



An empirical investigation of the determinants of CO₂ emissions: evidence from Pakistan

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Abstract

The aim of this paper is to examine the relationship between CO₂ emissions and its possible determinants and their direction of causality for Pakistan over the period of 1972 to 2017. The survey of literature guides us that the most frequently discussed factors are real GDP per capita, energy consumption, urbanization, trade openness, and financial development. Testing of environmental Kuznets curve (EKC) hypothesis is the most common in environment literature so we also incorporated the real GDP per capita squared term in the model. Autoregressive distributed lag (ARDL) bound testing approach to cointegration with structural break and error correction method (ECM) are applied to the selected time series to investigate the long-run relationship between CO₂ emissions and real GDP per capita, real GDP per capita squared term, energy consumption, urbanization, trade openness, and financial development. The empirical evidence confirms the cointegration among the variables and EKC holds for Pakistan support *H1* of the study, which though contradictory to the previous studies conducted on Pakistan but all of previous work faces the exclusion bias and their findings were skewed. The findings also suggest that energy consumption and urbanization have a positive effect on CO₂ emissions, supporting *H2* and *H3*. However, *H4* and *H5* rejected as trade openness and financial development found positively significant. Moreover, bidirectional Granger causality was exists only between CO₂ emissions and trade openness. The findings suggests that Pakistan need to settle the economic agenda of the nation through the resolution of economic controversies, energy mix need to tilt toward clean and renewable energy, and rural-urban migration need to manage for better air, water, and living.

Keywords CO₂ emissions · GDP · Energy · Urbanization · Trade openness · Financial development · Cointegration · Pakistan

Introduction

Ecosystem is adversely affected by the daily human activities which are responsible for creating serious environmental problems (Morales et al. 2008; Zhou et al. 2015). The emission of gasses especially carbon dioxide (CO₂) in most of these activities is one of the major causes of increase in the

average temperature of the Earth (Intergovernmental Panel on Climate 2013). It is also considered the major cause of pollution having almost 60% role in greenhouse effect along with other contributing factors (Baek and Pride 2014). Since, most of the developing countries are under serious pressure for the achievement of sustainable development goals. Achieving high socio-economic targets with cleaner environment is a real

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challenge for them. Therefore, there is much need to discuss the role of various other factors such as the rapid rural-urban migration, extensive extraction of natural resources, use of fossil fuels, and globalization in relation to the emissions of CO₂ and its impact over the environmental conditions.

An important concept regarding growth-environment nexus is environmental Kuznets curve (EKC). EKC asserts that CO₂ emission increases during the initial stages of industrialization/economic growth; however, with the passage of time and after attaining a certain level of economic growth, a decline in CO₂ emissions starts because of the availability of resources to finance environmentally friendly technologies (Dinda 2004; Marsiglio et al. 2016; Sharma 2011; Sinha and Bhatt 2017). However, such a mechanism does not always hold across countries and times raising concerns and criticism about the EKC on several counts. Many researchers attempted to reconcile the theory and data by introducing additional features into the model such as real GDP, energy consumption, urbanization, financial development, and trade openness (Ahmed et al. 2017; Alam et al. 2012; Ali et al. 2018; Al-Mulali et al. 2015a; Boutabba 2014; Chen et al. 2017; Dai et al. 2018; Hossain 2011; Oh and Bhuyan 2018; Shahzad et al. 2017). The generally accepted assertion about the failure of the EKC hypothesis given in the literature is the exclusion bias that some of other important variables not incorporated into the empirical models that produces spurious findings. In many of the previous studies multiple combinations of explanatory variables have been tested, but due to the missing of one or the other important variable, their findings are skewed toward one or other side. This study incorporated all of the possible determinants of CO₂ emissions like real GDP per capita, energy consumption, urbanization, financial development, and trade openness. All of the selected variables are really important for country like Pakistan, since its environment faces real threats from unplanned inflating cities, 98% of the energy composition contains fossil fuels, and growth rate of the economy majorly depends on large-scale industry which uses/applies obsolete technologies, machinery, and equipments. Unfortunately, due to small pool of engineers and scientists, primitive methodologies are preferred; despite being relatively open economy, the trade of goods and services does not reduce environmental issues. Finance is expanding especially after the IMF led structural reforms but the investment plans are not friendly to environment.

Although EKC hypothesis has rigorously tested in the literature, however, very few empirical studies have tried to give explanation of the potential reasons for the existence of EKC in context of Pakistan. Motivated by these deliberations, this study takes another look at this issue and empirically investigates the effects of different factors such as real GDP per capita, energy consumption, urbanization, financial development, and trade openness on CO₂ emissions. The paper contributes to the existing literature in three ways. Firstly, this

study applies autoregressive distributed lag (ARDL) bound testing approach, with structural breaks, to cointegration, over the period 1972–2017; secondly, this paper adopts a unified framework and examines the relative significance of all the possible factors on CO₂ emissions; and thirdly, this study also test EKC for Pakistan with the aim to draw fresh judgment.

The rest of the study is structured as follows: the “Literature review and hypothesis development” section reviews literature and develops hypotheses. The “Data and methodology” section discusses methodology and data. The “Empirical results and their discussion” section explains empirical findings, and the “Conclusion and policy recommendations” section concludes with policy recommendations.

Literature review and hypothesis development

Enormous amount of literature on environmental quality focuses mainly on the testing of the existence of EKC. Many studies have analyzed several factors of CO₂ emissions in one combination or another but none of the studies have simultaneously incorporated these six factors—CO₂ emissions, real GDP per capita, energy consumption, urbanization, financial development, and trade openness—in the case of Pakistan.

