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RESEARCH ARTICLE

Rethinking electricity consumption and economic growth nexus in Turkey: environmental pros and cons

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Abstract
The critical role of electricity consumption in influencing and reshaping the economic and environmental landscape of the global economy cannot be underestimated. Electricity is the most beneficial and commonly transformed energy source; however, the strength, weakness, opportunities and threat of its consumption require scientific scrutiny. This study investigates electricity-led growth hypothesis vis-à-vis its impact on economic growth and environmental quality of Turkey. The annual time series data set from 1970 to 2014 were employed in the analysis with a battery of unit root and stationary tests. The equilibrium relationship in the study is explored using Maki and Bayer-Hanck combined cointegration tests under multiple structural breaks along with the Pesaran's ARDL bounds test procedure for robust check. The study confirms the existence of cointegration relationship between electricity consumption, economic growth, capital, labour and ecological footprint. To detect the direction of causal relations, the VECM Granger causality test is employed. The causality analysis provides empirical evidence that supports the electricity-induced growth hypothesis in Turkey. This implies that embarking on conservative energy-efficient policies will slow down Turkey's economic growth. Thus, precautionary measures that ensure adequate policy on energy mix to guarantee availability and accessibility to modern electricity will sustain economic growth and improve environmental sustainability.

Keywords Energy conservation · Energy-efficient · Environmental pollution · Cointegration analysis · Turkey

Introduction

Following the seminal study on the US economy, the relationship between energy (electricity) consumption and economic growth has received much attention in the energy economics literature (Kraft and Kraft 1978). Subsequent studies include Owusu et al. (2016), Alola and Alola (2018), Emir and Bekun (2019), Sarkodie and Adams (2018), Akadiri et al. (2019), Bekun et al. (2019a, 2019b) and Shahbaz et al. (2019). However, the documented studies report divergent empirical findings, as no consensus has been reached on the nature of the relationship. According to the recent statistical report by the US Energy Information Administration (2018), there exists a strong correlation between national energy consumption and economic growth. There exists a positive trend between electricity (energy) consumption and economic growth (see

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Fig. 3 in the appendix). This position is further strengthened by the empirical findings of Mohiuddin et al. (2016).

The pertinent role of electricity consumption in the transformation of economies—whether developing, emerging or developed socioeconomic landscape—has been proven in the empirical literature. Electricity consumption is an integral part of a typical long-term economic growth process of global economies. Unfortunately, data from the global energy market reveal that the world currently experiences an energy shortage, given the global energy demand (Energy Information Administration 2018).

There exist a large body of theoretical studies on economic growth, bulk leverage on the well-known Solow growth model (SGM). The Solow growth model depicts a substantial level of labour and capital accumulation with the right level of technology known as the “Slow residual”, which explains economic growth. Though technological development is outside the scope of the Solow model, the endogenous growth model emphasizes the perspective of ensuring and enhancing economic growth. This is possible by maximizing profit using technological progress in making a sound investment decision that increases output overtime. Where deliberate efforts by the economic agents are targeted at market incentives through certain reactions, such tool or variable used is endogenous (Aghion and Howitt 2008). While the Solow growth model describes technology as physical capital, the endogenous model stresses the concept of learning by doing and human capital. This duo augments the marginal product of capital. This link shows the relationship between electricity consumption and economic growth. The influence of this relationship does have a spillover effect within and without an economy. Over the years, the conventional Solow growth model has been augmented with other variables like education, tourism, population and other demographic indicators (Soytas and Sari 2009).

Recently, ecological footprint has been introduced into models as a proxy for the environment (Dogan et al. 2019). This study includes ecological footprint, a composite variable, as a control variable in the econometric modelling to account for environmental quality. The motivation for the inclusion of ecological footprint follows several studies in the energy economics literature that utilized carbon dioxide emissions (CO_2) as a measure for environmental sustainability. Where there are high levels of CO_2 emissions, the environment suffers a negative impact from such action through pollution of all sorts. CO_2 is a proxy that enjoys massive recognition that cannot completely capture the quality of natural habitat. On the contrary, ecological footprint captures the quality of various natural ecosystem necessary to support the economy. The composite nature of ecological footprint motivates and justifies our rationale for using as a proxy variable for measuring the extent of environmental degradation. Few studies have used ecological footprint in the energy-environment and income nexus literature (Katircioglu et al. 2018; Ozturk et al. 2016). Hence, the inclusion of ecological footprint is expected to add value to the existing literature in the area where samples of electricity consumption and environmental proxies are involved. Contrary to previous attempts (Ghali and El-Sakka 2004; Soytas and Sari 2009; Solarin 2011), our study is the first to augment the electricity-led growth literature by incorporating capital and labour as a case study in Turkey.

Given the mentioned arguments, this study contributes to the existing literature by analysing the relationship between socioeconomic, energy and environmental outcomes for Turkey using multivariate modelling framework. We further augment for the first time the EKC hypothesis using capital, labour, electricity consumption and real output for Turkey with ecological footprint adopted as a proxy for environmental degradation in the energy economics literature. Using ecological footprint as a measure of environmental degradation is a much broader measure compared with CO_2 emissions. The ecological footprint incorporates among others, carbon footprint, water resources, marine ecosystem footprint, grazing holding capacity and forestry (Global Footprint Network 2018). All these are unit of various natural areas needed to support an economy. Thus, the use of ecological footprint is a useful indicator to measure environmental quality. The incorporation of several important inputs ensures that the problem of omitted variable bias is controlled, given the level of connectedness among the variables (see Kayhan et al. 2010; Tamba et al. 2017). The policy implication of this individual-country-based study comes with high research value as opposed to panel-based studies across countries. We reexamine the SGM with the integration of energy consumption as a key driver of economic growth in Turkey. This, in essence, improves the existing bulk of studies on the theme under consideration by extending the scope towards an interesting environmental dimension which is lacking in previous studies. Our methodological innovation through the adoption of up-to-date econometric procedures enhances the precision of estimates derived. Previously conducted studies on the Turkish economy mostly suffer from specification bias given their bivariate nature (see Aslan (2014) and Nazlioglu et al. (2014)). As such, we fear that estimates and policy recommendations emanating from such studies are unreliable.

Review of literature

The pioneering work on the nexus between GNP and income (Kraft and Kraft 1978) has birthed many other studies in the energy economics literature such as Cowan et al. (2014), Farhani et al. (2014), Salahuddin et al. (2015) and Bento and Moutinho (2016). Other examples include the study of Ozturk and Acaravci (2011) on 11 countries in the Middle East and North Africa (MENA) region. The authors investigated the electricity consumption-economic growth relationship using the autoregressive distributed lag (ARDL) model for the period 1971–2006. Their findings provided no evidence in support of a significant relationship. A similar study conducted with the aid of the vector autoregressive method on the Ghanaian economy by Twerefou et al. (2007) found that economic growth Granger causes the consumption of both electricity and petroleum products.

In literature, the relationship that exists between electricity consumption and economic output is classified into four categories, namely feedback, growth, conservative and neutrality hypotheses. The feedback hypothesis underlines a mutual response between electricity consumption and economic growth. This is identified through a bidirectional causal relationship (Lee et al. 2008; Tang and Tan 2013). The growth hypothesis posits that there is a positive monotonic relationship between electricity consumption and economic growth. This scenario suggests that electricity consumption drives economic growth (see Ghali and El-Sakka 2004; Damette and Seghir 2013). The conservative hypothesis assumes a unidirectional causality from economic growth to electricity consumption. This hypothesis suggests that shuffling of energy policies translate into little or no positive growth effects (Jamil and Ahmad 2010; Baranzini et al. 2013). The neutrality hypothesis postulates no causal interactions between economic growth and electricity consumption. This implies that economic growth is not dependent on either expansionary or conservative energy policies, particularly those targeted at electricity consumption, as they will have no significant impact on economic output (Soytas and Sari 2006; Halicioglu 2009).

