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RESEARCH ARTICLE

Revisiting the economic growth and electricity consumption nexus in Pakistan

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Abstract
This paper revisits the interaction between electricity consumption, real gross domestic product, and carbon dioxide emissions in Pakistan. To this end, our study relies on annual data from 1971 to 2014 for the econometric analysis while accounting for structural break(s). According to the Maki cointegration test, a cointegration equilibrium relationship exists among electricity consumption, economic growth, and carbon dioxide emissions. The empirical findings from Toda-Yamamoto causality test provided the following insights: (i) unidirectional causality was found running from economic growth to electricity consumption. Thus, this study validates the conservative hypothesis, meaning that in Pakistan, conservative energy strategies cannot harm economic progress. (ii) Causality was also found running from electricity consumption to carbon dioxide emissions. This implies that industrial activities trigger an increase in carbon emissions flaring which in return translates into environmental degradation. This outcome has inherent policy implications which are further discussed in the conclusion section.

Keywords Electricity consumption · Economic growth · Maki cointegration · Pakistan

JEL Classifications C32 · O41 · Q43

Introduction

Most economies around the globe have recently experienced energy shortage due to the swift increase in energy demand (Balcilar et al. 2010; Dlamini et al. 2015; Sekantsi and Okot 2016; Tamba et al. 2017). This is so, given that the integral role energy (electricity) plays in socioeconomic growth and development, both in developing and developed nations. The debate on whether economic development precedes energy consumption or vice versa is still heated in the energy economics literature and has led energy scholars to explore the dynamic relationship and causality between electricity consumption and macroeconomic variables like income, gross national product, employment, and energy price. Thus, this current study focuses on Pakistan, a country faced with a huge electrification deficit and an underdeveloped energy infrastructure which has crippled its economic productivity.

Recent statistics show that 49,500,000 inhabitants (27% of total population), 9% of urban residents and an alarming 38% of rural residents, do not have access to electricity in Pakistan (CIA 2018). Thus, the country relies on load shedding to meet their electricity demands (see Khan and Ahmad 2008; Shahbaz and Feridun 2012). Further report reveals that the country's electricity consumption is between 15,000 and 20,000 MW billion per day, yet the current production stands at a mere 11,500 billion MW per day. Furthermore, Khan and Ahmad (2008) assert that the huge electricity deficits pose a huge threat to the Pakistani energy sector and by extension, its economic growth, given the already established relationship between the two variables (electricity and economic growth).

The continuous increase in electricity demand in Pakistan has become more intense and threatens to become more severe in the near future if adequate and timely attention is not given to the energy sector. This study thus seeks to investigate the theme under consideration, given the urgent need for mitigation by energy economists, practitioners, and indeed all stakeholders. Our study also seeks to examine the causal

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long- and short-run relationships between electricity consumption and economic growth for a developing nation like Pakistan. This study, by way of contribution to the existing energy literature, incorporates carbon dioxide emissions into our econometric framework to ascertain the extent of environment-income nexus in the econometric modeling on economic growth.

The contribution of this paper to the pool of studies in the energy economics literature is twofold. First, this is the first study to investigate the current theme for Pakistan in a multivariate framework, to the best of the author's knowledge. Previously conducted studies were in bivariate framework (Acaravci and Ozturk 2010; Kayhan et al. 2010; Shahbaz and Feridun 2012; Ameyaw et al. 2016; Tamba et al. 2017) and are debated to be flawed and possess misspecification bias (that is, omitted variable bias). This translates into misleading analysis and spurious policy implication. Second, this study leverages on fairly new econometric techniques that circumvent structural break(s). Our study employs Kwiatkowski et al. (1992) stationarity test and Zivot and Andrews (1992) unit root test that accounts for single structural break, while Maki (2012) is employed for long-run equilibrium relationship. The Maki cointegration test can account for as much as five multiple structural breaks. We also use the Toda and Yamamoto (1995) causality test, which is an improved version of the Wald test (MWALD). The Toda-Yamamoto causality test is regarded as superior to the conventional Granger causality test (Lütkepohl and Krätzig 2004). The need for structural break model is preempted by the nature of most macroeconomic and financial datasets, to avoid spurious analysis which previous studies fail to address. Thus, our study extends the literature by methodological innovation and advancement. We also aim to provide energy practitioners and stakeholders ample evidences for adequate policy framework design and decision-making.

Figure 1 reports the visual presentation of trend movement between electricity consumption and real GDP from 1971 to 2014. Hodrick-Prescott (HP) smoothing filter was applied to the dataset for better visual glimpse. It is conspicuous that there exists a co-movement between the variables, and as such, the attention of energy users, energy practitioners, policymakers, and all stakeholders is needed, given the implications of this relationship.

The remainder of this study is as follows: the "Literature review" section provides a detailed review of relevant literature with a summary of selected literature survey in Table 1, the "Methodology framework" section presents the data and econometric procedures, the "Empirical results" section reveals the empirical results and discussions, and finally, the "Concluding remark/policy implications" section presents the conclusion and policy implications emanating from the study.

Literature review

The relationship between energy (electricity) consumption and economic growth has been well documented in the energy economics literature. The seminal study of Kraft and Kraft (1978) on the relationship between energy consumption and economic growth in the USA revealed unidirectional causality running from economic growth to energy consumption. The study ushered in numerous empirical studies such as Erol and Yu (1987), Asafu-Adjaye (2000), Stern (2000), Oh and Lee (2004), Wolde-Rufael (2006), Yoo and Kim (2006), Narayan and Singh (2007), Narayan and Smyth (2008), Apergis and Payne (2009), Soytas and Sari (2009), Shahbaz et al. (2011), Béläïd and Abderrahmani (2013), Shahbaz et al. (2014), Akadiri and Akadiri (2018), and Akadiri et al. (2018).

