.00
Short-run analysis				
Variables	Coeff.	Std. error	*T*-ratio	Prob.
DNRELC	−0.01	0.03	−0.03	0.97
DRELC	−0.03	0.02	−1.45	0.17
DK	0.33**	0.03	13.55	0.00
DL	0.31*	0.12	2.51	0.03
ECT(−1)	−0.75**	0.15	−4.78	0.00
R\widehat2	0.98			
F-statistic	109.72**			0.00
DW-statistic	2.28			
Diagnostic tests				
Test	*p*-Values			
Serial corr.	0.95			
Normality	0.74			
Functional form	0.51			
Heteroscedasticity	0.35			

** Denotes the significance at 1% level.
* Denotes the significance at 5% level.

Table 5
Zivot–Andrews unit root test results.

Levels					First differences				
Variables	ZA-test statistics	Lag length	Break date	5% critical values	Variables	ZA-test statistics	Lag length	Break date	5% critical values
GR	−3.42	0	1999	−5.08	ΔGR	−5.11*	0	2007	−5.08
RELC	−4.27	2	2000	−5.08	ΔRELC	−6.12*	0	2002	−5.08
NRELC	−3.05	0	1999	−5.08	ΔNRELC	−5.56*	0	2009	−5.08
K	−3.48	0	2001	−5.08	Δ*K*	−5.65*	0	2003	−5.08
L	−3.69	0	2007	−5.08	Δ*L*	−6.80*	0	2000	−5.08

* Denotes significance at 5% level.

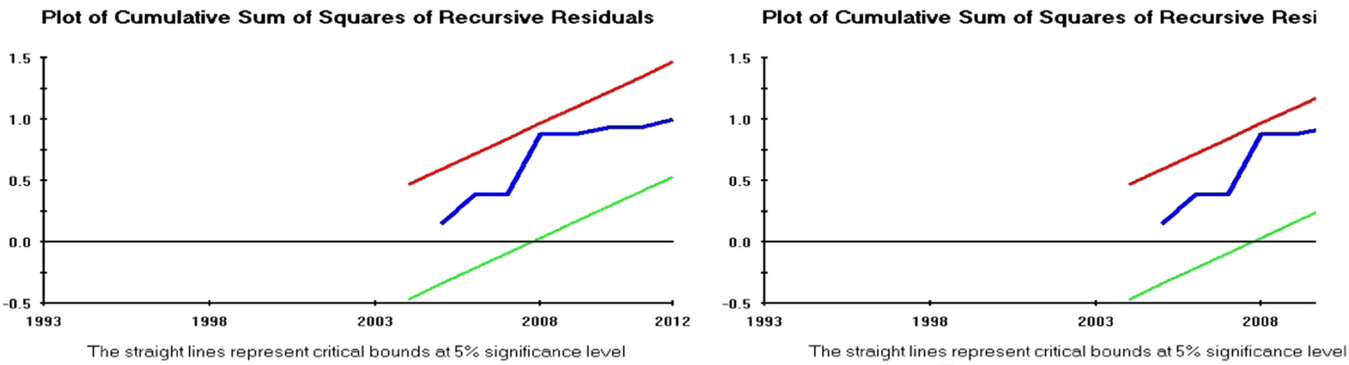

Fig. 2. CUSUM and CUSUMQ stability tests.

equilibrium relationship; Φ stands for the speed of adjustment to the long-run equilibrium. The VECM Granger approach can be tested in two following ways:

- A short-run Granger causality is conducted by testing the significance of the sum of the lagged differences of each right hand-side variable based on the Wald-test statistics. For example, the short-run causality between GR and RELC in Eq. (7) is detected by testing the null hypothesis of no-causality, H_0: $\vartheta_{1i} = 0$, against the alternative hypothesis of causality, H_a: $\vartheta_{1i} \neq 0$. Additionally, the short-run causality between RELC and NRELC in Eq. (8) is detected by testing the null hypothesis of no-causality, H_0:$q_{2i} = 0$, against the alternative hypothesis of causality, H_a: $q_{2i} \neq 0$.
- A long-run Granger causality is conducted by testing the significance of ECM_{t-1} based on the Wald-test statistics. For example, the long-run causality from RELC, NRELC, K and L to GR in Eq. (7) is investigated by testing the null hypothesis H_0: $\Phi_1 = 0$ against the alternative H_a: $\Phi_1 \neq 0$. Additionally, the long-run causality from GR, NRELC, K and L to RELC in Eq. (8) is investigated by testing the null hypothesis H_0: $\Phi_2 = 0$ against the alternative H_a: $\Phi_2 \neq 0$.