It is important to note that there is no unanimity in the electricity consumption-economic output nexus literature as contradictory results have been reported overtime for an array of countries. For instance, Yang (2000), Jumbe (2004), Yoo (2005), Asumadu-Sarkodie & Owusu (2016), Tang (2008), Odhiambo (2009), Sami (2011) and Shahbaz et al. (2011) report feedback causality between electricity consumption and economic growth. Studies by Chang et al. (2001), Shiu and Lam (2004), Altinay and Karagol (2005), Böhm (2008), Akinlo (2009) and Dlamini et al. (2015) represent instances where causality runs from electricity consumption to economic growth. Ghosh (2002), Narayan and Smyth (2005), Yoo and Kim (2006), Halicioglu (2007), Jamil and Ahmad (2010), Adebola et al. (2011) and Cowan et al. (2014) instead detect causal relations from economic growth to electricity consumption. No causal relationship between electricity consumption and economic growth has been reported by Soytas and Sari (2003), Payne (2009), Balcilar et al. (2010) and Akpan and Akpan (2012). For instance, in the recent study conducted by Balcilar et al. (2019) that explored the energy growth and environment nexus for the case of Turkey via the adoption of Maki cointegration technique for equilibrium relationship among the interest variables, the study found empirical support for the conservative hypothesis. Thus, informing policymakers that embarking on energy conservative policy does not have a deteriorating impact on the Pakistan economy. Conversely, the study of Bekun and Agboola (2019) joins the strands of studies that support the energy (electricity)-led growth hypothesis in Nigeria. This position is strengthened by the study of Samu et al. (2019), for the case of Zimbabwe with an energy-dependent economy. Thus, measure(s) to apply and implement energy conservative approach will hurt such economy. This is insightful and informative to policymakers for proper and decisive policy formulation and implementation. A detailed summary of studies on the theme over the last couple of decades is presented in Table 1.

Methodological construct

Data

This study explores the long-run and short-run relationship between energy consumption in our case, electricity consumption and economic growth (RGDP), capital (K) and labour (L) for the case of Turkey. The data for electricity consumption and real economic output were retrieved from the World Bank database[1] while data for ecological footprint measured in global hectares (gha) were retrieved from Global Footprint Network.[2] The annual data used for the econometric analysis spans 1961–2014. The data description, units of measurements and sources are presented in Table 2. The variables include ecological footprint (EFP) as a proxy for environmental quality, real gross domestic product (RGDP) measured in constant 2010 USD and electricity consumption measured in kWh/h per capita. Likewise, capital is measured with gross fixed capital formation constant 2010$. Labour is a measure of the total labour force. This study is distinct from previous studies in terms of choice of data selection. The motivation for the data choice is drawn from United Nations sustainable development goals (UNSDG 7, 8, 9 and 13). Goal 7 outlines the pivotal role of access energy use to sustainable economic growth. The contribution of goal 8 is informed by improved labour productivity and access to financial services (SDG 8). The advancement in labour/gross capital formation alongside labour productivity and manufacturing output relies on investment, which in turn build infrastructure and by extension spur industrial share of economic development (SDG 9). The quest to mitigate the menace of global warming triggered by greenhouse gas emissions (CO_2) motivates the efficient use of energy sources and its related services (SDG13).

[1] Available at https://data.worldbank.org/

[2] Available at https://www.footprintnetwork.org/our-work/ecological-footprint/. Note: The data span for this study spans from 1990 to 2014 informed based on data availability especially the proxy for labour from the WDI indicators.

Table 1 Summary of electricity consumption and economic growth nexus literature

Author(s)	Time	Study area	Method	Causality direction	Hypothesis
Ghosh (2002)	1950–1997	India	Engle-Granger Causality test	Y ⇒ EC	Conservative
Sarwar et al. (2017)	1960–2014	210 countries	PECM Granger causality test	EC ⇔ Y, OP ⇔ Y, GFCF ⇔ Y	Feedback
Narayan and Smyth (2005)	1966–1999	Australia	Cointegration Granger Causality Test	Y⇒ EC, E ⇒ EC	Conservative
Dlamini et al. (2015)	1971–2009	South Africa	Bootstrap rolling- window Approach	EC ⇒ Y for two sub-periods	Growth
Altinay and Karagol (2005)	1950–2000	Turkey	Dolado and Lütkepohl (1996) Causality Test	EC ⇒ Y	Growth
Cowan et al. (2014)	1990–2010	BRICS countries	Bootstrap panel causality test	EC ≠ Y, EC ≠ CO2, CO2 ⇒ Y for Brazil; EC ⇔ Y, Y⇒ EC, EC ≠ CO2, EC ⇎ CO2 and CO2 ≠ Y for Russia; EC ≠ Y, EC ⇒ CO2 and CO2 ≠ Y for India; EC ≠ Y, EC ≠ CO2 and CO2 ≠ Y for China; and Y ⇒ CO2 for South Africa	Neutrality and growth
Mozumder and Marathe (2007)	1971–1999	Bangladesh	Johansen Cointegration Test and Granger Causality Test based on VECM	Y ⇒ EC	Conservative
Nazlioglu et al. (2014)	1967–2007	Turkey	ARDL model, linear and non-linear Granger causality test	EC ⇔ Y for linear causality test, no non-linear causality between EC and Y	Growth
Samu et al. 2019	1971–2014	Zimbabwe	Zivot-Andrews, Maki Cointegration test, Toda-Yamamoto causality test	EC ⇒ Y	Growth
Narayan and Smyth (2009)	1974–2002	Middle Eastern Countries	Bootstrap Causality Approach	EC ⇔ Y	Feedback
Solarin and Shahbaz (2013)	1971–2009	Angola	ARDL bounds test and the VECM Granger causality test	EC ⇔ Y, U⇔ EC for the short run; EC ⇔ Y, U ⇒ Y and U ⇒ EC for the long run	Feedback, growth, conservative
Balcilar et al. (2010)	1960–2006	G-7 countries	Bootstrap Granger non-causality test	EC ⇒ GDP for only Canada, there is no causal links between energy consumption and economic growth for the other countries	Growth, Neutrality
Akpan and Akpan (2012)	1970–2008	Nigeria	Multivariate VECM	Y ⇒ CE, EC ≠ Y	Conservative and neutrality
Shahbaz et al. (2011)	1971–2009	Portugal	VECM Granger causality test	Y ⇒ EC, EC ⇔ E and E⇔ Y for the short run; Y⇔ EC, E⇔ EC and Y⇔ E for the long run	Conservative, feedback, feedback, feedback and feedback
Shahbaz and Lean (2012)	1972–2009	Pakistan	ARDL model and Granger causality tests	EC ⇔ Y	Feedback
Shahbaz and Feridun (2012)	1971–2008	Pakistan	ARDL bounds test	Y⇒ EC	Conservative
Soytas and Sari (2003)	1965–1994	Poland	Cointegration and error correction model	Y ≠ EC	Neutrality
Mutascu et al. (2011)	1980–2008	Romania	Bound test (Toda Yamamoto)	EC ⇔ Y	Feedback
Chontanawat et al. (2006)	1971–2000	Czech Republic	Granger causality	EC ⇒ Y	Growth
Narayan and Prasad (2008)	1960 –2002	Hungary	Granger causality	Y ⇒ EC	Conservative
Ozturk and Acaravci (2009)	1990–2006	European and Eurasian countries	Pedroni cointegration	EC ≠ Y	Neutrality

Table 1 (continued)

Author(s)	Time	Study area	Method	Causality direction	Hypothesis
Erdal et al. (2008)	1970–2006	Turkey	Johansen cointegration and Granger causality	EC ⇔ Y	Feedback
Halicioglu (2007)	1968–2005	Turkey	ARDL, Granger causality	Y ⇒ EC	Conservative
Böhm (2008)	1960–2002	Slovak Republic	Granger causality	EC ⇒ Y	Growth
Yoo (2005)	1971–2002	Indonesia, Thailand, Malaysia and Singapore	Engle-Granger; Granger causality; Johansen-Juselius and Hsiao's causality-VAR	Y ⇒ EC, Y ⇒ EC, EC ⇔ Y, EC ⇔ Y	Conservative, feedback

The symbols "⇒, ⇔, ≠" indicate unidirectional, bidirectional causality and neutrality hypothesis, respectively. Where EC is electricity consumption, FD is financial development, U is urbanization, E is employment and EI is energy intensity

The empirical route of this study follows after a brief descriptive statistics comprising of mean, standard deviation, maximum, minimum and correlation analysis. The path proceeds in four steps: (a) investigation of unit root test properties via conventional unit root test of augmented Dickey Fuller (ADF), Philips Perron (PP), Elliott, Rothenberg & Stock (ERS), Dickey-Fuller generalized least squares (DF-GLS) and stationarity test of Kwiatkowski, Phillips, Schmidt & Shin, (KPSS 1992). In the case of a possible structural break, the Clemente-Montanes-Reyes structural break detrend test and Zivot-Andrews (ZA) are utilized to know the asymptotic properties of the investigated series, to ascertain the maximum order of integration and avoid the error of working with variables integrated with ~I(2) as outlined by Moutinho et al. (2018). (b) Examining the long-run equilibrium (cointegration) properties of the variables under review with estimators that accommodate for possible structural breaks. (c) The exploration of the long-run magnitude in terms of coefficients among the investigated variables. (d) Finally, the detection of direction of causality among the series via the VECM Granger causality test approach. The vector error correction (VECM) model approach is the most appropriate technique when there exists a long-run equilibrium relationship among variables that are integrated of I(1). The essence of VECM Granger is to check the predictive power between the variables to help craft effective policies.