CO₂ emissions and economic growth

The EKC claims that environmental pollution in the initial stages of economic growth will be on the rise while it will improve when a certain level of per capita is achieved. Numerous studies including Al-mulali et al. (2015), Dogan and Seker (2016), Heidari et al. (2015), Jamel and Maktouf (2017), Saboori et al. (2012) and Yavuz (2014), among others, determine the relationship between income and CO₂ emissions and confirm the validity of the EKC hypothesis in different countries and regions. However, the study of Dogan and Turkekul (2016) does not support the existence of the EKC for the USA, Al-Mulali et al. (2015b) for Vietnam, and Farhani and Ozturk (2015) for Tunisia. Antonakakisa et al. (2017), Aye and Edoja (2017), and Sirag et al. (2018) also determined that there is no evidence that developed countries may actually grow-out of environmental pollution. Pollution is not simply a function of income but other factors as well, e.g., environmental pollution, cannot be reduced only with the increase in income; rather, it can be reduced with the effective implementation of government regulations, development of economy with modern technique of production which emits lesser pollution. In developing country like Pakistan, above stated factors as well as absence of well-coordinated institutional, structural, and technical policies concerning pollution reduction retain them from attaining a decreased level of pollution

even when the economic growth is improving. So, unless the above-stated issues are addressed, it is inconvenient for developing countries to pursue the direction that the EKC advocates. However, we hypothesized EKC as follows:

H1: EKC hypothesis holds for Pakistan

CO₂ emissions and urbanization

Extent of literature is available to explain the impact of urbanization on energy use and emissions in two different manners. One belongs to that group which considers that urbanization is one of the significant influencing components that raise energy consumption and emissions (Alam et al. 2007; Nguyen et al. 2017; Pata 2018). On the other side, point out that the process of urbanization increases productivity and efficiency which leads to reducing CO₂ emissions as an outcome of economic agglomeration and economic scale effects (Chen et al. 2017; Han et al. 2017; Raheem and Ogebe 2017). Whereas Xu et al. (2018) in a recent paper determined that urbanization, if studied by individual indicators, does have separate effects on CO₂ emissions. Many other studies show that the influence of urbanization on CO₂ emissions is not similar for all provinces. Different geographical areas have different effects on economic growth, energy, urban development, and environment. Differences in geographical distribution lead to disproportions in regional carbon emissions (Clarke-Sather et al. 2011; Dai et al. 2018; He et al. 2013; Martínez-Zarzoso and Maruotti 2011; Wang and Li 2018; Xin and Kemeng 2014).

H2: Urbanization will be positively associated with CO₂ emissions.

CO₂ emissions and energy consumption

Many studies have investigated the relationship between energy consumption and CO₂ emissions. Energy is one of the major factors of production and observed as a driving force for economic expansion and progress (Sahir and Qureshi 2007). Countries that are experiencing excessive energy utilization have higher living standard. Although, energy consumption also leads to numerous greenhouse gasses (ZiabakhshGanji 2015). Al-mulali and Normee Che Sab (2013) argued that a strong correlation exists between total primary energy consumption, CO₂ emissions, and economic progress. It was also investigated that both total primary energy consumption has a positive causal relationship with the economic development and other economic aspects playing an important role in achieving high economic performance with the consequence of higher pollution. Onafowora and Owoye

(2014) investigate the lasting and effective temporal connection between energy exhaustion and CO₂ discharge for eight developing countries, and their results reveal that energy consumption Granger causes both CO₂ emissions and economic development in all the countries. In another study Menyah and Wolde-Rufael (2010) show an improved version of the Granger causality test and discover unidirectional causality running from energy use to CO₂ emissions. In a study Kasman and Duman (2015) show that there is a positive relationship between per capita emissions and energy utilization.

H3: Energy consumption will be positively associated with CO₂ emissions.

CO₂ emissions and trade openness

International trade has many advocates but there are groups who oppose it, claiming that it has a negative impact on the environment, particularly in the developing countries. However, Ali et al. (2016) concludes in their study that with every 1% increase in trade openness, CO₂ emissions could reduce by 0.3% in Nigeria. Zhang et al. (2017) examines the case of ten newly industrialized countries, and concluded that increase of 1% in international trade results in a 0.2% decrease of CO₂ emissions. In case of Pakistan, a study conducted by Zhang et al. (2018) shows that trade has no impact on environment as it does not result in CO₂ emissions in the atmosphere. In a study conducted on Central and Eastern Europe, NjindanIyke and Ho (2017) found that high level of trade openness results in low CO₂ emissions in the long run. Trade liberalization process was found out to be the most beneficiary to the ready-made garments (RMG) industry in Bangladesh, in a study conducted by Oh and Bhuyan (2018). RMG industry in Bangladesh is the biggest contributor to the exports of the country standing at 81% of the total export income. On the contrary, Ahmed et al. (2017) and Farhani and Ozturk (2015) were of the opinion that trade openness increases the rate of CO₂ emissions in the atmosphere. In a panel study on the causal linkage between trade openness and CO₂ emissions, a negative short-run linkage was found between the two (Hossain 2011). Bombardini and Li (2016) and Shahbaz et al. (2017a) also gave strength to the claim after finding out a positive and significant relationship between trade openness and CO₂ emissions. Bidirectional causality between trade openness and CO₂ emissions was found out by Muhammad et al. (2012). This bidirectionality also exists between trade openness and energy consumption. Sadorsky (2012) conducted a study on South America, and his findings were also an indication of a bidirectional relationship between trade and domestic output. Liddle (2018) did a comparison of consumption-based CO₂ emissions and territory-based CO₂ emissions, and the data revealed that the

consumption-based emissions of most countries are higher than their territory-based emissions, making them net importers of carbon emissions.

H4: Trade openness will be negatively associated with CO₂ emissions.

CO₂ emissions and financial development

Many studies recognize that financial progress encourages economic development and minimize environmental degradation; for example, Diallo and Masih (2017), Jalil and Feridun (2011), Nasreen et al. (2017), and Shahbaz et al. (2013) have shown that financial firmness upgrades environmental standard. On the contrary, Shahzad et al. (2017) illustrates that 1% growth in financial progress will improve CO₂ emissions by 0.17% in case of Pakistan. Ali et al. (2018) results show that financial progress is connected to negative environmental outcome as it generates more carbon emissions in Nigeria. Al-Mulali et al. (2015) confirm for 23 selected European countries that financial development lessens environmental status. Boutabba (2014) has shown that financial progress has a long-term positive effect on carbon emissions.