This current study however focuses on energy (electricity) literature, which can be classified into four groups. The first group supports the growth hypothesis (see Altinay and Karagol 2005; Ho and Siu 2007; Shahbaz et al. 2011), asserting that electricity consumption births economic growth; that is, energy consumption drives economic growth. Thus, conservative energy policies will negatively impact economic growth. The second group, in favor of the conservative

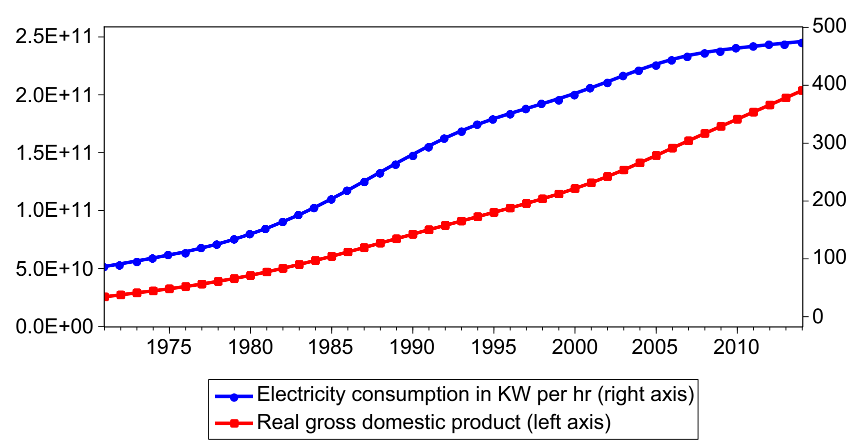

Fig. 1 Visual trend of electricity consumption and real GDP for 1971–2014

Table 1 Summary of literature on electricity consumption and economic growth

Author(s)	Period	Region	Methodology	Variables	Direction of causality
Chen and Fang (2018)	2003–2012	210 Chinese cities	Panel Granger causality test	Industrial electricity consumption, total output, fixed asset investment, and public expenditure on education and science and technology	$Y \Rightarrow ELC$, $ELC \Leftrightarrow H$ for China; $Y \Leftrightarrow ELC$, $ELC \Rightarrow H$ for East China; $Y \Rightarrow ELC$, $H \Rightarrow ELC$ for Middle China; $Y \Rightarrow ELC$, $ELC \Leftrightarrow H$ for West China
Bah and Azam (2017)	1971–2012	South Africa	ARDL bounds test, Toda and Yamamoto augmented Granger causality test	Electricity consumption, GDP, domestic credit to private sector, and CO_2 emissions	$ELC \neq Y$, $CO_2 \Rightarrow ELC$, $FD \Rightarrow CO_2$
Sarwar et al. (2017)	1960–2014	210 countries	PECM Granger causality test	Electricity consumption GDP, GFCF, population, and oil price	$ELC \Leftrightarrow Y$, $OP \Leftrightarrow Y$, $GFCF \Leftrightarrow Y$
Salahuddin et al. (2017)	1980–2013	Kuwait	ARDL bounds test and the VECM Granger causality test	Electricity consumption, CO_2 emissions, RGDP, FD, FDI	$Y \Rightarrow CO_2$, $ELC \Rightarrow CO_2$, $FDI \Rightarrow CO_2$, $Y \Leftrightarrow ELC$, $CO_2 \neq FD$, $CO_2 \neq FDI$, $ELC \neq FD$, and $ELC \neq FDI$
Osman et al. (2016)	1975–2012	GCC countries	Panel VAR Granger causality test	Electricity consumption, GDP, and GFCF	$Y \Leftrightarrow ELC$, $Y \Leftrightarrow GFCF$, and $ELC \Rightarrow GFCF$
Bildirici (2016)	1980–2011	OECD and non-OECD	ARDL bounds testing and Granger causality approach	Hydro energy consumption and real gross domestic product	$EC \Rightarrow GDP$ in the short run, $EC \Leftrightarrow GDP$ in the long run except Brazil and France
Dlamini et al. (2015)	1971–2009	South Africa	Bootstrap rolling window approach	Electricity consumption and GDP	$ELC \Rightarrow Y$ for two sub-periods
Shahbaz et al. (2015)	1980–2012	12 African countries	FMOLS, Pedroni cointegration test, and VECM	Energy intensity, CO_2, and real gross domestic product	$GDP \Leftrightarrow CO_2$, $EI \Rightarrow CO_2$
Karanfil and Li (2015)	1980–2010	160 countries	Pedroni panel cointegration tests and PECM Granger causality test	Electricity consumption and GDP, urbanization, and electricity net import	Mixed result for sub-samples
Cowan et al. (2014)	1990–2010	BRICS countries	Bootstrap panel causality test	Total electricity consumption, CO_2 emissions, and RGDP	$ELC \neq Y$, $ELC \neq CO_2$, and $CO_2 \Rightarrow Y$ for Brazil; $ELC \Leftrightarrow Y$, $ELC \nLeftrightarrow CO_2$, and $CO_2 \neq Y$ for Russia; $ELC \neq Y$, $ELC \Rightarrow CO_2$, and $CO_2 \neq Y$ for India; $ELC \neq Y$, $ELC \neq CO_2$, and $CO_2 \neq Y$ for China; $Y \Rightarrow ELC$, $ELC \neq CO_2$, and $Y \Rightarrow CO_2$ for South Africa
Hamdi et al. (2014)	1980–2010	Bahrain	ARDL bounds test	Electricity consumption, FDI, and GDP	$ELC \Leftrightarrow Y$, $FDI \Leftrightarrow ELC$
Nazlioglu et al. (2014)	1967–2007	Turkey	ARDL model, linear and non-linear Granger causality test	Electricity consumption and gross domestic product	$ELC \Leftrightarrow Y$ for linear causality test, no non-linear causality between ELC and Y
Solarin and Shahbaz (2013)	1971–2009	Angola	ARDL bounds test and the VECM Granger causality test	Electricity consumption, GDP, and urbanization	$ELC \Leftrightarrow Y$, $U \Leftrightarrow ELC$ for the short run; $ELC \Leftrightarrow Y$, $U \Rightarrow Y$, and $U \Rightarrow ELC$ for the long run
Akpan and Akpan (2012)	1970–2008	Nigeria	Multivariate VECM	Electricity consumption, carbon emissions, and economic growth	$Y \Rightarrow CE$, $ELC \neq Y$
Shahbaz and Lean (2012)	1972–2009	Pakistan	ARDL model and Granger causality tests	Electricity consumption, GDP, real capital, and labor	$ELC \Leftrightarrow Y$
Shahbaz and Feridun (2012)	1971–2008	Pakistan	ARDL bounds test	Electricity consumption and GDP	$Y \Rightarrow ELC$
Shahbaz et al. (2011)	1971–2009	Portugal	VECM Granger causality test	Electricity consumption, GDP, and employment	$Y \Rightarrow ELC$, $ELC \Leftrightarrow E$, and $E \Leftrightarrow Y$ for the short-run; $Y \Leftrightarrow ELC$, $E \Leftrightarrow ELC$ and $Y \Leftrightarrow E$ for the long run
Balcilar et al. (2010)	1960–2006	G-7 countries	Bootstrap Granger non-causality test	Energy consumption and GDP	