Model specification

The neoclassical aggregate production model proposed by Ghali and El-Sakka (2004) provides the foundation for examining the relationship between electricity consumption and economic growth. This model treats capital, labour and electricity (used as a proxy for energy) as separate inputs in the production process. This model can be expressed as:

$$RGDP = f(K, L, EU, EFP) \tag{1}$$

To achieve homoscedasticity in the underlying data series, a logarithm transformation of Eq. (1) is carried out.

$$lnRGDP = \delta + \beta_1 lnK + \beta_2 lnL + \beta_3 lnEU + lnEFP + \varepsilon_t \tag{2}$$

A carbon-income function is formulated to investigate the trade-off between economic growth and environmental degradation a phenomenon well known in the energy literature as the environmental Kuznets curve (EKC) hypothesis (Tiwari et al. 2013), presented as:

$$lnEFP = \delta + \beta_1 lnK + \beta_2 lnL + \beta_3 lnEU + \beta_4 lnGDP + \beta_5 lnGDP^2 + \varepsilon_t \tag{3}$$

where δ represents constants, and β_1, β_2, β_3, β_4 & β_5 are partial slope parameters. K denotes capital; this represents the capital stock in the production process; L denotes labour which represents the level of employment in the production process; EC represents the total consumption of electricity, and RGDP denotes real gross domestic product which represents the aggregate output of gross domestic product. The constant parameter δ and the partial slope coefficients βs, used in the model, measure the marginal effect of capital and electricity on the output. In the production function earlier stated that posit long-run movement of variables may be connected (Ghali and El-Sakka 2004). In addition, to account for the short-run dynamics in the factor-input behaviour, the functional specification in Eq. (2) suggests that past behavioural changes in variables (capital, labour and electricity) can be useful in predicting future changes of output (Lorde et al. 2010). In a simple term, causality can be used to investigate the relationship between the variables. The present study draws strength following the studies of Ghali and El-Sakka, (2004), Solarin (2011), Saidi and Hammami (2015), Galli et al. (2012), Dlamini et al. (2015), Mutascu (2016), Bimonte and Stabile (2017), Sarwar et al. (2017), Amri (2017), Destek et al. (2018), and Akadiri et al. (2020).

Stationarity test

Testing for stationarity among variables in time series analyses is required for establishing the order of integration of the variables. This is essential for the avoidance of spurious regression. In econometrics literature, several tests such as the augmented Dickey and Fuller (1981), Phillips and Perron (1988) and Elliott et al. (1992) tests can be applied to determine the order of integration of variables. However, these conventional unit root tests are unable to account for the structural break(s) and are thus prone to producing invalid and inconsistent estimates when structural break(s) exist in the data series. Most macro-economic datasets are characterized by economic occurrences, which cause structural breaks. Hence, this study balances with structural break unit root tests with Clemente et al. (1998) and Zivot and Andrews (1992) unit root tests which are known generally for capturing structural breaks.

Zivot-Andrews test models are computed as stated below:

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \gamma DU_t + \sum_{i=0}^{r} \Phi_i \Delta Y_{t-i} + \varepsilon_t \quad (4)$$

$$\Delta Y_t = \beta_1 + \beta_2 t + \lambda Y_{t-1} + \phi DT_t + \sum_{i=0}^{r} \Phi_i \Delta Y_{t-i} + \varepsilon_t \quad (5)$$

$$\Delta Y_t = \beta_1 + \beta_2 t + \lambda Y_{t-1} + \gamma DU_t + \phi DT_t + \sum_{i=0}^{r} \Phi_i \Delta Y_{t-i} + \varepsilon_t \quad (6)$$

There is a shift that occurs at each point of likely breaks at both intercept and trend or either one of them as shown by the dummy variable DU. In the Zivot-Andrews unit root test, a null hypothesis of unit root $H_0: \theta > 0$ is tested against an alternative of stationarity $H_1: \theta < 0$. This implies that failure to reject H_0 indicates the presence of unit roots, while rejection confirms stationarity.

Procedures for measuring cointegration relationships

There are numerous procedures documented in econometrics literature for testing cointegration relationship among data series. The long-run relationship is said to exist between two series if there is some sort of linear stationary combination among them (Engle and Granger 1987; Johansen and Juselius 1990; Phillips and Ouliaris 1990; Johansen 1991; Gregory and Hansen 1996; Carrion-i-Silvestre and Sansó 2006). However, all the abovementioned cointegration tests render diverse conclusions of cointegration and non-cointegration null hypotheses. More robust results can be obtained by exploring the individual test statistics of Engle and Granger (1987), Johansen (1991), Boswijk (1995) and Banerjee et al. (1998) as recently advanced by Bayer and Hanck (2013).

$$EG\text{–}JOH = -2[\log(P_{rob.EG}) + (P_{rob.JOH})] \quad (7)$$

$$EG\text{–}JOH\text{–}BO\text{–}BDM = -2[\log((P_{rob.EG}) + (P_{rob.JOH}) + (P_{rob.BO}) + (P_{rob.BDM}))] \quad (8)$$

where $P_{rob.\ EG}$, $P_{rob.\ JOH}$, $P_{rob.\ BO}$ *and* $P_{rob.\ BDM}$ are the individual probabilities of each of the test.

Table 2 Description of data and unit of measurement

Series name	Unit of measurement	Source
Real gross domestic product (RGDP)	Constant 2010 $ USD	WDI
Electricity consumption (EC)	kW/h per capita	WDI
Labour (L)	Labour force total	WDI
Capital (K)	Constant 2010 $ USD	WDI
Ecological footprint (EFP)	The global hectare of land	GFP

ARDL approach

The ARDL bounds testing technique which guarantees more efficiency and robustness, especially in small sample size, is used to test for cointegration among electricity consumption, economic output and ecological footprint (EFP). The merit of this technique is the possibility of both long- and short-run dynamics of the fitted regression with error correction model being reported at the same time as well as determining the case of an unknown order of integration of series as long as the series is I(0) and I(1), certainly not I(2). The unrestricted version of the error correction model is specified, and it assumes that all variables are endogenous.

$$\Delta Y = \delta_0 + \delta_1 t + \beta_1 y_{t-1} + \sum_{k=1}^{z} \gamma_1 v_{kt-1} + \sum_{n=1}^{X} \varphi_n \Delta Y_{t-n} + \sum_{k=1}^{Z} \sum_{n=1}^{X} \mu_{kn} \Delta V_{kt-n} + \theta D_t + \varepsilon_t \quad (9)$$

D_t is an exogenous variable which accommodates structural breaks in the framework, while V_k represents the vector. F statistics computed from the bounds test is used to validate the null hypothesis when there is no cointegration. Three different scenarios exist in making this decision: first, the rejection of the null of no cointegration where the F-statistic computed is greater than the upper bounds of the critical values reported. Second, an inconclusive cointegration where the F-statistic lies within both lower and upper bounds. Third, a case of no cointegration where the F-statistic is below the upper bound critical value. The specification of the hypotheses for bounds test is expressed as:

$$H_0 : \beta_1 = \beta_2 = \ldots = \beta_{k+2} = 0 \quad (10)$$

$$H_1 : \beta_1 \neq \beta_2 \neq \ldots \neq \beta_{k+2} \neq 0 \quad (11)$$

Cointegration estimation techniques

The need to investigate the magnitude of long-run associations among variables is essential in time series estimation. The most widely known long-run estimators include the fully modified ordinary least squares (FMOLS) advanced by Phillips and Hansen (1990), the dynamic ordinary least squares (DOLS) proposed by Stock and Watson (1993) and the canonical cointegration regression of Park (1992). These are useful methods that provide robust cointegrated regression estimates in cases where long-run relationships exist. They are particularly efficient in small sample sizes.

FMOLS

The FMOLS method of cointegration estimation is distinct in its ability to provide optimal cointegrating regression estimates among series integrated of order one (Phillips and Hansen 1990; Phillips 1995; Pedroni 2001a, b). The approach also addresses the problem of endogeneity and autocorrelation without compromising the robustness of the estimates.