H5: Financial development will be negatively associated with CO₂ emissions.

Data and methodology

We apply the Cobb-Douglas functional form to examine the relationship between CO₂ emissions and its possible determinants such as real GDP per capita, energy consumption, urbanization, financial development, and trade openness in case of Pakistan for the period 1972 to 2017. Extent of literature is available that have applied similar settings because of many advantages that are associated with Cobb-Douglas functions (Hossain 2011; Farhani and Ozturk 2015; Farhani et al. 2014; Shahbaz and Lean 2012; Sharma 2011), like (i) it can handle multiple inputs in its generalized form and easy to estimate, (ii) it can measure the responses in elasticity form, and (iii) various econometric estimation problems, like serial correlation, heteroscedasticity, and multicollinearity can be handled adequately and easily. The general non-linear form is given below:

$$CO_2 = AY^{\alpha_1} \cdot E^{\alpha_2} U^{\alpha_3} T^{\alpha_4} F^{\alpha_5} \mu^\varepsilon \tag{1}$$

where CO₂ is the CO₂ emission and Y, E, U, T, and F denote the real GDP per capita, energy consumption,

urbanization, trade openness, and financial development, respectively. A and μ represent the technological and residual parameters, respectively. α₁...α₅ are the constant returns to scale (CRS) linked with real GDP per capita, energy consumption, urbanization, trade openness, and financial development, respectively. We convert Eq. 1 into linear specification by taking natural logs for empirical estimation ease and the new model takes the form of log-log linear or double-log form which means that parameters will measure the responsiveness of CO₂ emissions to a change in real GDP per capita, energy consumption, urbanization, trade openness, and financial development in elasticities. The linear model is given as below:

$$\ln CO_{2t} = \ln A + \alpha_1 \ln Y_t + \alpha_2 \ln E_t + \alpha_3 \ln U_t + \alpha_4 \ln T_t + \alpha_5 \ln F_t + \varepsilon_t \tag{2}$$

Suppose lnA = α₀ than Eq. 2 is

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln Y_t + \alpha_2 \ln E_t + \alpha_3 \ln U_t + \alpha_4 \ln T_t + \alpha_5 \ln F_t + \varepsilon_t \tag{3}$$

where lnCO_{2t}, ln Y_t, ln E_t, ln U_t, ln T_t, and ln F_t is the natural logarithm of CO₂ emissions measured as CO₂ metric tons per capita, real GDP per capita in constant 2010 US\$, energy consumption is measured as energy use in kg of oil equivalent per capita, urbanization as urban population (% of total), trade openness as exports and imports of goods and services (% of GDP), and financial development as domestic credit to private sector (% of GDP), respectively. ε_t is the error term and supposed to be normally distributed. All data set were taken from the World Bank Development Indicators (WDI 2018) for the periods 1972 to 2017.

In order to test whether the EKC hypothesis exists when other than income factors are incorporated into the environmental function such as energy consumption, urbanization, trade openness, and financial development, the above model can be modified as follows:

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln Y_t + \alpha_2 \ln Y_t^2 + \alpha_3 \ln E_t + \alpha_4 \ln U_t + \alpha_5 \ln T_t + \alpha_6 \ln F_t + \varepsilon_t \tag{4}$$

where t, α₀ and ε_t denote time, country fixed effect, and error term, respectively, while α₁, α₂...α₆ are long-run elasticities of real GDP per capita, real GDP per capita squared term, energy consumption, urbanization, trade openness, and financial development. As for the expected signs in Eq. 4, it is expected that the coefficients of α₁ and α₂ should be, respectively, positive and negative to hold the EKC hypothesis true.

Numerous studies including Al-Mulali et al. (2015b), Dogan and Seker (2016), Heidari et al. (2015), Jamel and Maktouf (2017), Saboori et al. (2012), and Yavuz (2014) among others determine the relationship between income and CO₂ emissions and confirm the validity of the EKC hypothesis in different countries and regions.

The sign α_3 is expected to be positive because a significant increase in energy consumption may increase economic activity and stimulate CO₂ emissions. Many authors have found this relationship (Al-mulali and Normee Che Sab 2013; Arouri et al. 2012; Farhani et al. 2014; Kasman and Duman 2015; Menyah and Wolde-Rufael 2010; Onafowora and Owoye 2014; Ozcan 2013; ZiabakhshGanji 2015).

The sign α_4 is mixed depending on the level of economic development of a concerned country or a panel of countries. Alam et al. (2007), Nguyen et al. (2017), and Pata (2018) consider that urbanization is one of the significant influencing components that raise energy consumption and emissions. However, Chen et al. (2017), Han et al. (2017), and Raheem and Ogebe (2017) point out that the process of urbanization increases productivity, efficiently decreasing CO₂ emissions as an outcome of economic agglomeration and economic scale effects.

The expected sign of α_5 is mixed as well because it depends on the level of economic development stage of a country. For most developed countries, this sign is expected to be negative because these countries follow a strategy of producing a few quantities of national importing pollution intensive goods, while the basic strategy consists to import those types of goods from other countries with less restrictive environmental protection laws. Many authors including Ali et al. (2016), Oh and Bhuyan (2018), NjindanIyke and Ho (2017), Zhang et al. (2017, 2018) studied this relationship. Per contra, for most developing countries, this sign is reversed for the reason that they tend to produce without having tools or means of environment protection. Thus, they result dirty industries with heavy share of pollutants. This also means that due to a dirty production under weaker environmental regulations of developing countries, a higher level in trade openness will increase pollution. Authors including Ahmed et al. (2017), Bombardini and Li (2016), Farhani and Ozturk (2015), Hossain (2011), Liddle (2018), Muhammad et al. (2012), Shahbaz et al. (2017b), and Sadorsky (2012) determined this relationship. Finally, the sign α_6 is expected to be positive (Ali et al. 2018; Al-Mulali et al. 2015a; Boutabba 2014; Shahzad et al. 2017).