Table 1 (continued)

Author(s)	Period	Region	Methodology	Variables	Direction of causality
					EC $\Rightarrow$ GDP for only Canada, there is no causal links between energy consumption and economic growth for the other countries
Narayan and Smyth (2009)	1974–2002	Middle Eastern countries	Bootstrap causality approach	Electricity consumption, exports, and GDP	ELC $\Leftrightarrow$ Y
Mozumder and Marathe (2007)	1971–1999	Bangladesh	Johansen cointegration test and Granger causality test based on VECM	Electricity consumption and GDP per capita	Y $\Rightarrow$ ELC
Altinay and Karagol (2005)	1950–2000	Turkey	Dolada and Lütkepohl (1996) causality test	Electricity consumption and GDP	ELC $\Rightarrow$ Y
Hatemi and Irandoust (2005)	1965–2000	Sweden	A leveraged bootstrap approach	Electricity consumption, GDP and consumer price index	Y $\Rightarrow$ ELC
Narayan and Smyth (2005)	1966–1999	Australia	Cointegration Granger causality test	Electricity consumption, GDP per capita, and index of employment	Y $\Rightarrow$ ELC, E $\Rightarrow$ ELC
Shiu and Lam (2004)	1971–2000	China	Johansen cointegration test and ECM	Electricity consumption and GDP	ELC $\Rightarrow$ Y
Ghosh (2002)	1950–1997	India	Engle-Granger causality test	Electricity consumption and GDP	Y $\Rightarrow$ ELC

The symbols "$\Rightarrow$, $\Leftrightarrow$, and $\neq$" indicate unidirectional, bidirectional causality and neutrality hypothesis, respectively, where ELC is the electricity consumption, FDI is the foreign direct investment, FD is the financial development, U is the urbanization, E is the employment, and EI is the energy intensity

hypothesis, asserts that economic growth has the tendency to spur electricity consumption; that is, there exists unidirectional causality running from economic growth to energy (electricity) consumption. Thus, this group supports the conservative strategies and measures (see Jumbe 2004; Jamil and Ahmad 2010; Lean and Smyth 2010; Ameyaw et al. 2016). The third group affirms the feedback hypothesis and asserts that there is bidirectional causality between energy (electricity) consumption and economic growth. This pattern of causality supports the conservation hypothesis which suggests that energy conservative policy adversely affects economic growth. Similarly, an increase in economic activity triggers economic growth (Bélaïd and Abderrahmani 2013; Hu and Lin 2013; Tang and Tan 2013; Aslan 2014). Finally, the fourth group affirms the neutrality hypothesis. This group of studies posits that there is no causal relationship between energy (electricity) consumption and economic growth (Acaravci and Ozturk 2010[1]; Nazlioglu et al. 2014).

More recently, literature in the electricity-economic growth nexus has burgeoned with no consensus in empirical outcomes. These variances in the empirics could be attributed to data and sampling procedures applied by the researchers, and the study area which could either be country-specific or a panel of countries. The more pronounced reason could be methodological techniques adopted in estimations. Single-country studies on the electricity-growth nexus include Bélaïd and Abderrahmani (2013), Aslan (2014), Hamdi et al. (2014), Ameyaw et al. (2016), Shahbaz et al. (2017a), and Wang et al. (2018).

In the study conducted in Portugal by Shahbaz et al. (2017a), it was revealed that the Portuguese economy is electricity driven, as unidirectional causality was observed running from electricity consumption to economic growth. The study also accounted for financial development and capital formation from 1960 to 2015. Hamdi et al. (2014) focused on the Kingdom of Bahrain and examined the interaction between electricity consumption and economic growth while accounting for the role of capital and foreign direct investment with the aid of Cobb-Douglas production function. The empirical finding lends support to the long-run equilibrium relationship between the variables. The study joins the group of literature in support of bidirectional causality between electricity consumption and economic growth. The same position is also resonated in the studies of Aslan (2014) for the Turkish economy implying feedback causality. The Ghanaian experience documented by the study of Ameyaw et al. (2016) with the aid of Cobb-Douglas growth production function lends credence to the growth-led energy (electricity) hypothesis, thus showing that the Ghanaian economy is not reliant on electricity consumption for its economic growth. In China,

[1] For brevity, interested readers can see Payne (2010) literature survey studies on electricity growth nexus.