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t} \quad \forall_t = 1, \ldots, T, \quad i = 1, \ldots ..N \quad (12)$$

Allowing for $Y_{i,\ t}$ and $X_{i,\ t}$ are cointegrated with slopes β_i, where β_i may or may not be homogeneous across i. Hence, the equation becomes:

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \sum_{k=-K_i}^{K_i} \gamma_{i,k} \Delta X_{i,t-k} + \varepsilon_{i,t} \quad \forall t = 1, 2, \ldots, T, \quad i = 1, \ldots..N \quad (13)$$

We reflect $\xi_{i,t} = \left(\widehat{\varepsilon}_{i,t}, \Delta X_{i,t}\right)$ and $\Omega_{i,t} = lim_{T \to \infty} E \left[\frac{1}{T}\left(\sum_{i=1}^{T} \xi_{i,t}\right)\left(\sum_{i=1}^{T} \xi_{i,t}\right)\right]$ as the long covariance. Here, $\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i^{'}$; The simultaneous covariance is depicted as Ω_i^0 while the weighted sum of autocovariance is Γ_i. Thus, the equation of the FMOLS is rendered as:

$$\widehat{\beta}^*_{\mathrm{FMOLS}} = \frac{1}{N} \sum_{i=1}^{N} \left[\left(\sum_{i=1}^{T} \left(X_{i,t} - \overline{X}_i \right)^2 \right)^{-1} \left(\sum_{i=1}^{T} \left(X_{i,t} - \overline{X}_i \right) Y^*_{i,t} - T_{\widehat{\gamma}_i} \right) \right] \quad (14)$$

where

$$Y^*_{i,t} = Y^*_{i,t} - \overline{Y}_i - \frac{\widehat{\Omega}_{2,1,i}}{\widehat{\Omega}_{2,2,i}} \Delta X_{i,t} \text{ and } \widehat{\gamma_i} = \widehat{\Gamma}_{2,1,i} + \widehat{\Omega}^0_{2,1,i} - \frac{\widehat{\Omega}_{2,1,i}}{\widehat{\Omega}_{2,2,i}} \left(\widehat{\Gamma}_{2,2,i} + \widehat{\Omega}^0_{2,2,i} \right) \quad (15)$$

DOLS

The DOLS technique is an alternative long-run equation estimator. It is known to possess merits over FMOLS, and the unique feature of DOLS being an efficient estimator asymptotically and also the ability to eliminate feedback in the cointegrating system, DOLS can be substituted for FMOLS as advanced by Saikkonen (1991) and Stock and Watson (1993). The estimation process of DOLS has lags and leads in the cointegration regression.

$$Y_t = \alpha_i + \beta X'_t + D'_{1t} D' \gamma_1 \sum_{j=-q}^{r} \Delta X'_{t+j} \rho + v_{1,t} \quad (16)$$

From the above equation, the differenced explanatory variables with lag and lead of q and r accordingly absorb all the long-run relationship between $v_{1,\ t}$ and $v_{2,\ t}$ while the least-square estimates of $\theta = (\beta', \gamma')'$ harbour asymptotic distribution parallel to CCR and FMOLS.

CCR

The OLS estimator has a shortfall when transforming variables in their second-order. Hence, the CCR technique is exceptional in avoiding the bias of the second-order. The covariance matrix form of the CCR is expressed as follows:

$$\Omega = \lim_{n\to\infty} \mathrm{E}\sum_{t=1}^{n}(u_t)\sum_{t=1}^{n}(u_t)' = \begin{bmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{bmatrix} \tag{17}$$

From the above expression, Ω can be:

$$\Omega = \sum + \Gamma + \Gamma' \tag{18}$$

and

$$\sum = \lim_{n\to\infty} \mathrm{E}\sum_{t=1}^{n}(u_t u'_t) \tag{19}$$

$$\Gamma = \lim_{n\to\frac{1}{n}} \mathrm{E}\sum_{k=1}^{n-1}\sum_{t=k+1}^{n} \mathrm{E}(u_t u'_{t-k}) \tag{20}$$

$$\cap = \sum + \Gamma = (\cap_1, \cap_2) = \begin{bmatrix} \cap_{11} & \cap_{12} \\ \cap_{21} & \cap_{22} \end{bmatrix} \tag{21}$$

The series transformed obtained from above is given as:

$$Y^*_{1t} = Y_{2t} - \sum^{-1}(\cap_2)' \ u_t \tag{22}$$

$$Y^*_{2t} = Y_{2t} - \sum^{-1}(\cap_2)' \ u_t \tag{23}$$

$$Y^*_{1t} = Y_{1t} - \left(\sum^{-1}\left(\cap_2 \beta + \left(0, \Omega_{12}, \Omega_{22}^{-1}\right)'\right)'u_t\right. \tag{24}$$

From the above, the long run estimator will acquire the following form:

$$Y^*_{1t} = \beta' + Y^*_{2t} + u^*_{1t} \tag{25}$$

From the outlined equation, the OLS estimators share the same style as the ML estimation. The asymptotic endogeneity caused by the long-run correlation between $y_{1,\ t}$ and $y_{2,\ t}$ was avoided by the transformation of the variables. The asymptotic bias due to cross-correlation between u1t and u2t is resolved with the transformation of the variables expressed as:

$$Y^*_{1t} = u_{1t} - \Omega_{12}, \Omega_{22}^{-1} u_{2t} \tag{26}$$

Granger causality approach

Causality test is required to determine the direction of causality between variables as traditional regression does not necessarily imply causal relationships. This is necessary to provide policymakers and stakeholders clear insight into predictability powers that exist between variables. The expression X_t Granger causes Y_t implies that X_t (in its entirety, i.e., its present and past realizations) is a good predictor

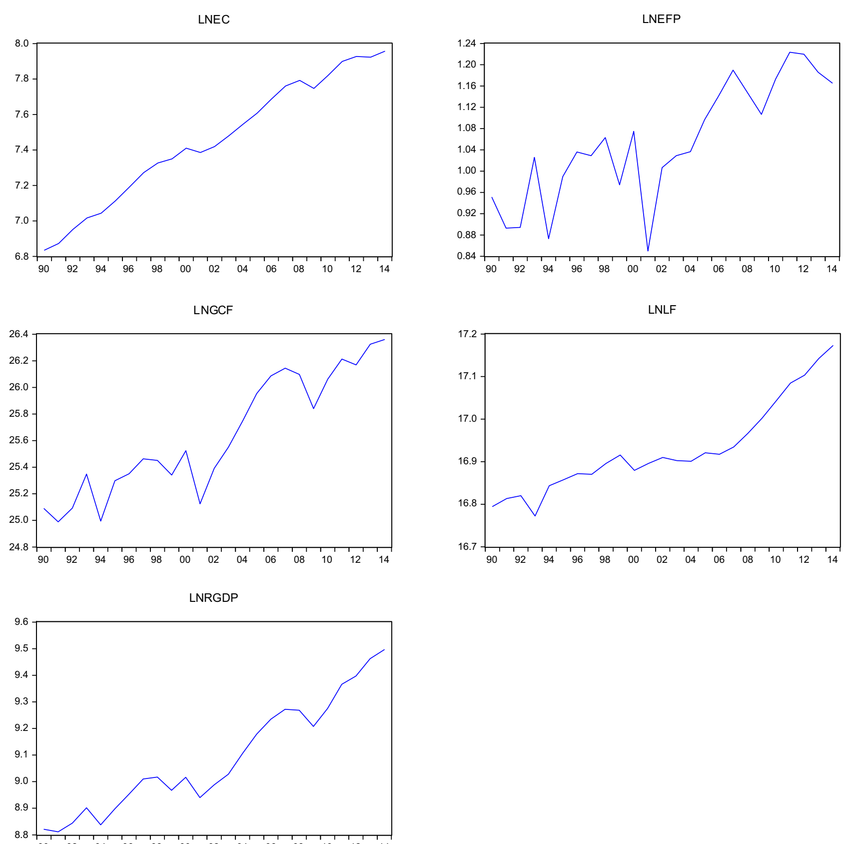

Fig. 1 Trend plot of the sampled variables (1990–2014)

of Y_t. Granger causality test in a bivariate form is specified as:

$$X_t = \delta_0 + \delta_1 X_{t-1} + \delta_2 Y_{t-1} + \varepsilon_t \tag{27}$$

$$Y_t = \delta_0 + \delta_1 Y_{t-1} + \delta_2 X_{t-1} + \varepsilon_t \tag{28}$$

The null hypothesis that X_t does not Granger cause Y_t is tested against the alternative hypothesis that X_t Granger causes Y_t. Granger causality relationships can take the following forms: (1) unidirectional (implying either from X_t to Y_t or otherwise), (2) bidirectional (meaning feedback relationship from X_t to Y_t and Y_t to X_t) and (3) neutrality (this means that there is no causal interaction between the variables X_t and Y_t).