There is a need to have comprehensive analysis to find out the impact of possible determinants of CO₂ emissions. This study tries to determine the long-run and short-run relationships as well as the Granger causality among variables in the system. Time series properties of the data will be checked by applying unit root tests both conventional and structural break, cointegration, and Granger causality. Since we have six

variables in the system, the common econometric practice is to estimate the model in a VAR/VECM framework.

Unit root tests (ADF, PP, Zivot-Andrews)

Numerous unit root tests are available in applied economics to test the stationarity properties of the variables such as Augmented Dickey-Fuller (ADF) by Dickey and Fuller (1979), Phillips-Perron (PP) by Phillips and Perron (1988), and Ng and Perron (2001). These tests may provide biased and spurious results if structural break(s) occur in the series. To circumvent this problem, we apply both conventional as well as structural break unit root tests. Zivot and Andrews (2002) test the stationarity of the series by endogenously detecting the structural break-point.

ARDL bound testing approach to cointegration

As some of the variables under analysis were found stationary at level while, others were found stationary at first difference which allow us to use ARDL bound testing to check the long-run relationship among variables developed by Pesaran et al. (2001, 1999) and argued that ARDL have several advantages over Johansen cointegration and other approaches.

- i) ARDL does not need that all variables are stationary at same order.
- ii) ARDL approach is best in case of small or finite data size.
- iii) Application of ARDL produce unbiased estimates of long-run model.

The below given unrestricted error correction model (UECM) is used for estimation.

$$\begin{aligned} \Delta \ln \text{CO2}_t = & \alpha_0 + \alpha_T T + \alpha_1 \ln \text{CO2}_{t-1} + \alpha_2 \ln Y_{t-1} + \alpha_3 \ln Y_t^2 \\ & + \alpha_4 \ln E_{t-1} + \alpha_5 \ln U_t + \alpha_6 \ln T_{t-1} + \alpha_7 \ln F_{t-1} \\ & + \sum_{i=0}^k \alpha_i \Delta \ln \text{CO2}_{t-i} + \sum_{j=0}^m \alpha_j \Delta \ln Y_{t-j} + \sum_{k=0}^n \alpha_k \ln Y_t^2 \\ & + \sum_{l=0}^o \alpha_l \Delta \ln E_{t-k} + \sum_{m=0}^p \alpha_m \Delta \ln U_{t-l} + \sum_{n=0}^q \alpha_n \Delta \ln T_{t-n} \\ & + \sum_{o=0}^r \alpha_o \Delta \ln F_{t-o} + \varepsilon_t \end{aligned} \tag{5}$$

where Δ is the first difference operator, α_0 is the constant, α_s are the long-run coefficients; k, m, o, p, q and r represent the short-run dynamics, and ε_t is the error term which is assumed to be white noise, respectively. The time trend is indicated by T . AIC is used to select the optimal lag length. Cointegration is to be found if calculated F -statistic is higher than the upper critical bound; otherwise, the decision is in favor of non-cointegration if lower critical bound is more than the

calculated *F*-statistic. The decision about cointegration is questionable if calculated *F*-statistic lies between the upper and lower critical bounds. The stability of ARDL model estimates is tested by applying cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsq) tests.

VECM Granger causality

The confirmation of cointegration between the variables demands us to check the direction of causality between the variables. The Granger causality test suggests that there will be a Granger causality at least from one direction if there exists a

cointegration relationship among the variables provided that the variables are integrated of order one. Engle and Granger (1987) argued that if the Granger causality test is conducted at first difference through VAR method, it will be misleading in the presence of cointegration. Therefore, the inclusion of an additional variable to the VAR method is necessary like the error correction term (ECT) and it would help to capture the long-run relationship. Therefore, ECT is added in the augmented version of Granger causality test. The VECM framework for our model is presented as follows:

$$(1-L) \begin{bmatrix} \ln CO2_t \\ \ln Y_t \\ \ln Y_t^2 \\ \ln E_t \\ \ln U_t \\ \ln T_t \\ \ln F_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} + \sum_{i=1}^p (1-L) \begin{bmatrix} b_{11i} & b_{12i} & b_{13i} & b_{14i} & b_{15i} & b_{16i} & b_{17i} \\ c_{21i} & c_{22i} & c_{23i} & c_{24i} & c_{25i} & c_{26i} & c_{27i} \\ d_{31i} & d_{32i} & d_{33i} & d_{34i} & d_{35i} & d_{36i} & d_{37i} \\ e_{41i} & e_{42i} & e_{43i} & e_{44i} & e_{45i} & e_{46i} & e_{47i} \\ f_{51i} & f_{52i} & f_{53i} & f_{54i} & f_{55i} & f_{56i} & f_{57i} \\ g_{61i} & g_{62i} & g_{63i} & g_{64i} & g_{65i} & g_{66i} & g_{67i} \\ h_{71i} & h_{72i} & h_{73i} & h_{74i} & h_{75i} & h_{76i} & h_{77i} \end{bmatrix} \begin{bmatrix} \ln CO2_t \\ \ln Y_t \\ \ln Y_t^2 \\ \ln E_t \\ \ln U_t \\ \ln T_t \\ \ln F_t \end{bmatrix} + \begin{bmatrix} \theta \\ \vartheta \\ \phi \\ \rho \\ \delta \\ \delta \end{bmatrix} + [ECT_{t-1}] + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \\ \varepsilon_{6t} \\ \varepsilon_{7t} \end{bmatrix} \tag{6}$$

where $(1 - L)$ is the difference operator, ECT_{t-1} is the lagged error correction term. and $\varepsilon_{1t}, \varepsilon_{2t}, \dots, \varepsilon_{7t}$ are the error terms. If there is significant relationship in the first *p* difference of the variables, it will show the short-run causal relationship through the significance of *F*-statistics. A significant coefficient of ECT_{t-1} via its *t*-statistic shows the long-run causality.