Wang et al. (2018) also advanced the nexus between electricity consumption and economic growth by the adoption of a more sophisticated econometric technique. Their study employed bootstrap causality approach, a seemingly unrelated regression approach, for more reliable results. The study joins the group in support of economic growth-induced electricity consumption for the Chinese economy for the sampled period.

Nazlioglu et al. (2014) examined the electricity-growth nexus in Turkey. The authors considered symmetric and asymmetric dynamics in their estimations by implementing linear and non-linear Granger causality test. The linear Granger causality supports the feedback causality in both the short and long run. On the contrary, the non-linear causality that accounts for asymmetry supports the neutrality divide in the electricity-growth literature, thus indicating that the Turkish energy sector and government administrator can embark on the conservative policies without adverse implication on economic growth.

Other scholars have also investigated the electricity-growth nexus for a panel of countries. Examples abound in the empirics. The recent studies of Balsalobre-Lorente et al. (2018) examined the nexus between electricity consumption and economic growth via a carbon emission production function while controlling for trade openness, natural abundance, energy innovation, and carbon dioxide emissions. The study was conducted for Germany, France, Italy, Spain, and the UK (collectively known as the European Union-5 countries) and asserts that renewable electricity consumption helps to enhance environmental quality for the sampled countries. In the same vein, Shahbaz et al. (2017b) examined the theme under consideration in a neoclassical framework by controlling for oil prices in 157 countries from 1960 to 2014. Cointegration relationship was achieved by Pooled Mean Group (PMG) estimator between capital, labor, oil prices, electricity consumption, and economic growth over the sampled regions and period. The study affirms and supports the feedback relationship between electricity consumption and economic growth, thus implying that conservative policies cannot be implemented. The study further buttresses that developing countries rely heavily on electricity consumption to drive their economies. The study also advocates for pragmatic steps to be taken by policymakers and governmental administrators to attain sustainable growth in the long run.

In the case of Mediterranean countries (MCs), Kahouli (2018) explored the relationship between electricity consumption, carbon dioxide emissions, research development, and economic growth with the aid of GMM, 3SLS, and SUR as estimation techniques. The study joins the league that supports the electricity-induced growth for the Mediterranean countries investigated. This is also the position of Gulf cooperation countries (GCC) as seen in the study by Salahuddin et al. (2015). Wolde-Rufael (2014), using bootstrap panel Granger causality test for transition countries, examined the electricity-economic growth nexus while accounting for cross-sectional dependence and heterogeneity and found mixed results among the selected transition countries. Policy directions were offered to different countries accordingly. Also, Khobai (2018) examined the BRICS experience of the electricity-growth nexus while accounting for carbon dioxide emissions and urbanization. The study affirms the cointegration relationship among the variables and also confirms the conservative hypothesis over the period investigated.

Table 1 provides a detailed review of selected studies on electricity consumption-economic growth nexus across diverse countries.

Pakistan energy sector: a synopsis

Pakistan has a huge and increasing population which suffers high electricity deficit in recent times, with over 49,500,000 million residents without electrical access. Twenty-seven percent of the total population lack access to electricity, with 9% of urban residents and an alarming 38% of rural residents affected (CIA 2018). The country electricity consumption hits 85.9 billion kWh in recent time. Pakistan's electricity system has previously been studied by Dunn (1991), Malik (2007), and Muneer and Asif (2007). Electricity generation, transmission, and distribution in Pakistan are handled by two public companies, namely, Water and Power Development Authority (WAPDA) responsible for the entire country with the exclusion of Karachi and Karachi Electricity Supply Corporation (KESC) responsible for Karachi and her environs. Since the1990s, over 16 Independent Power Producers (IPPs) have also generated electricity in Pakistan, thereby accounting for one-third of the electricity generation in the country.

Pakistan's electricity supply over the years falls below its demand. This gap is being managed by load shedding in the country. The epileptic electricity supply has threatened the Pakistani economy a great deal. This occurrence has also had a toll on investment and investors. Furthermore, Joskow (2003) and Smith (2004) both linked this problem to poor institution and avoidance of electricity tariff by both individuals and institutions. Also, the theft of electrical installations was also identified as part of the bottleneck in the electrification of Pakistan.

Methodology framework

Data

This study relies on annual data from 1971 to 2014 in consideration of the dynamic relationship between electricity consumption, carbon dioxide emissions, and economic growth in Pakistan.[2] The data span is restricted due to data availability. The data for our study was retrieved from World Bank Development Indicators (2018) (https://data.worldbank.org/indicator). Our study empirically follows the studies of Kayhan et al. (2010), and Sekantsi et al. (2016). The variables used in this paper are real gross domestic product constant 2010 USD (RGDP), which is proxy for economic growth, carbon dioxide emissions (CO_2) in Kt as indicator for environmental quality (degradation), and electricity consumption (EC) in kWh per capita. The empirical route is as follows: (i) Zivot and Andrews (1992) unit root test and Kwiatkowski et al. (1992) stationarity test are used to validate the asymptotic traits and order of integration of all variables under review to avoid the problem of spurious regression. (ii) The estimation of long-run equilibrium relationship is carried out using the Maki (2012) cointegration test and dynamic ordinary least squares (DOLS) for long-run coefficient subsequently. (iii) Causal relationships are estimated through the Toda and Yamamoto (1995) Granger causality test.

Model specification

The econometric model for our study is given as

$$\mathrm{EC} = f(\mathrm{RGDP}, \mathrm{CO}_2) \tag{1}$$

Logarithm transformation is carried out in Eq. 1 to achieve homoscedasticity

$$\ln \mathrm{EC} = \alpha + \beta_1 \ln \mathrm{RGDP}_t + \beta_2 \ln \mathrm{CO}_{2,t} + \varepsilon_t \tag{2}$$

where α signifies constant and $\beta_{1,}\ \beta_2$ are the partial slope parameter. Also, lnEC, lnRGDP, and $\ln CO_2$ are the natural logarithm for real gross domestic product (RGDP), electricity consumption (EC), and carbon dioxide emissions (CO_2).