3. Empirical results

3.1. Unit root tests

ADF test is applied to detect the possible presence of unit roots in GR, RELC, NRELC, K and L because the ARDL approach to cointegration will not be an accurate estimator when the order of integration of a variable is greater than one, i.e. $I(k)$ where $k \geq 2$. The null hypothesis of unit root can be rejected in favor of the alternative hypothesis of no unit root when the absolute value of ADF-test statistic is greater than the absolute value of critical value. Because our sample size is relatively small, the critical values for ADF are computed for the indicated lagged numbers by stochastic simulations using 1000 replications. Table 4 represents that no variable is stationary in their levels since the absolute values of test statistics for each variable are smaller than 5% critical values. On the other hand, economic growth, electricity consumption from renewable and non-renewable sources, capital and labor are stationary process in their first differences because the absolute values of test statistics for each variable are greater than 5% critical values.

In order to confirm integration properties of the analyzed variables found by using the ADF test, Table 5 reports the results obtained from the Zivot–Andrews (ZA) unit root test with single structural break. As it is the case in the ADF test, ZA test indicates that GR, RELC, NRELC, K and L are not stationary in their levels but become stationary in their first differences at 5% level of significance. Since the variables are found to be integrated in order one, we can confidently apply the ARDL method, the Johansen cointegration test and the Gregory–Hansen cointegration test to find out the possible presence of a cointegration relation among the variables using Eqs. (4)–(6).

3.2. Cointegration tests and short–long run estimates

The calculated F-statistic from the ARDL approach to cointegration is reported in Table 6. The optimal lag length is selected based on the AIC. The critical value bounds in Table 6 are computed by stochastic simulations using 20,000 replications because the actual critical values for relatively small sample sizes can potentially differ from the critical values posted in [55]. The null hypothesis of no cointegration can be rejected in favor of the alternative hypothesis of cointegration for f (GR/RELC, NRELC, K, L) at 5% level of significance because the calculated F-statistic is greater than, $I(1)$, the 5% upper critical bound. Therefore, we can conclude that a long-run relationship exists between economic growth, electricity consumption from renewable and non-renewable sources, capital and labor.

To further confirm the result obtained from the ARDL approach to cointegration, we also apply the Johansen cointegration test and the Gregory–Hansen cointegration test with one structural break. The appropriate lag length for both cointegration tests is 2 (two) and selected based on the AIC. Table 7 obtained from the Johansen cointegration test shows that GR, RELC, NRELC, K and L are cointegrated as indicated by the star wherein the value of trace statistic is smaller than 5% critical value. In addition, Table 8 shows the finding of the Gregory–Hansen cointegration test with single structural point. We have enough evidence to reject the null hypothesis of no cointegration in favor of cointegration among economic growth, electricity consumption from renewable and non-renewable sources, capital and labor at 1% level of significance. Because Gregory–Hansen test allows structural break in the series, it further approves the long-run relationship between the analyzed variables. As a result, it is reported that economic growth, electricity generation from renewable and non-renewable sources, labor, and capital are cointegrated for Turkey. The results of the Johansen and the Gregory–Hansen cointegration tests verify the presence of long-run relationship between GR, RELC, NRELC, K and L.

After we find the existence of cointegration among the variables, the further step is to estimate the short and long run estimates of electricity consumption from renewable and non-renewable sources, capital and labor. Table 9 reports the short and long run coefficients on RELC, NRELC, K and L. Since all variables are transformed into the form of natural logarithmic values, the reported coefficients are formally and econometrically equal to the elasticities of GR with respect to RELC, NRELC, K and L. The statistical significance of a coefficient is posed by the related p-value, in which an elasticity of economic growth is significant at 1% level of significance and 5% level of significance if indicated p-Values are smaller than 0.01 and 0.05, respectively. Starting with the long run analysis, a 1% increase in electricity consumption from non-renewable sources stimulates GR by 0.22% at 5% level of significance; however, the coefficient on electricity

Table 10
Comparison between the long run estimates of this study and earlier studies.

Dependent variable: economic growth				
	RELC	**NRELC**	***K***	***L***
This study	Statistically insignificant	Statistically significant and positive	Statistically significant and positive	Statistically significant and positive
[35]	Statistically insignificant	Statistically significant and positive	Statistically significant and positive	Statistically significant and positive
[36]	Statistically insignificant	Statistically significant and positive	Statistically significant and positive	Statistically significant and positive
[37]	Statistically significant and positive	Statistically significant and positive	Statistically significant and positive	Statistically significant and positive
[38]	Statistically significant and positive	Statistically significant and positive	Statistically significant and positive	Statistically significant and positive

Table 11
The VECM Granger causality analysis.