Empirical results and their discussion

Table 1 reports the pair-wise correlation and descriptive statistics of the variables. The results of the pair-wise correlation show positive and significant association between CO₂ emissions and real GDP per capita, energy consumption, and urbanization. Sample *t* test was applied to test the significance levels of correlation coefficients. On the basis of initial enquiry, *H2*: that there is a positive association between energy consumption and CO₂ emissions was found true however, this result does not indicate the direction of causality which was actually found in Table 6 of the study. Similarly, *H3* also supported about the main hypothesis *H1* that whether EKC does holds or not? We have not run the correlation between real GDP per capita squared term with CO₂ as it shows a perfect collinearity with the real GDP per capita. The correlation between real GDP and CO₂ emissions was significant at 1%, which may imply that high economic activity is the main cause of environmental pollution in Pakistan. According to the economic survey of Pakistan the level of industrialization/manufacturing is stagnant around 24% for last 4 decades

(Pakistan Economic Survey (PES) 2017–18) and the economy heavily dependent upon the annual growth of industry, especially large-scale manufacturing which does not improve its production processes and still using outdated and obsolete technologies for production. Hence, high growth is only achievable at the cost of environmental pollution. The other two contributors, trade openness and financial development, were found insignificant. Trade openness and financial development could proxy globalization, which in our case was hypothesized as negatively associated with CO₂ emissions. Since, both of these activities does not directly produce carbine dioxide and many studies support this argument in the literature (Astierou et al. 2014; Ren et al. 2014; Shahbaz et al. 2017a).

The descriptive statistics of the study were presented in level for ease of understanding; they could be represented in log form but in that case their interpretation became complex. On average Pakistan pollute the global environment by 84.69 (kt) tons per capita of CO₂ per year, which by any standard is very high compare to the countries having similar economic structure like Turkey, Malaysia, Indonesia, and India, which produce 28.35, 43.91, 25.91, and 45.71 (kt) tons per capita of CO₂ per year, respectively. It not only damages global but also severely affects our local environment, from 2005 earthquake that took 73,000 lives and costs around US \$100 billion to every year heat waves in which temperatures reaches 52°C took many lives and reduces human productivity. The per capita real GDP on average is US \$780, which indicates that Pakistan is a low-middle income country and the living

Table 1 Descriptive statistics

	CO ₂	GDP	Energy consumption	Urbanization	Trade openness	Financial development
CO ₂	1					
GDP	0.7957***	1				
Energy consumption	0.8131***	0.8842***	1			
Urbanization	0.6858***	0.5356***	0.4456***	1		
Trade openness	0.1950	-0.0751	0.2036	-0.1754	1	
Financial development	-0.1969	-0.4719***	-0.1424	-0.4719	0.4228**	1
Mean	84.69	797.93	407.89	32.01	33.05	23.50
Median	78.01	805.98	421.73	31.71	33.29	24.37
Standard deviation	50.51	218.22	75.54	3.99	3.31	3.81
Minimum	18.93	453.79	285.18	25.35	25.31	15.39
Maximum	166.30	1222.52	523.76	39.70	38.91	29.79
Observation	43	46	43	46	46	46

Note. All of the variables are in natural log form in the empirical model. CO₂ is measured in kt tons per capita, GDP (Y) is real GDP per capita in constant 2010 US\$, energy consumption (E) is measured as energy use in kg of oil equivalent per capita, urbanization (U) as urban population (% of total), trade openness (T) as exports plus imports of goods and services as (% of GDP), and financial development (F) as domestic credit to private sector (% of GDP). ***Significant at 1%, **significant at 5%, and *significant at 10%

standard of the people of Pakistan is really low as compare to the region; however, the country is growing and striving hard to improve its people lives, the current real per capita income is US \$1222, and many economist have found very high correlation between per capita income, education, health, and environmental degradation. Extent of literature supports association between high-energy use per capita and economic development; however, the relation between energy use and environment found negative in many studies. But the new form of energy which mostly called green/alternative energy is environment friendly, and 50% of the energy composition mix will be renewable in the globe in 2040; however, in case of Pakistan presently only 2% energy is coming from renewable sources (Pakistan Economic Survey (PES) 2017–18), which means that Pakistan heavily rely on the imported fossil fuels; those are not only unaffordable but also environmentally unfriendly. Around 32% of the population of Pakistan is living in cities and Pakistan is facing very high rural-urban migration phenomenon. Pakistan is fifth largest nation of the world consisting of 207.77 inhabitants and rapid urbanization process is accompanied with major complications, such as traffic congestion, air pollution, water pollution, and resource scarcity (Population Census of Pakistan 2017). The globalization proxies of trade openness and financial development are relatively low as compare to the regional statistics.

Before conducting a formal analysis of the data, time series properties of the variable under analysis were checked. Table 2 of the study reports the results of the unit root tests; three unit root tests were conducted, two conventional, i.e., ADF and PP, and one break-point, i.e., Zivot-Andrews (ZA). According to ADF and PP some of the series were stationary at level, while others on differences; for example, $\ln U_t$ was

found stationary at level. Moreover, their orders of integration were also not found similar.

However, keeping in view the structural breaks that mostly occur in time series data, we apply ZA test that endogenously detect the break-point. All of the series were found stationary at first difference with varying break years; for example, 1993 was found the year of structural break in case of real GDP per capita. The date is perfectly consistent with the implementation/adaptation of IMF-led structural adjustment programs in the country in early 1990s. The program shifts the trend in all of our time series macroeconomic variables as Pakistan has started the liberalization policies of privatization of state-owned enterprises, flexible exchange rate, opening-up of the economy through custom duties and tariff reductions, devaluation of currency, financial reforms, etc. The selection of suitable lag length is necessary for the application of ARDL bound testing approach as the existence of cointegration varies with the lag selection order. Several alternative lag selection criteria have been applied to the data series and AIC was selected being most suitable criteria of lag selection with a lag of 4.