Unit root test

Stationarity test is vital in time series econometric analyses, to avoid the problem of spurious analysis. The econometric literature has several unit root test procedures, namely, augmented Dickey-Fuller (ADF 1981), Phillips and Perron (PP 1988, Elliott et al. (1992), and Ng and Perron (2001). However, all aforementioned tests fail to account for structural break(s) which is known to plague most macro and financial datasets. Thus, to establish the asymptotic traits and order of integration of time series variables, stationarity test is crucial. Zivot and Andrews (1992) unit root test circumvent the abovementioned problem by accounting for a single structural break.

The ZA test null hypothesis states unit root where $H_0 : \theta = 0$ against an alternative of stationarity $H_1 : \theta < 0$. Thus, failure to reject H_0 implies the presence of unit roots while and rejection denotes stationarity.

Cointegration test

Cointegration test is crucial because it helps to depict long-run equilibrium bond among variables. Standard conventional cointegration tests (Engle and Granger 1987; Johansen and Juselius 1990; Johansen 1991) fail to account for structural break(s). It is well known in economics and finance literature that most macro data possess breaks/jumps. We thus argue that previous tests may give spurious analysis (Westerlund and Edgerton 2007).

The new breed of cointegration tests that accounts for structural breaks includes Gregory and Hansen (1996), Carrion-i-Silvestre and Sansó (2006), Westerlund and Edgerton (2007), and Hatemi-J (2008). However, it is also argued that economic series are highly unpredictable with jumps and several breaks. It is on this premise that Maki (2012)[3] proposed a cointegration procedure that accounts for multiple structural breaks. It however requires all series to be integrated of order one.

The formulae for Maki (2012) are given as

Model A: Break in intercept and without trend

$$z_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \delta' x_t + u_t \tag{3}$$

Model B: Break in intercept and coefficients and without trend

$$z_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \delta' x_t + \sum_{i=1}^{m} \delta_i' x_t D_{i,t} + u_t \tag{4}$$

Model C: Break in intercept and coefficients and with trend

[2] The data set is trimmed bases on data availability and for uniformity of estimations, given that carbon dioxide emissions and electricity consumption are available in 2014 on the WDI database. Available at https://data.worldbank.org/

[3] The authors are appreciative to Daiki Maki of the Faculty of Economics, Ryukoku University, for the availability of the codes in GAUSS that facilitated simulation of the cointegration results.

$$z_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \beta t + \delta' x_t + \sum_{i=1}^{m} \delta_i' x_t D_{i,t} + u_t \quad (5)$$

Model D: Break in intercept, coefficients, and trend

$$z_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \beta t + \sum_{i=1}^{m} \beta_i t D_{i,t} + \delta' x_t + \sum_{i=1}^{m} \delta_i' x_t D_{i,t} + u_t \quad (6)$$

Here, $t = 1, 2, \ldots, T$, y_t, and $x_t = (x_{1,\ t}, x_{2,\ t}, \ldots, x_{k,\ t})'$ are observable $I(1)$ variables, the $D_{i,t}$ is a dummy, where $D_{i,t} = 1$ when $t > T_{bi}$ and $D_{i,t} = 0$ otherwise, where T_{bi} indicates possible break point with $i = 1, 2, \ldots, m$, and u_t is an equilibrium error.

Estimation of long-run coefficients

Long-run equilibrium coefficients precede the establishment of cointegration relationship among series under consideration in this study. To this end, dynamic ordinary least squares (DOLS) estimation test is utilized to ascertain the magnitude of long-run equilibrium. The advantages of the DOLS include the following: (a) It can be estimated irrespective of the order of integration of series, but the dependent variable is expected to be integrated of order one. (b) It also eliminates serial correlation issues arising from the estimation of the model and other internalities (Esteve and Requena 2006).

The DOLS formulate model is presented as

$$\ln EC = \beta_0 + \beta_1 \ln CO_{2,t} + \beta_2 \ln RGDP_t + \sum_{i=-q}^{q} \varphi_i \Delta \ln CO_{2,t-i} + \sum_{i=-q}^{q} \gamma_i \Delta \ln RGDP_{t-i} + u_t \quad (7)$$

Here, q represents the optimum lag level as suggested by Schwarz information criterion.

Causality test

Conventional regression does not depict causation. Thus, the need for causality arises, given the inherent policy implication from the directional causality flow. To this end, our study relies on the Toda and Yamamoto (1995) causality approach for causation and predictability power among the series under review. The Toda-Yamamoto (TY) is an improved version of the Wald test. The Toda-Yamamoto (TY) has obvious merits relative to traditional Granger causality test. The TY causality is resilient and gives robust estimates. In addition to being resilient, the TY technique is unique, as it can be estimated regardless of the order of integration of variables under review. TY procedure is structured in a vector autoregressive framework VAR with $(k + d_{max})$, where K is the optimal order