The VECM Granger causality approach

The need for causality is crucial because of the directional causality flow and insight for policy and decision-makers. The VECM approach is the most appropriate technique when there exists a long-run equilibrium relationship among variables that are I(1). The empirical construction of VECM Granger causality is rendered as:

$$(1-L)\begin{bmatrix} LnY_t \\ LnK_t \\ LnL_t \\ LnEC_t \\ LnEFP_t \end{bmatrix} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \end{bmatrix} + \sum_{i=1}^{p}(1-L)\begin{bmatrix} \beta_{11i}\beta_{12i}\beta_{13i}\beta_{14i}\beta_{15i} \\ \beta_{21i}\beta_{22i}\beta_{23i}\beta_{24i}\beta_{25i} \\ \beta_{31i}\beta_{32i}\beta_{33i}\beta_{34i}\beta_{35i} \\ \beta_{41i}\beta_{42i}\beta_{43i}\beta_{44i}\beta_{45i} \\ \beta_{51i}\beta_{52i}\beta_{53i}\beta_{54i}\beta_{55i} \end{bmatrix} \tag{29}$$
$$\times \begin{bmatrix} LnY_{t-1} \\ LnK_{t-1} \\ LnL_{t-1} \\ LnEU_{t-1} \\ LnEFP_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \varepsilon_{t1} \\ \varepsilon_{t2} \\ \varepsilon_{t3} \\ \varepsilon_{t4} \\ \varepsilon_{t5} \end{bmatrix}$$

where $(1-L)$ represents the difference operator, and ECT_{t-1} is lagged error correction term. ε_{it} is the stochastic term (disturbance term) which is required to be IID~N(0,) meaning that disturbance term is independently identically normally distributed with constant variance and zero mean. T statistic indicates a long-run causal relationship between the variables.

Results and discussion

A graphical representation showing the behaviour of the dataset used in the time series estimations is depicted in Fig. 1. The possibility of a structural break is evident in Fig. 1, informing our decision to account for structural breaks in the estimation process. The descriptive statistics that renders the basic summary statistics like mean, median, standard deviation, data distribution (reported by Kurtosis and Jargue Bera) and correlation coefficients matrix are presented in Table 3. The Jarque Bera test statistic in Table 3 reports that all the variables are normally distributed (p value > 0.05). Though there is a huge difference between the minimum and maximum values for the period investigated, this suggests a need for further tests. The correlation analysis reports a positive and statistically significant relationship between electricity consumption and the economic output (GDP). The ecological footprint has a positive interaction with economic growth. The association established between the variables cannot be statistically inferred, hence, requires subsequent econometric estimation for statistical inferences.

This study proceeds to investigate the stationarity properties of the investigated variables using a battery of unit root and stationarity test. This is necessary to ascertain the accuracy of the estimates, thereby providing the needful policy insights. The results of the stationary/unit root test are reported in Tables 4 and 5. Precisely the ADF and PP, results are in harmony of variables integrated of order one. Although, the ERS unit root test renders mixed results, thus the need to investigate the variables using the KPSS stationarity test. The KPSS with reverse null hypothesis supports the integration of order 1. The consensus of the results declares that the variables are integrated of order one, ~I(1). Subsequently, the Zivot and Andrews (1992) and the Clemente-Montanes-Reyes structural break detrend unit root test results with simple structural break dates are reported in Table 5. The results of the break test of ZA and Clemente-Montanes-Reyes structural break detrend unit root test results corroborate the integration status of the variables. These identified break dates correspond with significant economic and political events in Turkish history.

The maximum lag length selection criteria are presented in Table 6. These selection criteria offer the opportunity for a parsimonious model to be chosen. From Table 6, the most appropriate criteria for selection are Akaike information criteria (AIC) which can accommodate sample size and suitable for the nature and structure of this study (Lütkepohl 2006).

The next step is the establishment of long-run equilibrium relationship (cointegration) via a battery of cointegration techniques, namely Bayer and Hanck (2013) combined cointegration in conjunction with Pesaran ARDL bounds test and Maki (2012) cointegration test. All aforementioned cointegration tests are in the consensus of a cointegration relationship between electricity consumption, economic growth ecological footprint, capital and labour over the investigated period. This implies that there is some sort of convergence among the variables. The use of Maki cointegration test is to capture the possible structural break given the robustness of the test to accommodate up to 5 structural breaks.[3]

The Bayer & Hanck cointegration test results are reported in Table 7, confirming the presence of an equilibrium

[3] More details regarding Maki cointegration test can be provided upon request, although the test is reported in the appendix section. The results are in harmony as ARDL bounds test and the Bayer and Hanck cointegration results.

Table 3 Descriptive statistics and correlation analysis

	lnEC	lnEFP	lnK	lnL	lnRGDP
Mean	7.453377	1.055078	25.64037	16.92926	9.091968
Median	7.419034	1.036616	25.52474	16.90245	9.017334
Maximum	7.956675	1.223487	26.35993	17.17263	9.496455
Minimum	6.834862	0.84991	24.9895	16.77223	8.81122
Std. dev.	0.353451	0.110373	0.448173	0.10668	0.209281
Skewness	−0.18471	−0.20913	0.139954	0.848321	0.416491
Kurtosis	1.842195	2.067187	1.627793	2.895078	1.977383
Jarque-Bera	1.538529	1.088619	2.043021	3.010006	1.812087
Probability	0.463354	0.580242	0.360051	0.222017	0.40412
Sum	186.3344	26.37695	641.0093	423.2314	227.2992
Sum sq. dev.	2.998264	0.292373	4.820608	0.273135	1.051169
Correlation matrix analysis					
lnEC	1.0000				
t stat	-				
Prob	-				
lnEFP	0.8620***	1.0000			
t stat	8.1555	-			
Prob	0.0000	-			
lnK	0.9436***	0.9464***	1.0000		
t stat	13.6738	14.0525	-		
Prob	0.0000	0.0000	-		
lnL	0.9000***	0.7657***	0.8506***	1.0000	
t stat	9.9023	5.7103	7.7602	-	
Prob	0.0000	0.0000	0.0000	-	
lnRGDP	0.9614***	0.9067***	0.9803***	0.9299***	1.0000
t stat	16.7740	10.3099	23.8128	12.1323	-
Prob	0.0000	0.0000	0.0000	0.0000	-

Source: computation by Authors

***, ** and * indicate 1%, 5% and 10% statistical significance level, respectively

relationship among the series investigated (p value < 0.01), thus inferring a long-run bond between the outlined variables. For precision and robustness check, an ARDL bounds test is conducted to validate the results of the Bayer and Hanck as documented in the appendix section.

Table 8 presents the ARDL long- and short-run results which affirm the long-run equilibrium relationship for all the estimated models. This implies that there is convergence among the variables (RGDP, EFP, K, L and EC). The validation of the long-run relationship is evident in the rejection of the null hypothesis. Table 8 reveals a very high speed of adjustment of over 70% with the contribution of the regressors. Both capital and labour contribute to economic growth and environmental degradation in both short- and long-run. More precisely, a 1% increase in K stimulates GDP and EFP at ~ 0.34% and ~ 0.41%, respectively, both in short- and long-run. This outcome is indicative of policymakers, as capital and labour accumulation are the key drivers of growth in Turkey. This finding is in line with the Solow growth model and Soytas and Sari (2009). Energy (electricity) consumption increases environmental degradation and economic growth, meaning that Turkey's economy is energy-dependent. A 1% increase in EC stimulates EFP at ~ 0.34% both in short- and long-run, whereas GDP at 0.38% increases and 0.06% decreases in short- and long-run, respectively. These results corroborate with others in the literature such as Farhani and Ozturk (2015) and Al-Mulali et al. (2015a, b). This is in line with the electricity-led growth hypothesis; thus, caution is advised in the adoption of conservative energy policy measures in order not to jeopardize economic growth. As such, any action on the path to apply energy cut will harm economic growth. This is consistent with the study conducted for Zimbabwe by Samu et al. (2019). However, energy (electricity) consumption in the long-run has a negative statistical impact ($p < 0.10$) on economic growth. This is insightful for decision-makers that in the long-run intensification of energy will harm economic growth. This is further reinforced by the outcome of environmental degradation on economic growth. We observe a trade-off between economic growth and environmental quality. This phenomenon re-echoes the