The ARDL bound testing approach to cointegration results was presented in Table 3. Cointegration exists in both equations of 3 without EKC and 4 with EKC as the *F*-statistics were found significant. The break-point of 1978 was found in Eq. 3, which is comparable date in our economic history since, during the 1970s the nationalization of the private-owned enterprises was occurred with the slogan that private businesses exploit their monopoly positions and earned undue profits from the public. In Eq. 4, 1981 was the time shift and that is also align with the IMF-led structural adjustment programs of

Table 2 ADF, PP, and Zivot-Andrews unit root test results

Variable	ADF Statistics, $I(\bullet)$	PP Statistics, $I(\bullet)$	Zivot-Andrews Statistics (k)	Break date
$\ln CO_{2t}$	0.90	0.71	-1.898 (0)	1993
$\Delta \ln CO_{2t}$	-7.50***, $I(0)$	-7.41***, $I(0)$	-8.844*** (0)	1978
$\ln Y_t$	-2.66	5.92	-4.193 (2)	1997
$\Delta \ln Y_t$	-4.99***, $I(1)$	-4.98***, $I(1)$	-5.620*** (0)	1993
$\ln E_t$	0.32	0.31	-2.744 (0)	2006
$\Delta \ln E_t$	-5.01***, $I(1)$	-5.51***, $I(0)$	-6.929*** (0)	2008
$\ln U_t$	-3.28*	2.82	-3.858 (2)	2003
$\Delta \ln U_t$	-0.86*, $I(0)$	-5.30***, $I(1)$	-6.729*** (1)	1981
$\ln T_t$	-2.27	-0.97	-3.635 (0)	1979
$\Delta \ln T_t$	-7.21***, $I(1)$	-9.07***, $I(1)$	-7.991*** (0)	1978
$\ln F_t$	-2.19	-0.63	-4.517 (1)	2003
$\Delta \ln F_t$	-5.27***, $I(1)$	-5.19***, $I(1)$	-6.552*** (0)	2009

Note. ***, **, and * denote the significance level at 1%, 5%, and 10%, respectively. In ADP and PP unit root tests order of integration is presented in parenthesis, while in Zivot-Andrews (ZA) structural break unit root test k indicates lag order, and the lag level is selected on the basis of AIC method, the critical values of the ZA are -5.57, -5.08, and -4.82 at 1%, 5%, and 10%, respectively, from Zivot & Andrews (1992)

1980s when the economic structure of the country was drastically jolted by the economic and finance reform process.

The results of the ARDL test confirm the long-run relationship between the variables in Pakistan and allow us to explore the impact of independent variables on CO₂ emissions. Before proceeding to the long-run elasticities, we additionally run the Johansen cointegration test, presented in Table 4, to check the robustness of the long-run relationship between the variables under study which indicates three cointegrating equations. This test also confirms that long-run relationship between the variables is stable and robust.

Table 5 shows the long-run elasticities of the variables and reveals that EKC holds in case of Pakistan and supports *H1* of the study. The coefficient of real GDP per capita is positively significant, and the coefficient of its squared term was found negatively significant. Our result is contrary to many of the studies on EKC conducted in Pakistan such as Ahmed and Long (2013), Ahmed et al. (2017), and Shahbaz et al. (2016). This contradiction in our finding could be supported as the previous literature in Pakistan on EKC ignores the other important determinants which our study has

incorporated. Our study is more comprehensive on the subject as it takes into account all possible factors that could influence the CO₂ emissions, avoiding potential biases that the previous studies have faced. However, there exists extent of literature that supports our finding like Saboori et al. (2012) for Malaysia, Heidari et al. (2015) for ASEAN region, Yavuz (2014) for Turkey, Al-mulali et al. (2015) for EU region, and Dogan and Turkekul (2016) for USA.

The coefficient of energy consumption is 1.65, which is different from zero at 1% level that implies that a 1% increase in energy use will omit 1.65% CO₂ into the air. The energy mix of Pakistan is heavily tilted toward those fuels that are highly environmentally unfriendly; only 2% energy comes from renewable sources. Our finding is consistent with the work of Sahir and Qureshi (2007) for Pakistan, Menyah and Wolde-Rufael (2010) for South Africa, Ozcan (2013) for Middle East countries, and Al-mulali and Normee Che Sab (2013) for MINA region. Pakistan needs to invest in those energy projects that are environmentally friendly; our comparative advantage also lies in hydropower projects on running water. The installation of IPPs is not only

Table 3 Results of ARDL test (bound testing to cointegration)

Dependent variable	$\Delta \ln CO_{2t}$ (Eq. 3 without GDP ²)	$\Delta \ln CO_{2t}$ (Eq. 4 with GDP ²)
Optimal lag length	2,4,3,3,1,0	1,0,2,3,3,0,3
F -statistics	4.452**	7.235***
Structural break	1978	1981
R^2	0.883	0.911
Adjusted R^2	0.779	0.830

Note. ***, **, and * denote the significance level at 1%, 5%, and 10%, respectively

Table 4 Johansen tests for cointegration results

Hypothesis	Trace statistic	Maximum eigenvalue
None*	210.4631	124.24***
At most 1	127.6218	94.15***
At most 2	74.6058	68.52**
At most 3	43.3884	47.21
At most 4	23.3696	29.68
At most 5	9.7009	12.41
At most 6	0.7996	3.76

Note. *** and ** indicate significance at 1% and 5% levels, respectively

unaffordable but also pollutes our environment (Quadrat-Ullah 2015).

The association between urbanization and CO₂ emissions was also found positive and significant with estimated parameter of 2.76% at 1% level of significance. This is also more than unitary elastic and indicates that high rural-urban migration is environmentally damaging. The cities of Pakistan are inflating in a very rapid rate; e.g., Karachi the largest city grew up 38, Lahore the second largest city inflated by 54%

compared to the previous population census, and the overall population size is 207.77 million making Pakistan fifth largest country in the world. There is dire need to stop the rapid inflows of urban migrants by providing basic facilities in the countryside and improving the absorption capacities of the large cities; otherwise, the existing massy urbanization is not only disastrous for environment but also hampers the efficiency of productive resources.