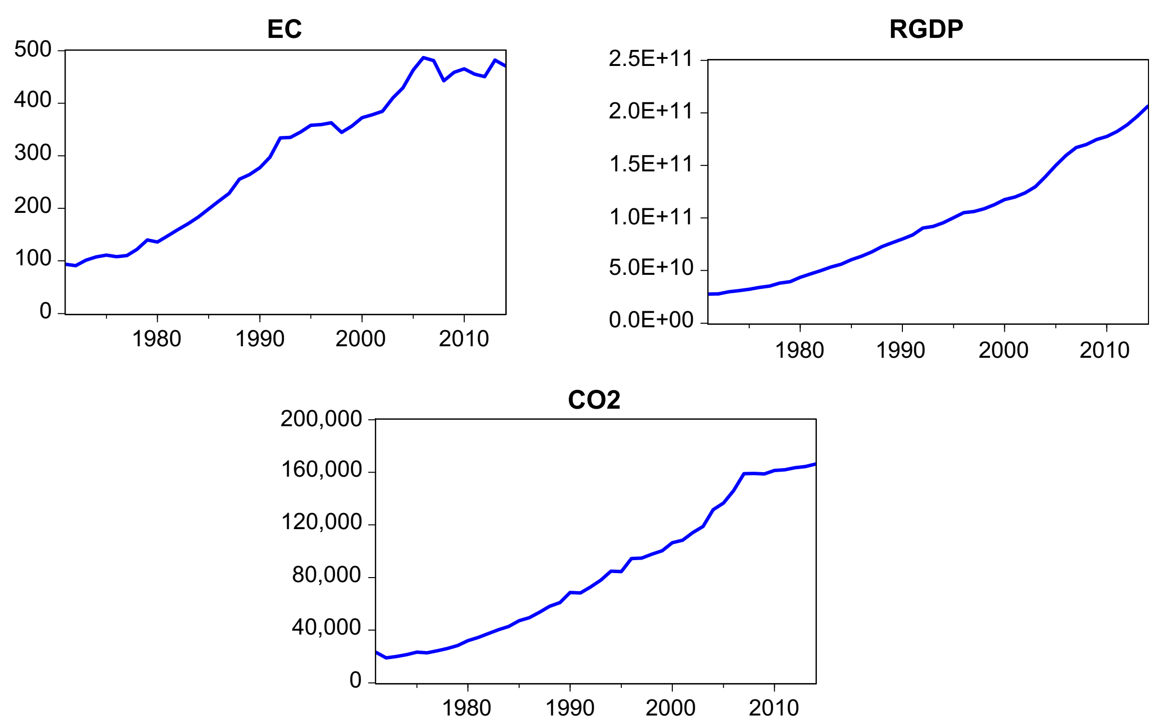

Fig. 2 Visual plot of variables in their level form

Table 2 Descriptive statistics of the variables for Pakistan

	lnEC	$\ln CO_2$	lnRGDP
Observations	44	44	44
Mean	5.55	11.11	25.12
Median	5.81	11.23	25.24
Maximum	6.19	12.02	26.05
Minimum	4.51	9.85	24.04
Std. dev.	0.56	0.72	0.62
Skewness	− 0.55	− 0.31	− 0.26
Kurtosis	1.82	1.75	1.84
Jarque-Bera	4.75	3.58	2.99
Probability	0.09	0.17	0.22
Sum	244.21	488.75	1105.42
Sum sq. dev.	13.41	22.03	16.63

EC, CO, and RGDP represent electricity consumption, carbon dioxide consumption, and real GDP, respectively

of integration in the VAR and $d_{\max}$ is the maximum integration order.

The VAR $(k + d_{\max})$ is constructed as

$$\begin{aligned}\ln \mathrm{EC} = \beta_0 &+ \sum_{i=1}^{k} \beta_{1i} \ln \mathrm{EC}_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \ln \mathrm{EC}_{t-j} \\ &+ \sum_{i=1}^{k} \alpha_{1i} \ln \mathrm{CO}_{2,t-i} + \sum_{j=k+1}^{d_{\max}} \alpha_{2j} \ln \mathrm{CO}_{2,t-j} \\ &+ \sum_{i=1}^{k} \delta_{1i} \ln \mathrm{RGDP}_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \ln \mathrm{RGDP}_{t-j} + \varepsilon_{1t}\end{aligned} \tag{8}$$

$$\begin{aligned}\ln \mathrm{CO}_2 = \alpha_0 &+ \sum_{i=1}^{k} \alpha_{1i} \ln \mathrm{CO}_{2,t-i} + \sum_{j=k+1}^{d_{\max}} \alpha_{2j} \ln \mathrm{CO}_{2,t-j} \\ &+ \sum_{i=1}^{k} \beta_{1i} \ln \mathrm{EC}_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \ln \mathrm{EC}_{t-j} \\ &+ \sum_{i=1}^{k} \delta_{1i} \ln \mathrm{RGDP}_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \ln \mathrm{RGDP}_{t-j} \\ &+ \varepsilon_{2t}\end{aligned} \tag{9}$$

$$\begin{aligned}\ln \mathrm{RGDP} = \delta_0 &+ \sum_{i=1}^{k} \delta_{1i} \ln \mathrm{RGDP}_{t-i} \\ &+ \sum_{j=k+1}^{d_{\max}} \delta_{2j} \ln \mathrm{RGDP}_{t-j} + \sum_{i=1}^{k} \alpha_{1i} \ln \mathrm{CO}_{2,t-i} \\ &+ \sum_{j=k+1}^{d_{\max}} \alpha_{2j} \ln \mathrm{CO}_{2,t-j} + \sum_{i=1}^{k} \beta_{1i} \ln \mathrm{EC}_{t-i} \\ &+ \sum_{j=k+1}^{d_{\max}} \beta_{2j} \ln \mathrm{EC}_{t-j} + \varepsilon_{3t}\end{aligned} \tag{10}$$

Empirical results

In time series analysis, the need for inspection of visual plots (eyeball test) is crucial. Figure 1 shows the visual plot of the series in this current study. Figure 2 reveals noticeable evidence of possible structural break(s). Thus, the need for estimators that accounts for such is crucial. Table 2 reports the descriptive statistic for each variable. Table 2 reveals that all series are negatively skewed. Also