Table 4 Unit root tests

Variables	ADF	PP	ERS	DF-GLS	KPSS	ZA
lnEC	− 1.8263	− 1.7198	15.3736***	− 2.8079	2.1308**	− 3.6691 (1) [2001]
ΔlnEC	− 4.2171***	− 5.0137***	3.4264	− 4.4515***	3.1399	− 4.9266* (1) [2004]
lnRGDP	− 2.0424	− 2.1196	13.9451***	− 2.1705	2.1457**	− 3.5459 (1) [2001]
ΔlnRGDP	− 4.8769***	− 4.8766***	7.4965***	− 5.0918***	0.0464	− 5.1214** (1) [2003]
lnEFP	− 2.6698	− 1.6979	7.5376***	− 4.7507***	3.0867**	− 5.8043*(1) [2001]
ΔlnEFP	− 4.6537***	− 10.2486***	11.3365***	− 8.7275***	0.0995	− 9.1528***(2) [2003]
lnK	− 3.3665	− 3.3605*	8.3731***	− 3.4625**	4.0832***	− 4.4499 (1) [2003]
ΔlnK	− 6.7221***	− 6.7671***	8.9450***	− 6.9434***	0.0780	− 7.2603**(1) [2003]
lnL	− 0.6452	− 0.3619	25.6038***	− 1.0496	3.1513**	− 3.8856 (1) [2001]
ΔlnL	− 5.7006***	− 5.7006***	8.0736***	− 5.8887***	0.1138	− 7.0600** (1) [2000]

***, ** and * indicate 1%, 5% and 10% statistical significance level respectively. [] break year while () denotes optimal lag length. All tests are conducted with a model of both intercept and trend orientation

environmental Kuznets curve (EKC) hypothesis. This indicates that Turkey's economy is yet to attain its environmental target. This implies a scale stage development as an emerging economy where economic growth has priority over environmental quality.

The fitted model in Table 8 further affirms the significant contribution of capital and labour stock to economic output in both the long and short run. The striking revelation of the model is the affirmation of the EKC hypothesis for Turkey both in the short run and in the long run. This is consistent, as a statistical positive sign for GDP and negative sign of squared GDP are observed. This implies an inverted U-shaped characteristic in the relationship between economic output and environmental quality. This unique shape explains that the environmental quality declines first as economic growth increases until a certain threshold of GDP, where environmental quality increases with increasing economic output (Saboori et al. 2012; Fodha and Zaghdoud 2010). From the initial economic growth stage (scale stage), there is little or no environmental consciousness in the course of increasing economic output; it is done at the expense of the environment; however, after a certain level of GDP, the environment is given a top priority while sustaining the economic output trajectory.

Table 5 Unit root with structural break using Clemente-Montanes-Reyes test

Variables	Innovative outliers†	Break†	Additive outlier†	Break†
lnEC	− 0.151	2002	− 2.216	2004
ΔlnEC	− 4.27**	2000	− 5.347**	1999
lnRGDP	− 1.541	2002	− 2.151	2007
ΔlnRGDP	− 5.25**	2000	− 4.33**	1999
lnEFP	− 4.508	2004	− 4.769	2003
ΔlnEFP	− 9.239**	2000	− 6.199**	1999
lnK	− 3.139	2002	− 3.518	2003
ΔlnK	− 7.283**	2000	− 4.805**	1999
lnL	− 1.469	2007	− 2.382	2009
ΔlnL	− 4.484**	2007	− 7.053**	2007

Source: Authors computation

***, ** and * indicate 1%, 5% and 10% statistical significance level, respectively

The estimation outcome in Table 9 shows a positive and statistical relationship between variables of interest (RGDP, EFP K, L and EC). That is, EFP and EC, K and L are positively related to the dependent variable (RGDP). The three cointegration techniques reveal positive and significant levels among the regressand and the chosen regressors. Empirically, our estimation validates the electricity-induced growth hypothesis, as there is a positive relationship between electricity consumption and economic growth in Turkey which is consistent with the result of ARDL results. This study reveals that a 1% increase in electricity consumption will result in a corresponding increase in economic output by ~ 0.36%, ~ 0.41% and ~ 0.37% for FMOLS, DOLS and CCR, respectively. Also taking a quick look at EFP, a negative and statistically significant relationship exists. This negative relationship that exists between EFP and economic growth is suggestive as well as informative to policy-makers and administrators, especially in the field of environment.

The model specification was subjected to diagnostic tests to validate the estimated models presented in Table 10. From the results, we fail to reject the null hypothesis that there is homoscedasticity, normality of disturbances, no autocorrelation and no functional form misspecification at 5% significance level. Thus, no evidence on heteroscedasticity, non-normality, autocorrelation and misspecification of the explanatory variables is observed in the model. This test validates the suitability of the model for policy construction.

Figure 2 reports the CUSUM and CUSUMSQ stability diagnostic test of the fitted model. The test shows that the fitted model is stable given that the blue line is within the 5% threshold boundaries. Thus, the fitted model is free from model misspecification issues and parsimonious for policy modelling.

Table 6 Lag criteria selection or maximum lag length selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	159.4791	NA	1.77E-12	− 12.87326	− 12.62783	− 12.80814
1	271.8332	168.5312*	1.28e-15*	− 20.15277*	− 18.68020*	− 19.76210*

Source: Authors computation

LR denotes sequential modified LR statistic, and FPE represents final prediction error. AIC stands for Akaike information criterion, while SIC means Schwarz information criterion and finally Hannan Quinn information for HQ

The VECM Granger causality test is adopted to detect the causality relationship among the variables under consideration as well as decompose the directions of the relationship into short and long run as reported in Table 11. The direction of their causality is important to ascertain suitable energy policies, environmental and economic policies to make an informed decision. We observe a short- and long-run relationship between capital, labour and economic growth. As observed in Table 11, bidirectional causality exists between capital, labour and economic growth. This implies that capital and labour are good predictors of economic growth and vice versa, supporting the SGM hypothesis. A one-way causality is observed running from electricity consumption to economic growth—corroborating the energy-induced growth hypothesis for Turkey. By implication, electricity consumption is essential for economic output (Böhm 2008). This is consistent with Samu et al. (2019) for the case of Zimbabwe where a recommendation of a diversified energy portfolio was reported. Cleaner and environmentally friendly energy technologies in the face of the global consciousness of climate change mitigation are essential in carbonized economies. This study supports the electricity consumption-induced economic growth hypothesis in Turkey—as causality is observed from electricity consumption to economic growth. Therefore, any attempt to implement a conservative energy policy jeopardizes economic growth.

We further observe a one-way causality flow for environmental degradation and income level (GDP). This is insightful as the quality of the environment is predestined by income level to a threshold before awareness creation. Although, over time measures are taken to improve conditions of production and maintain a cleaner environment by the adoption of friendlier renewable energy sources (Balsalobre-Lorente et al. 2018). Thus, there is a trade-off between economic development and environmental quality. Therefore, this study affirms the need for fossil fuel switching to renewable energy. This will diversify the energy mix, promote energy innovation and reduce the negative effects of energy consumption on environmental degradation (Owusu et al. 2016).

Conclusion

This study offers a new perspective on the electricity-led growth hypothesis in Turkey within a multivariate framework. Studies of this sort are necessary given the global demand for energy as an integral component of most economies. The role of electricity on the socioeconomic growth of most economies is well established in the energy economics literature—as energy consumption is a catalyst of most economic activities. This study adopted up-to-date econometric techniques that ensure reliable and robust estimates. We investigated the stationary properties and cointegration relationship between electricity consumption, economic growth and ecological footprint over the investigated period. We further examined the long-run bond among electricity consumption, capital and labour, real income level and ecological footprint over the sampled period.

We found strong evidence of long-run convergence between electricity consumption and environmental degradation that drives economic development in Turkey. However, carefulness should be exercised concerning the relationship between economic growth and ecological footprint as well as economic growth and conservative policies of electricity consumption. Our study underscores the need to ensure an increase in output through capital and labour contributions with energy consumption as key drivers to boost productivity while minimizing environmental degradation.