Dependent variable	Short-run causality					Long-run causality
	ΔGR	ΔRELC	ΔNRELC	ΔK	ΔL	ECT(−1)
ΔGR	–	2.10 (0.14)	0.01 (0.97)	183.6** (0.00)	0.51 (0.47)	5.38** (0.02)
ΔRELC	0.05 (0.81)	–	57.75** (0.00)	2.24 (0.32)	16.86** (0.00)	0.08 (0.77)
ΔNRELC	0.55 (0.45)	70.30** (0.00)	–	0.27 (0.59)	10.91** (0.00)	6.67** (0.01)
ΔK	279.49** (0.00)	4.06* (0.04)	0.05 (0.81)	–	18.41** (0.00)	32.04** (0.00)
ΔL	1.25 (0.53)	13.90** (0.00)	11.73** (0.00)	2.89 (0.09)	–	1.49 (0.22)

* Denotes the significance at 1% level, ** denotes the significance at 5% level. Values in parenthesis are p-values for Wald test based on Chi-square distribution.

Table 12
Comparison between the directions of causality in this study and earlier studies.

		GR and RELC	**GR and NRELC**	**GR and *K***	**GR and *L***
This study	**Short run**	Neutrality hypothesis	Neutrality hypothesis	Feedback hypothesis	Neutrality hypothesis
	Long run	Growth hypothesis	Feedback hypothesis	Feedback hypothesis	Growth hypothesis
[35]	**Short run**	Growth hypothesis	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis
	Long run	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis
[36]	**Short run**	Conservation hypothesis	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis
	Long run	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis
[37]	**Short run**	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis
	Long run	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis
[38]	**Short run**	Feedback hypothesis	Growth hypothesis	Growth hypothesis	Neutrality hypothesis
	Long run	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis	Feedback hypothesis

consumption from renewable sources is not statistically significant at 5% level of significance. In addition, 1% rises in capital and labor also promote economic growth with a fair degree of 0.31% and 0.35%, respectively. In short, increases in NRELC, *K* and *L* stimulate economic growth in the long run; however, RELC is ineffective on economic growth in the long run.

Considering the short run analysis, neither electricity consumption from renewable sources nor electricity consumption from non-renewable sources is a statistically significant factor in determining economic growth at 5% level of significance. On the other hand, 1% increases in capital and labor promote economic growth by 0.33% and 0.31%, respectively, at 5% level of significance. Considering the lagged error correction term, ECT_{t-1}, the negative and statistically significant coefficient estimate at 1% level of significance confirms the existence of a long-run relationship between GR, RELC, NRELC, *K* and *L*. In addition, the coefficient on ECT_{t-1} implies that deviations from the long-run equilibrium are corrected by nearly 75% in each year. As a summary of the short run, economic growth is not affected by the changes in RELC and NRECL even though capital and labor add in GR in the short run.

The estimated ARDL model also passes necessary diagnostic tests. The null hypothesis of no serial correlation is tested against the alternative hypothesis of serial correlation, and the null of no serial correlation cannot be rejected at 5% level of significance as the related *p*-Value is much greater than 0.05. Likewise, the null hypotheses of normality of residuals, no misspecification and no heteroscedasticity cannot be rejected in favor of the alternative hypotheses at 5% level of significance since the related *p*-Values are fairly greater than 0.05. In other words, we find no evidence of serial correlation, non-normality, misspecification and heteroskedasticity. In addition, the goodness of fit of the specification ($R^2=0.98$) is very close to one, which is preferred in econometric analysis. The last identification related to the goodness of fit of the model is stability tests. For this purpose, we perform cumulative sum (CUSUM) and cumulative sum of squares (CUSUMQ) tests. As seen in Fig. 2, the estimated parameters are stable over time since the plot of CUSUM and CUSUMQ test statistics fall within the boundaries.[4]

For the sake of comparison between the long run elasticities of economic growth with respect to electricity consumption from renewable sources, capital and labor in this study and that of earlier studies, we present Table 10. Because the previous studies did not estimate the short run coefficients on RELC, NRELC, *K* and *L*, only the long run estimates are compared. The findings of this

[4] The straight lines stand for the critical bounds at 5% significance level.

study are fully consistent with that of [35,36]. In addition, the long run elasticities of GR with respect to NRELC, *K* and *L* are in line with that of [37,38]. As mentioned in the introduction section, the previous studies are based on a panel study of multiple countries whereas we focus on a single country case. This might cause the mentioned differences.