Trade openness and financial development variables were found positive and significant rejecting *H4* and *H5* of the study. They were considered negatively associated with environmental degradation since they do not directly involve into the production/manufacturing activities. Though their impact is relatively marginal on CO₂ emissions, they are positive and significantly impact the environment of the country. It is highlighted in many of studies on textile sector and even in other sectors that mostly businessmen imports outdated machinery/technology as they find it cheap and do not care its affect on labor and environment. The concerned authorities need to impose certain date limit on the imported machinery and equipments as has already been exercising in case of imported cars. Similarly, commercial banks also instructed

Table 5 Long- and short-run elasticities

Dependent variable $\ln CO_{2t}$			
Variable	Coefficient	Standard error	t-statistics
Long-run results			
$\ln Y_t$	9.2389	1.0222	9.04***
$\ln Y_t^2$	- 1.5737	0.1915	-8.22***
$\ln E_t$	1.6473	0.1351	12.19***
$\ln U_t$	2.7653	0.3671	7.53***
$\ln T_t$	0.0884	0.0504	1.75*
$\ln F_t$	0.0957	0.0414	2.31**
Constant	1.3973	1.2243	1.1413
Short-run results			
$\ln Y_t$	11.1935	6.0727	1.84*
$\ln Y_t^2$	1.9919	1.6540	1.20
$\ln E_t$	1.0657	0.3745	2.85**
$\ln U_t$	106.414	37.411	2.84**
$\ln T_t$	- 0.1807	0.0779	- 2.32*
$\ln F_t$	- 0.1921	0.0534	- 0.36
Constant	- 18.5248	3.0493	- 6.08***
ECT_{t-1}	- 0.6509	0.1749	- 3.7164***
R^2	0.91		
Adjusted R^2	0.83		
F -statistics(p value)	7.2350 (0.0000)		
Diagnostic test			
χ^2_{serial}	F -statistics	Probability value	
χ^2_{serial}	0.4580	0.4986	
χ^2_{serial}	0.4533	0.5006	
χ^2_{Ramsay}	0.1179	0.7540	

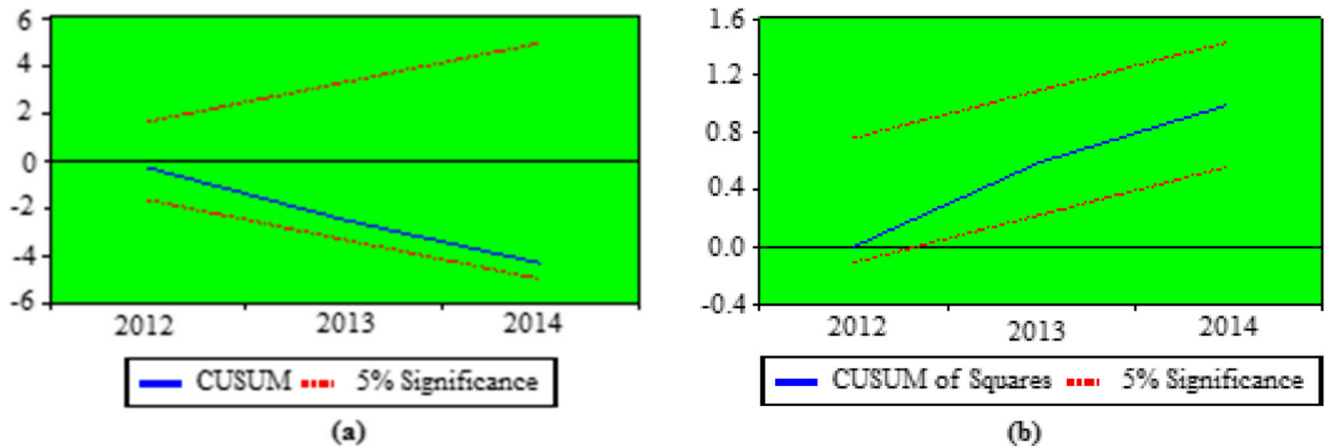


Fig. 1 a Plot of cumulative sum of recursive residuals. b Plot of cumulative sum of squares of recursive residuals

to take care of investment plans on the basis of environment care. The governmental agencies need to strictly implement “the climate change bill of 2017” passed by the parliament of Pakistan to mitigate the environmental threats.

The short-run coefficients do not support EKC in case of Pakistan. However, remaining variables have significant affect on CO₂ emissions except financial development which was found insignificant, although it was marginally significant in case of long-run estimations. On interest result was the negative and significant sign of trade openness which may imply that traded goods and services take longer times to show their actually impact on the environment. The error correction term was found negative and significant at 1%, which shows that the system took 65% corrected from previous year and the speed of adjustment is quite reasonable. The CUSUM and CUSUMSQ tests were also run to check the stability of the long-run parameters. Figure 1 shows that the plotted model is within the critical bounds of 5%, implying that the long-run coefficients are stable.

Table 6 illustrates the results of the Granger causality. The existence of cointegration demands the direction of relationship between the variables; the direction of causality can be divided into short-run and long-run causations. Starting with the long-run

causality, the coefficients of ECM_{t-1} are having negative sign but not significant for all of the equations. ECM_{t-1} term was found significant only when CO₂ emissions, real GDP per capita squared term, and financial development were dependent variables, while for others such as real GDP per capita, energy consumption, and urbanization, it was found insignificant. This implies that bidirectional causality was found for CO₂ emissions and financial development, and if the system is exposed to any shock in the long run, it will recover toward equilibrium at a relatively slow speed of 15% for CO₂ and 42% for financial development.