Contrary to previous attempts, our study augmented the neoclassical growth model with energy (electricity) consumption and environmental degradation. A key finding from this research is that electricity consumption is a key driver of the

Table 7 Bayer and Hanck cointegration results

Fitted model	EG-JOH	EG-JOH-BO-BDM	Cointegration remark
lnRGDP = *f*(lnk, lnL, lnEC, lnEFP)	70.464***	180.988	Yes
lnEFP = *f*(lnGDP, lnGDP^2, lnEC, lnK, lnL)	56.624***	167.148	Yes

Source: Authors computation

***, ** and * denote 1%, 5% and 10% statistical significance level, respectively

Table 8 ARDL long-run and short-run results

Model	RGDP = *f*(lnK, lnL, lnEC, lnEFP)			LNEFP = *f*(lnK, lnL, lnEC, lnRGDP, lnRGDP2)		
Variable	Coefficient	Std error	*t*-stat	Coefficient	Std error	*t*-stat
Short-run results						
ECT(− 1)	− 0.7275*	0.3284	−2.2151	− 0.7052*	0.1291	− 5.4638
ΔlnK	0.4245*	0.0964	4.4025	0.3499***	0.1893	1.8482
ΔlnL	0.4031*	0.1052	3.8298	0.6035*	0.2776	2.1737
ΔlnEC	0.3898**	0.1457	2.6746	0.3449**	0.1561	2.2088
ΔlnEFP	− 0.0659***	0.0306	− 2.1485			
ΔlnRGDPC				0.7144**	0.3357	2.1284
ΔlnRGDPC^2				− 0.8229**	0.3723	− 2.2102
Constant	− 17.8533*	3.7392	− 4.7746	11.1077*	4.4874	− 2.4743
Long-run results						
lnK	0.4191*	0.1386	3.0238	0.3466**	0.1732	2.0013
lnL	0.9928*	0.2093	4.7434	0.5978**	0.2964	2.0171
lnEC	− 0.0651**	0.0273	− 2.3806	0.3416**	0.1671	2.0442
lnEFP	− 0.3341***	0.1781	− 1.8767			
lnRGDPC				0.8376**	0.4005	2.0916
lnRGDPC^2				− 0.9132**	0.4229	− 2.1425
Constant	− 17.6247*	2.3077	− 7.6373	− 11.5773**	4.9669	− 2.3309

Source: Authors computation

*, ** and *** denote 1%, 5% and 10% statistical significance level, respectively

Turkish economy. As such, measures to embark on conservative policies will have a deteriorating impact on the economy. However, energy (electricity consumption) has environmental implication on economic growth over the investigated period. The piece of empirical evidence from the VECM Granger causality shows one-way causality from electricity consumption to economic output and from ecological footprint to economic growth. This electricity consumption induces both economic output and environmental degradation in Turkey. Hence, more electricity consumption leads to economic output while in contrast, worsens environmental quality. This suggests a trade-off between economic growth and the quality of the environment. As such, government and other relevant stakeholders in Turkey are encouraged to explore and promote more efficient use of electricity that will negate environment degradation in a bid to promote economic growth and sustainable development. The empirical evidence from the VECM Granger causality shows a bidirectional Granger causality between economic growth and labour and capital for Turkey. This implies that the government of the day can

Table 9 FMOLS, DOLS and CCR estimation results

Dependent variables	LNRGDP			LNEFP		
Variables	FMOLS	DOLS	CCR	FMOLS	DOLS	CCR
lnK	0.3107*	0.2939*	0.3364*	0.3704*	0.3377**	0.3297***
	[9.3141]	[8.1957]	[7.4981]	[3.9329]	[2.5929]	[1.6879]
lnL	0.5399*	0.4355*	0.6051*	0.6962*	0.7152**	0.6780***
	[5.2879]	[4.0595]	[4.8477]	[3.2977]	[2.5087]	[1.7777]
lnEC	0.3562*	0.4078*	0.3692**	0.4886***	− 0.3981*	− 0.3896*
	[3.0606]	[3.2272]	[2.0509]	[2.1039]	[− 3.1309]	[− 3.0548]
lnEFP	− 0.1972**	− 0.1964**	− 0.2985**			
	[− 2.4871]	[− 2.3086]	[− 2.0327]			
lnRGDP				19.3242*	21.9485*	21.9478*
				[3.0652]	[3.0707]	[3.0163]
lnRGDP^2				− 1.0845*	− 1.1975*	− 1.1968*
				[−3 .2182]	[− 3.1735]	[− 3.1256]
C	− 10.2826*	− 8.4614*	− 11.4257*	− 19.4547*	− 17.2564*	− 16.5362*
	[− 4.9979]	[− 3.9252]	[− 4.3437]	−3.8634	[− 3.5125]	[− 3.4555]
R^2	0.9963	0.9967	0.9959	0.9515	0.9289	0.9281
Adjusted R^2	0.9950	0.9956	0.9945	0.9303	0.9091	0.9081
S.E. of regression	0.0145	0.0138	0.0152	0.0292	0.0333	0.0335
Long-run variance	0.0001	0.0002	0.0001	0.0003	0.0007	0.0007
Mean dependent var.	9.1032	9.0919	9.1033	1.0594	1.0594	1.0594
S.D. dependent var.	0.2058	0.2092	0.2058	0.1105	0.1105	0.1105
Sum squared resid	0.0035	0.0034	0.0039	0.0136	0.0199	0.0202

*, ** and *** denote 1%, 5% and 10% statistical significance level, respectively. [] denotes *t* stat

Table 10 Residual diagnostic tests for the fitted model RGDP = *f*(lnK, lnL, lnEC, lnEFP)

Test	Coefficient	*p* value
Heteroscedasticity (ARCH)	0.4177	0.5251
Normality	2.6545	0.2656
Autocorrelation	0.0135	0.9088
Functional form (Ramsey RESET)	1.5751	0.1348

Source: Authors computation

embark on more human and capital reforms. This is motivated by the fact that capital and labour have been identified as drivers of economic growth. This affirms the stand of the United Nation on the sustainable development goals on access to energy. The one-way causality exists between ecological footprint and economic growth, implying that economic growth drives environmental degradation. This confirms the theory that growth in developing economies is often tied to poor environmental conditions that result from economic activities based on fossil fuel-based electricity consumption. But as the economy transits to a developed economy, a clean environment is of utmost importance and as such, more efficient use of electricity consumption. The inclusion of an environmental proxy as observed in the current study is novel to capture the trade-off between economic output and environmental quality in the bid for more electricity consumption.

The outcome of pollutant emission first increase along with a corresponding increase in real income level until a certain threshold, then experience a decline in pollutant emission while real income level increases. The confirmation of the EKC hypothesis in Turkey suggests the effectiveness of growth policies, which calls for sound policy construction to aid long-term and sustainable growth in Turkey. In addition,