3.3. Granger causality tests

Accompanying with the evidence of a long-run relationship between GR, RELC, NRELC, *K* and *L*, it is an interest for researchers to perform the Granger causality test in order to present a clear picture for policy makers to regulate appropriate economic policies and energy strategies by understanding the directions of causality between the variables. For this purpose, the Granger causality in the vector error correction mechanism can be applied to reveal the directions of causality between economic growth, electricity consumption from renewable sources and non-renewable sources, capital and labor as well as to decompose the directions of causality into the short and long run effects. The short-run causality is tested based on the statistical significance of the partial Wald-statistics related with the explanatory variables. The long-run causality is explored by the statistical significance of the ECT_{t-1} from the Wald-statistic.

The results from the VECM Granger causality tests are represented in Table 11. Considering the short run, there is bidirectional Granger causality between RELC and NRELC in the short run at 1% level of significance because the Wald-statistics are 57.75 and 70.30, and the related *p*-Values are smaller than 0.01; however, we find no evidence of causality between electricity consumption from renewable sources and economic growth, and between electricity consumption from non-renewable sources and economic growth in the short run at 5% level of significance since the Wald-statistics are 2.10 and 0.01, and the related *p*-Values are quite higher than 0.05. By looking at the *p*-Values, we also find that there is two-way causality between capital and economic growth, and no-causality between GR and *L* in the short run. Furthermore, labor and renewable electricity consumption Granger causes each other just as labor and non-renewable electricity consumption does.

Considering the long run Granger causality, we show that electricity consumption from renewable sources and non-renewable sources, capital and labor jointly Granger cause economic growth at 5% level of significance since the related *p*-Value is smaller than 0.05. Regarding the indicated *p*-Values; moreover, the results in Table 11 indicate that Granger causality runs from economic growth, electricity consumption from renewable sources, capital and labor to electricity consumption from non-renewable sources in the long run although there is no long run causality from GR, NRELC, *K* and *L* to RELC at 5% level of significance. Furthermore, Granger causality runs from GR, RELC, NRELC and *L* to *K*; however, there is no causality from GR, RELC, NRELC and *K* to *L* in the long run at 5% level of significance. In short, empirical results support the evidence of neutrality hypothesis and growth hypothesis between GR and RELC in Turkey in the short run and long run, respectively, and the evidence of neutrality hypothesis and feedback hypothesis between GR and NRELC in Turkey in the short and long run.

Since the variable of interest is economic growth, we only compare the short run and long run causality directions between GR and RELC, GR and NRELC, GR and *K*, and GR and *L* found in this study to that of found in the previous studies in Table 12. The findings are mixed at best, and without any kind of doubt, no consensus on the relationship between economic growth and electricity consumption from renewable and non-renewable sources has been reached yet.

4. Conclusions

By using the ARDL approach to cointegration, the Johansen cointegration test and the Gregory–Hansen cointegration test, and the VECM Granger causality, the objective of this paper is to analyze the short and long run relationships as well as the direction of Granger causality between economic growth, electricity consumption from renewable sources and non-renewable sources for Turkey in a multivariate model wherein labor and capital are included as additional variables. The main reason is that there is a lack of study that examines the relationship between economic growth and electricity consumption by sources for Turkey.

The empirical results show that a long-run relationship exists between economic growth, electricity consumption from renewable and non-renewable sources, capital and labor. Based on the short and the long run analyses using the ARDL model, a 1% increase in electricity consumption from non-renewable sources stimulates GR by 0.22%; however, coefficient on electricity consumption from renewable sources is not statistically significant at 5% level in the long run. In addition, neither electricity consumption from renewable sources nor electricity consumption from non-renewable sources is a statistically significant factor in determining economic growth in the short run. The Granger causality based on the VECM reveals the evidence of neutrality hypothesis between GR and RELC as well as between GR and NRELC in Turkey in the short run. In addition, the Granger causality runs from RELC, NRELC, *K* and *L* to GR as well as from GR, RELC, *K* and *L* to NRELC in the long run. It is advised that policy makers in the Turkish government should continue to reduce the share of electricity consumption from renewable sources and encourage the usage of electricity from non-renewable sources to have sustainable long run growth rates because only NRELC has statistically significant and positive effect on economic growth. It is also essential to promote the investment projects to increase the efficiency of electricity generation from non-renewable sources considering the fact that Turkey is a net energy exporter country. The further studies may investigate the relationship between economic growth and renewable electricity consumption by type i.e. hydroelectric, wind, solar and geothermal to explore if some renewable sources significantly impacts economic growth in the long run.

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