In the short run, bidirectional causality was found only in case trade openness. However, unidirectional causality was found in case of four variables when CO₂ emission was a dependent variable, i.e., real GDP per capita squared term with negative sign, energy consumption, urbanization, and trade openness with all positive signs, respectively. In case of trade openness it was observed that both affect each other; i.e., high-trade creates environmental threats and environmental issues may compel the policymakers to open the borders for environmentally efficient technologies. The case of unidirectional is also interesting and proves many of the hypotheses that negative sign of real GDP

Table 6 VECM Granger causality test results

Variables	Short-run							Long-run
	$\sum \Delta \ln CO_{2t}$ <i>F-statistics</i>	$\sum \Delta \ln Y_t$	$\sum \Delta \ln Y_t^2$	$\sum \Delta \ln E_t$	$\sum \Delta \ln U_t$	$\sum \Delta \ln Y_t$	$\sum \Delta \ln F_t$	ECM_{t-1} λ_t
$\sum \Delta \ln CO_2$...	0.444	-0.311**	0.732**	0.219*	1.237*	-0.002	-0.15***
$\sum \Delta \ln Y_t$	0.551	...	7.473**	1.401*	-0.355***	-3.163	-1.341	-0.68
$\sum \Delta \ln Y_t^2$	-0.621	2.295***	...	-1.312*	0.05***	0.422	0.321	-0.381*
$\sum \Delta \ln E_t$	0.804	-0.167	-0.895	...	-0.005*	-0.832	-0.684	-0.28
$\sum \Delta \ln U_t$	-1.693	-1.353*	-2.676*	-0.263	...	0.802	1.357*	-0.40
$\sum \Delta \ln Y_t$	0.262**	0.139***	0.783***	0.146***	-0.052*	...	-0.865	-0.26
$\sum \Delta \ln F_t$	0.080	0.534*	0.307*	0.06**	-0.002	-0.196	...	-0.42***

Note. ***, **, and * denote significance at 1%, 5%, and 10%, respectively

per capita squared term indicates EKC, while well-recognized impact of massy urbanization and use of traditional fossil fuels on environmental degradation and finally the positive unidirectional effect of trade openness on CO₂ emissions may be true for developing countries like Pakistan.

Conclusion and policy recommendations

This paper investigates comprehensively the relationship between CO₂ emissions and its possible determinants and their direction of causality. The empirical evidence from the survey of literature guides us that the most frequently discussed factors are as follows: real GDP, energy consumption, urbanization, trade openness, and financial development. Testing EKC is most common in environment literature so we also incorporated the real GDP per capita squared term in the model. The data on the variables is taken from World Bank WDI for the period 1972 to 2017. Cobb-Douglas functional form is applied in the model as suggested by many authors due to its functional superiority over other forms. Extensive amount of literature is available that have many times revisited the subject matter and comes with inconclusive results. In many of the previous studies multiple combinations of the selected variables have been tested, but due to their exclusion bias of one or the other important variable, their findings are skewed toward one or other side. Especially, in case of Pakistan, no such study comprehensive analyzed the phenomena of EKC. All of the selected variables are really important for country like Pakistan since its environment face real threats from unplanned inflating cities, 98% of the energy composition contains fossil fuels, and growth rate of the economy majorly based on large-scale industry which uses/applies obsolete technologies, machinery, and equipments. Unfortunately, due to small pool of engineers and scientists, primitive methodologies are preferred; despite being relatively open economy, the openness of trade of goods and services does not high reduce environmental issues. Finance is expending especially after the IMF led structural reforms but the investment plans are not friendly to environment.

This study encountered a surprising result that EKC holds for Pakistan, which though contradictory to the previous studies conducted on Pakistan but all of those studies faces the exclusion biases and their findings are skewed. In the long-run all elasticities were found confirming the designed hypotheses except trade and finance and these two variables represent globalization. The economic benefits of globalization are well recognized but its environmental benefits are still need to be debated in the global policy circles. Bidirectional causality was found only in case of trade openness but the unidirectional causality when CO₂ emission was the dependent variable was run from real GDP per capita squared term with

negative sign confirming EKC, energy and urbanization with positive signs confirming *H2* and *H3* but with positive sign in case of trade rejecting *H4*.

Few important policy recommendations derived from the results of the study are as follows:

- (i) The confirmation of EKC suggest that Pakistan is in a transitory stage of its growth trajectory since, the country's economic policies faces many controversies, the history of growth process reveals nationalization vs. privatization, inward oriented vs. outward oriented policies, one step forward to economic reforms to two-step backward, agriculture vs. industry, etc.; the political and economic leadership of the country need to settle the economic agenda of the nation to grow faster and to ripe the benefits of cleaner air, water, and natural resources.
- (ii) Pakistan's energy mix depicts very serious threats to the environments; 98% of the energy comes from sources that highly pollute the atmospheres and only 2% comes from renewable energy. The results also confirm this situation as high positive association between CO₂ emissions and energy use was found. The geography of Pakistan reflects unending blessings regarding renewable energy production that is unmatched in the region; for example, Pakistan has more than 300 sunshine days in a year with potential of 2900-GW solar energy and wind speed in Sindh and Balochistan is about 4–12 m/s with height of 10–50 m. These areas have potential of 123 GW (Mirjat et al. 2017; Pakistan Economic Survey (PES) 2017–18; Rafique and Rehman 2017). Government needs to amend 2013 energy policy to focus on small and large hydropower projects, winds, solar, and biomass so as to save money and environment.
- (iii) In the history of mankind, cities are the centers of growth and innovations; rural-urban migration is a natural process of economic well-being, but cities only promise all these advantages if their absorption capacities improve well before their infrastructure crumbles. City and town planning is a high need of Pakistan being fifth largest nation with inflating cities and lake of basic facilities of clean drinking water, cleaner air, and living. The concern authorities need to strengthen local body system and must be empowered financially and administratively so that they can cope with their needs.
- (iv) Both the globalization proxies of trade openness and financial development were a cause of pollution in case of Pakistan. Pakistan needs to redesign its external economic policies focusing more on environmentally friendly trade and investment plans and strict implementation of “climate change bill of 2017” passed by the parliament.

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