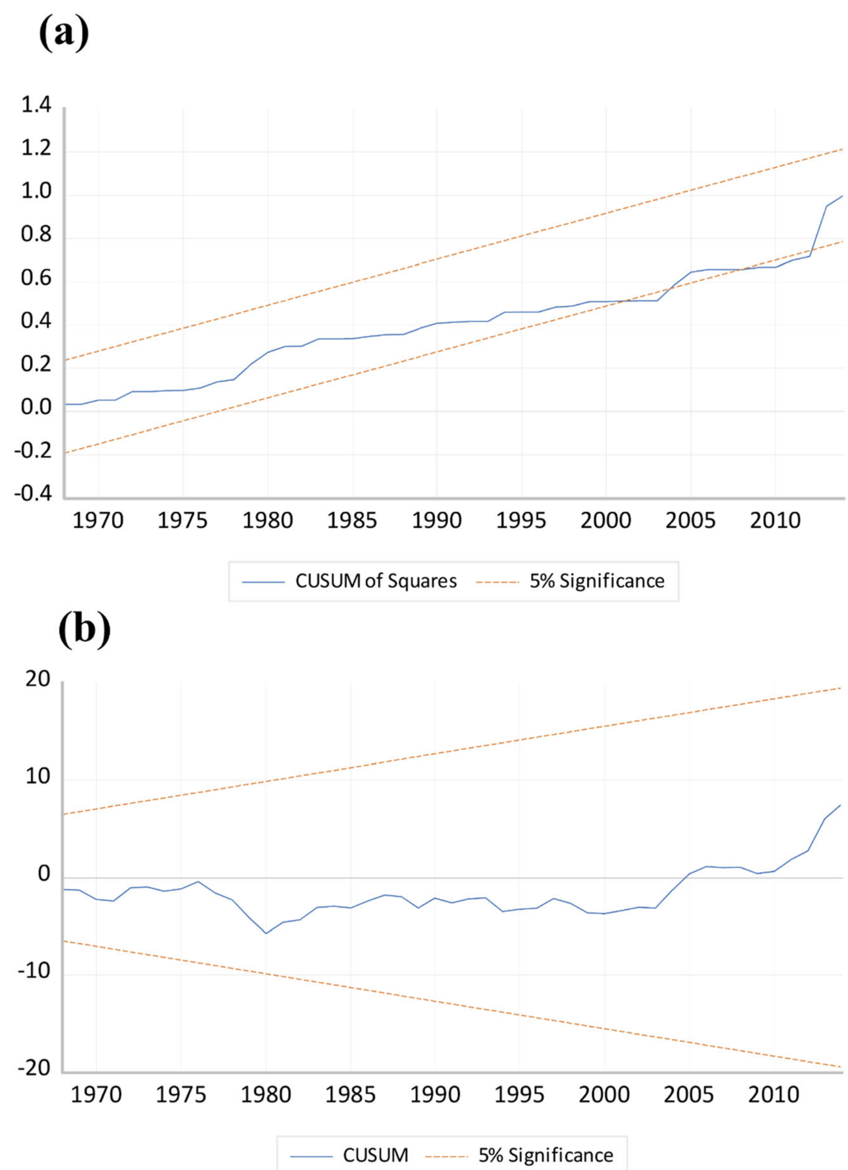

Fig. 2 Diagnostic plots. **a** CUSUM square and **b** CUSUM

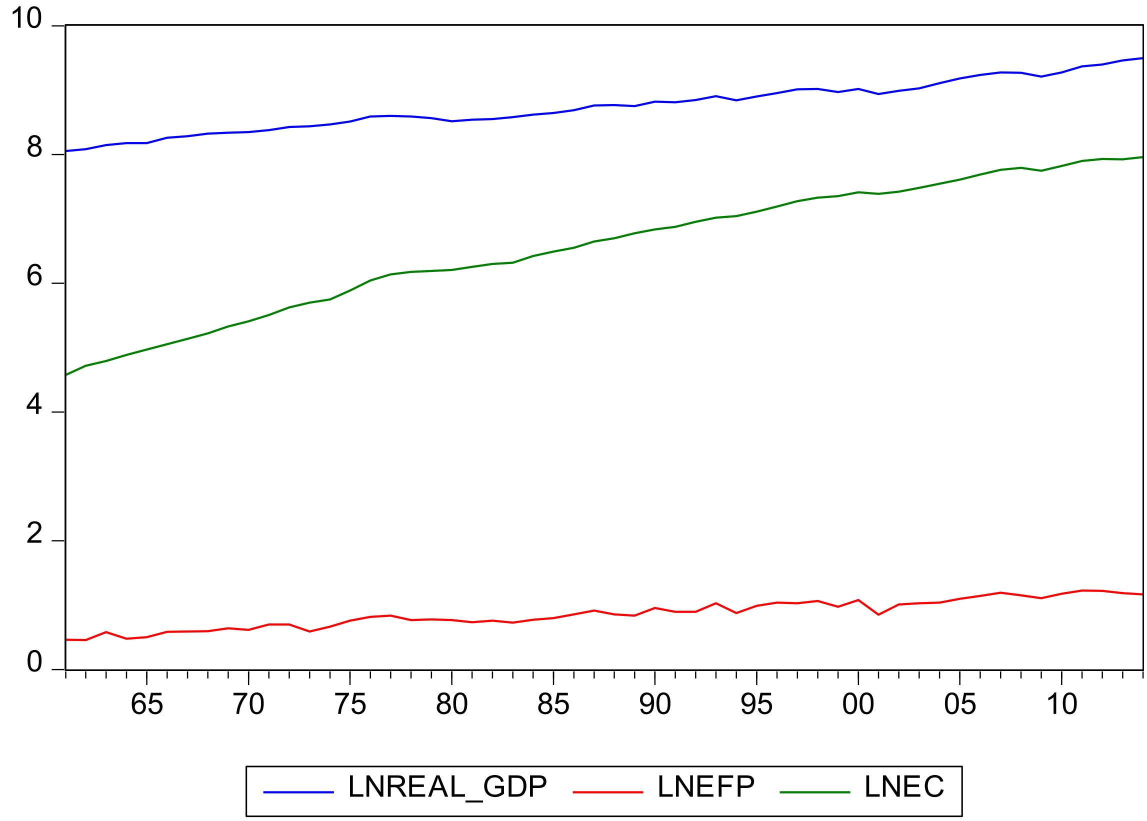

Fig. 3 Trend plot of the relationship between electricity consumption and real output (1990–2014)

the results of energy-induced emission imply that energy demand is associated with intensifying pollutant emission measured by EFP. Thus, the need for renewable energy sources is pertinent to mitigate pollutant emission and desirable as a substitute for pollutant emission in the quest to decouple economic growth from pollutant emission. From a policy standpoint, energy management policies such as paradigm shift from fossil fuel-driven economy to cleaner and ecosystem friendly energy sources and adoption of cleaner energy production technologies in Turkey are highly encouraged.

Conclusively, we present a new paradigm for other research on the EKC hypothesis by exploring other co-variates not captured in this study like demographic indicators, and financial development, in order to test the validity of the EKC concept as room for extension and comparison with other regions.

Appendix

Table 11 Results of VECM causality analysis

Dependent Variable	Direction of causality					
	Short run					Long run
	$\Delta \ln Y_{t-i}$	$\Delta \ln K_{t-i}$	$\Delta \ln L_{t-i}$	$\Delta \ln EFP_{t-i}$	$\Delta \ln EC_{t-i}$	ECT_{t-1}
ΔlnY	_	2.7150* (0.0966)	4.3361** (0.0313)	2.3796 (0.1245)	3.2014* (0.0677)	− 2.9675** (0.0459)
ΔlnK	0.5816 (0.571)	_	2.0942* (0.0915)	0.4649 (0.6364)	0.4649 (0.6364)	−3.5689*** (0.0205)
ΔlnL	2.8659** (0.0863)	2.5232** (0.0211)	_	2.2874 (0.1337)	1.8651 (0.1870)	0.5910 (0.2680)
ΔlnEFP	4.6726* (0.0967)	9.7667*** (0.0076)	10.4771*** (0.0053)	_	19.2560*** (0.0001)	− 0.9166 (0.5500)
ΔlnEC	2.1416** (0.0344)	1.8260 (0.1931)	2.4687 (0.1163)	0.5523 (0.5862)	_	− 0.0180** (0.0880)

Source: Authors computation

*, **, *** denote 10%, 5% and 1% significance rejection level, respectively, while () are *p* values

Table 12 Maki (2012) cointegration test under multiple structural breaks. Model: lnGDP = *f*(lnK, lnL, lnEC, lnEFP)

Number of break Points		Test statistics (critical values)	Break points
TB ≤ 1			
	Model 0	− 5.760 (− 5.650)*	1999
	Model 1	− 6.187 (− 5.913)*	1993
	Model 2	− 4.576 (− 6.520)	1999
	Model 3	− 8.330 (− 6.911)*	2004
TB ≤ 2			
	Model 0	− 12.305 (− 5.839)*	1999; 2007
	Model 1	− 6.187 (− 6.055)*	1993; 2000
	Model 2	− 11.160 (− 7.244)*	1999; 2005
	Model 3	− 17.168 (− 7.638)*	1997; 2004
TB ≤ 3			
	Model 0	− 12.305 (− 5.992)*	1994; 1999;2007
	Model 1	− 6.187 (− 6.214)*	1993; 2000; 2007
	Model 2	− 11.160 (− 7.803)*	1999; 2005; 2011
	Model 3	− 28.421 (− 8.254)*	1997; 2001; 2004
TB ≤ 4			
	Model 0	− 12.305 (− 6.132)*	1994; 1999; 2003; 2007
	Model 1	− 41.316 (− 6.373)*	1993; 2000; 2004; 2007
	Model 2	9.73 (− 8.292)*	1979; 1991; 1997; 2007
	Model 3	− 28.421 (− 8.871)*	1997; 2001; 2004; 2010
TB ≤ 5			
	Model 0	− 12.305 (− 6.306)*	1994;1999; 2003;2007; 2011
	Model 1	− 41.316 (− 6.494)*	1993; 1997;2000; 2004;2007
	Model 2	9.74 (− 8.869)*	1974; 1979; 1991; 1997; 007
	Model 3	− 28.421 (− 9482)*	1994; 1997; 2001; 2004;2000

Numbers in corner brackets are critical values at 0.05 level from Maki (2012). * denotes statistical significance at 0.05 level

Table 13 ARDL bounds test based on F-bounds test

Test Statistic	Value	Signif. (%)	I(0) Asymptotic: $n = 1000$	I(1)
F-statistic	6.17068	10%	3.03	4.06
k	4	5%	3.47	4.57
		2.5%	3.89	5.07
		1%	4.4	5.72
Actual sample size	24		Finite sample: $n = 35$	
		10	3.374	4.512
		5	4.036	5.304
		1	5.604	7.172
			Finite sample: $n = 30$	
		10	3.43	4.624
		5	4.154	5.54
		1	5.856	7.578

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