Table 3 Pearson correlation estimates

	lnEC	$\ln CO_2$	lnRGDP
lnEC	1		
T-statistic	–		
P value	–		
$\ln CO_2$	0.99	1	
T-statistic	43.75	–	
P value	0.00*	–	
lnRGDP	0.99	1	1
T-statistic	37.59	86.47	–
P value	0.00*	0.00*	–

Correlation is significant at *1% and **5%, respectively

Table 4 KPSS unit root analysis

	Level		First differences	
	H_0: $I(0)$		H_0: $I(0)$	
Series	KPSS[a]	KPSS[b]	KPSS[a]	KPSS[b]
lnEC	0.21**	0.79*	0.1	0.52***
$lnCO_2$	0.19**	0.82*	0.17**	0.24
lnRGDP	0.19**	0.83*	0.09	0.31

Single, double, and triple asterisks denote significance at 1, 5, and 10% levels, respectively

[a] Test allows for a constant and a linear trend; one-sided test of the null hypothesis that the variable is stationary; 1, 5, and 10% critical values equals 0.21, 0.14, and 0.11, respectively

[b] Test allows for a constant; one-sided test of the null hypothesis that the variable is stationary; 1, 5, and 10% critical values equals 0.73, 0.46, and 0.34, respectively

Table 5 ZA [1992] tests for unit root under a single structural break

	Statistics (level)			Statistics (first difference)			Conclusion
	ZA_I	ZA_T	ZA_B	ZA_I	ZA_T	ZA_B	
lnEC	− 1.68	− 3.89	− 3.45	− 7.1*	− 6.61*	− 6.77*	*I*(1)
Time break	1981	1983	1991	1978	1986	2007	
Lag length	0	0	0	0	0	0	
$lnCO_2$	− 1.15	− 1.91	− 1.77	− 3.89	− 4.96*	− 6.2*	*I*(1)
Time break	2008	1991	1993	2007	2007	2004	
Lag length	1	1	1	1	1	1	
lnRGDP	− 3.38	− 3.42	− 3.33	− 6.43*	− 5.76*	− 6.24*	*I*(1)
Time break	1980	1989	1980	1993	1981	1993	
Lag length	1	1	1	0	0	0	

EC is the electricity consumption, CO_2 is the carbon dioxide consumption, and RGDP is the real gross domestic product. All of the variables are at their natural logarithms. ZA_I represents the model with a break in the intercept; ZA_T is the model with a break in trend; ZA_B is the model with a break in both the trend and intercept. Asterisk indicates significance at 1% level

seen is normally distributed series, with the exception of electricity consumption which is significant at 10% level.

Furthermore, Table 3 presents the Pearson correlation coefficient results between variables. A positive significant

Table 6 Maki (2012) cointegration test under multiple structural breaks economic model: lnEC = *f* ($lnCO_2$, lnERGDP)

Number of break points		Test statistics [critical values]	Break points
$m \leq 1$			
	Model 0	− 4.71 [− 5.00]	2009
	Model 1	− 4.83 [− 5.35]	1979
	Model 2	− 4.63 [− 5.55]	1991
	Model 3	− 4.93 [− 6.05]	1991
$m \leq 2$			
	Model 0	− 4.98 [− 5.21]	1997; 2007
	Model 1	− 5.89 [− 5.51]*	1979; 2006
	Model 2	− 5.07 [− 6.09]	1991; 2007
	Model 3	− 6.31 [− 6.65]	1975; 1991
$m \leq 3$			
	Model 0	− 5.59 [− 5.39]*	1987; 1997; 2007
	Model 1	− 6.38 [− 5.69]*	1979; 1990; 2006
	Model 2	− 5.70 [− 6.51]*	1979; 1991; 2007
	Model 3	− 7.28 [− 7.14]*	1975; 1991; 2007
$m \leq 4$			
	Model 0	− 5.61 [− 5.55]*	1983; 1987; 1997; 2007
	Model 1	− 6.91 [− 5.83]*	1979; 1990; 1995; 2006
	Model 2	− 5.73 [− 6.87]	1979; 1991; 1997; 2007
	Model 3	− 7.97 [− 7.63]*	1975; 1991; 1997; 2007
$m \leq 5$			
	Model 0	− 6.03 [− 5.76]*	1983; 1987; 1997; 2007; 2010
	Model 1	− 6.98 [− 5.99]*	1979; 1985;1990; 1995; 2006
	Model 2	− 7.74 [− 7.28]*	1974; 1979; 1991; 1997; 2007
	Model 3	− 9.31 [− 8.12]*	1975; 1979; 1991; 1997; 2007

Numbers in brackets show critical values at 5% significance level from Table 1 of Maki (2012). Asterisk indicates significance at 5% level

Table 7 DOLS estimation of the level EC equation

Variable	Coefficient	Std. error	T-statistic	*P* value
$lnCO_2$	0.87***	0.46	1.88	0.06
lnRGDP	0.77	0.69	1.12	0.27
Constant	− 22.55***	12.29	− 1.83	0.07
Trend	− 0.44*	0.01	− 3.65	0.00
R-squared	0.99			
S.E. of regr.	0.05			
Long-run variance	0.01			

Single, double, and triple asterisks denote significance at 1, 5, and 10% levels, respectively

correlation coefficient exists between all the series in this study. This pattern of association provides useful insight in the study area.

According to the results from Table 4, Kwiatkowski et al.'s (1992) stationarity test for *lnEC*, $lnCO_2$, and *lnRGDP* is all integrated of order 1, that is, *I*(1), which means that the series are not stationary in levels, but stationary at first differences at 1% significance level. Similarly, Table 5 reports the ZA unit root test results. The null hypothesis that there is a unit root under a single structural break cannot be rejected at their level forms for *lnEC*, $lnCO_2$, and *lnRGDP*. All the variables however became stationary at their first difference, *I*(1).

Table 5 reports Zivot and Andrews (1992) unit root test results, suggesting that all the data series are integrated of the same order when breaks are allowed. Based on these results, Maki (2012) cointegration test is most appropriate to analyze long-run relationship among the variables.[4] The long-run equilibrium relationship between electricity consumption, CO_2 emissions, and real GDP under multiple structural breaks is reported in Table 6. The null hypothesis of no cointegration is rejected under the existence of multiple structural breaks for different models of Maki (2012).

The dynamic ordinary least square (DOLS) approach is applied to find long-run coefficients and the results are provided in Table 7. CO_2 emissions have inelastic, positively statistically significant effects on electricity consumption. However, economic growth has inelastic, positive, and statistically insignificant at all significance levels.

Toda and Yamamoto (1995) causality test is employed to find the direction of the causal relationship between the variables. According to Table 8, there is a unidirectional relationship running from electricity consumption (EC) to carbon dioxide emissions (CO_2). Similarly, causal relationship is seen running from economic growth to electricity consumption. This implies that any percentage change in CO_2 emissions and economic growth in Pakistan causes change in electricity

[4] For brevity, the results of the Johansen cointegration also reconcile with the Maki cointegration test results. The simulation can be made available upon request.

Table 8 Toda and Yamamoto (1995) causality analysis

Hypothesis	Chi-square *P* value	Decision
lnEC does not cause $lnCO_2$	0.01**	Reject
$lnCO_2$ does not cause *lnEC*	0.28	Fail to reject
lnRGDP does not cause *lnEC*	0.02**	Reject
lnEC does not cause *lnRGDP*	0.38	Fail to reject
$lnCO_2$ does not cause *lnRGDP*	0.79	Fail to reject
lnRGDP does not cause $lnCO_2$	0.13	Fail to reject

Double asterisk indicates 5% significance level

consumption. Furthermore, our empirical findings validate the economic-electricity growth nexus. Energy-intensive economic activities such as industrial and agricultural production processes increase the demand for energy. On the other hand, there is a tradeoff between environmental quality and economic growth. This claim, popularly referred to as the environmental Kuznets curve (EKC) hypothesis, was first validated by Grossman and Krueger (1991).

Figure 3 shows the flow chart of the causality results. This study reviews causal effect from economic growth to electricity consumption, thus validating the conservative hypothesis. However, this study also reviews causal effect from electricity consumption to carbon dioxide emissions, implying that industrial activities trigger increased carbon emissions flaring which in turn translates into environmental degradation.

Concluding remark/policy implications

This study investigates the causal interaction among electricity consumption, real gross domestic product, and carbon dioxide emissions in Pakistan within a multivariate econometric framework that accommodates structural break(s), given the asymptotic traits of most financial and economic datasets. The data for this study was sourced from the World Bank development indicators' database (https://data.worldbank.org/indicator) from 1971 to 2014. Our study leverages on relatively new econometric estimators that thrive in the presence of structural breaks and also give robust and reliable estimates. The unit root properties and asymptotic traits of the series are validated by Zivot and Andrews

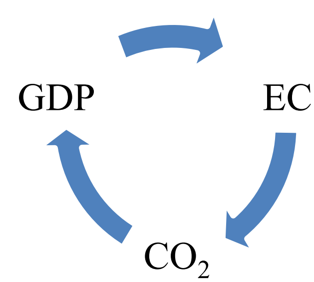

Fig. 3 Causality flow chart

(1992) unit root test that accounts for a single structural break and Kwiatkowski et al. (1992) stationarity test. Tables 4 and 5 report the unit root test with KPSS stationarity test and ZA unit root test. The empirical results are in harmony and reveal that all series are integrated of order one. For long-run equilibrium relationship, Maki (2012) was utilized with null hypothesis of no cointegration.

Our study finds cointegration among the series in the presence of structural breaks. This implies that a long-run bond exists among electricity consumption, real gross domestic product, and carbon dioxide emissions. Next, our study examines direction of causality by Toda and Yamamoto (1995) Granger causality test. The TY causality test reveals the following: (i) unidirectional causality is found running from electricity consumption to carbon dioxide emission. This implies that electricity consumption triggers industrialization and translates into environmental degradation in Pakistan. (ii) Similarly, unidirectional causality is also found running from economic growth to electricity consumption. Thus, our findings resonate with the economic growth-induced electricity consumption hypothesis (Mehrara 2007; Jamil and Ahmad 2010; Baranzini et al. 2013; Gokmenoglu et al. 2015). For example, similar to this study, Itodo et al. (2017) also affirm that increased economic growth increases industrial production activities and, by extension, increases carbon dioxide emission. On the contrary, Dlamini et al. (2015) find unidirectional Granger causality running from electricity consumption to GDP with the adoption of bootstrap rolling window techniques, while Hamdi et al. (2014) find feedback causal effect between electricity consumption and economic growth in Bahrain. Also, Soytas and Sari (2006) interestingly show no causal interaction among the bloc of countries studied. The variance in results from the various studies could be attributed to methodological disparity and differing sample selection.

The causality analysis shows unidirectional causality running from electricity consumption to CO_2 and from RGDP to electricity consumption. Thus, this study validates the conservative hypothesis in the energy economics literature. Furthermore, from the dynamic causality test result, more economic activities trigger increased income level at both individual and corporate fronts. This translates into increased demand for electricity, and also births industrialization. However, increase in industrial activities has detrimental impact on environment quality.

In summary, the key policy recommendation of our study is that government officials/energy policymakers who design the energy/environment framework in Pakistan should embark on conservative energy policies as such policies will not have adverse effects on economic growth. However, there is a need for them to adopt a policy mix that curbs environmental degradation, since there is a causal relationship between electricity consumption and carbon dioxide emissions. The need to spread the energy portfolio to include renewable energy alternatives such as solar, wind, and biofuel is paramount in the quest to achieve green environment in Pakistan.

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