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Carbon emission, energy consumption, trade openness and financial development in Pakistan: A revisit

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ABSTRACT

The paper empirically examines the cointegrating relationship between carbon emissions, energy consumption, trade openness and financial development in Pakistan using ARDL bounds test for cointegration procedure. Annual time series data is used for the period 1971–2011. The results reveal an inverted U-shaped relationship between carbon emission and energy consumption with a maximum threshold value of energy consumption per capita 640 kg of oil equivalent. Currently, the economy is operating below this level and therefore it is expected that carbon emission will continue to rise gradually over some time until the threshold level is reached. The lower than threshold level of energy consumption implies that scale and composition effects dominate the technology effect in terms of energy use. Further, the long-run results indicate that one percent increase in trade openness and financial development will increase carbon emission by 0.247% and 0.165%, respectively. The short-run elasticities are 0.122% and 0.087% for trade openness and financial development, respectively. The Granger causality results indicate a unidirectional causality from energy consumption, trade openness and financial development to carbon emission; and a bi-directional causality between energy consumption and financial development. In line with the results and given the growing focus on climate change effects in Pakistan, the paper discusses some policy issues for consideration and highlights the need to interpret elasticities with caution.

1. Introduction

Among greenhouse gas emissions carbon dioxide is the most important as it contributes to 58% of the total greenhouse emissions of the world. Globally carbon emission is increasing at a higher rate since 1970s [9] and Pakistan is no exception. Pakistan has gradually shifted from agriculture driven growth economy to industry-led growth. This industry-led growth has increased energy demand which in turn is increasing pollution in the country. Alongside this, carbon emission is increasing and the country is experiencing adverse effects of climate change. As noted by Cheema [12], the 2015 summer's heatwave was the worst in more than 30 years, which caused more than 1,200 deaths in Karachi alone. In another part of the country, hundreds of people were killed and thousands were left homeless by the floods. According to the Global Climate Risk Index (2015) Pakistan is among the top ten countries which is adversely affected by climate change. Amidst these, the energy crisis in Pakistan is a serious issue, which has adversely affected the economic growth [25]. However, financial sector of Pakistan is showing promising signs of supporting growth and the country's small equity market is ranked among the top performing markets of the world by the Bloomberg.

The weak environmental protection laws have called for government action [13]. In 2005, Pakistan implemented controls on environmental degradation through National Environmental Policy (NEP). The rising carbon dioxide emission in Pakistan is primarily due to the heavy use of petroleum in transportation and industrial sector. Globally,

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although Pakistan contributes a marginal 0.4% of the world's total carbon emissions, this is gradually increasing. Furthermore, during the period 2005–2011, income per capita at 2005 constant dollars has increased from US$693.18 (PKR 48,984.39) to US$755.41 (53,381.94). As a result, the demand for industrial goods and hence energy consumption has increased. The latter has direct association with carbon emission which has increased from 0.86 metric tons to 0.92 metric tons over the same periods.

Against these backdrops, in this paper we examine the relationship between energy consumption and carbon emission. The relationship may be obvious; however, what is interesting and important is to examine the threshold level of energy consumption to examine the tipping point. We examine the non-linear relationship and hence estimate the threshold level of energy consumption in Pakistan. Relying on the vast literature on energy-growth and environmental Kuznet curve (EKC), we draw on some notable and relevant macroeconomic factors besides energy consumption that has a plausible influence on carbon emission in the country. Based on literature we have included trade openness and financial development in our analysis.

It is noted that energy consumption (and hence economic growth) and carbon emission are inextricably linked. Energy consumption releases combustion products, especially carbon emissions, which are polluting the atmosphere. Thus a positive impact of energy consumption is contemplated on carbon emission. Financial development is another source of carbon emission [55,63]. Financial development gives more access to the financial capital to both business firms and households. This increases the demand for machinery, automobiles, etc., which increases manufacturing and transport activities. The increasing consumption of energy, in turn, elevates carbon emissions into the air and of organic pollutants into water [47]. In turn, developed financial markets provide capital for renewable energy sector and offer credits for environmental friendly projects at low financing costs, which can help to reduce energy use and carbon emissions by stimulating technological progress in the energy sector [59]. Financial development also promotes research and development activities and hence improves environmental quality. Thus, the overall effect of financial development on energy consumption is equivocal.

Trade openness is also an important variable which affects carbon emission and environment. Trade openness has three types of effects on environment i.e. technology effect, scale effect and composition effect [8]. In technology effect, when trade increases it helps to improve technology which in turn decreases carbon emission. In scale effect, free trade increases trade volume and output, which subsequently results in deleterious effect on the environment. Finally, in composition effect, developing countries attract pollution intensive industries which subsequently contribute to the deterioration of the environment. It indicates that technology effect has positive effect while scale and composition effects have negative effects on carbon emission and environment. The net effect of trade openness on environment is ambiguous as it depends on which effect is dominant of the three. Generally, scale and composition effects are dominant and both of which have adverse impact on the environment. For developing country like Pakistan, we argue that both trade openness and financial development will have a positive impact on carbon emission because greater focus is on increasing investment and creating employment than ensuring green production.

Copeland and Taylor [14] stipulate two types of hypotheses to explain nexus between trade openness and environment: pollution haven hypothesis and factor endowment hypothesis. According to the pollution haven hypothesis, low income countries with weak environmental regulation will specialize in the production of the polluting goods and multinational companies will take advantage of this by reallocating their polluting industries into these countries. As a result, low income countries will become havens for polluters so trade openness will deteriorate environment in these countries, while rich countries will benefit from free trade. Factor endowment hypothesis stipulates that capital rich countries will specialize in the production of the capital-intensive goods without any consideration given to the environmental policy. Consequently, rich countries by exporting goods will become dirtier and countries that are relatively abundant in resources that are used in the production of the clean goods will become cleaner with free trade. It again indicates that the relationship between free trade and environment is ambiguous as it depends on the distribution of the comparative advantages among countries. In a recent study, Mavragani et al. [30] examine the extent to which the openness and the quality of the institution affect environmental performance using a large dataset of 75 countries and environmental performance index (EPI). The study shows a significant positive correlation between a country's economic growth, the openness of an economy, high levels of effective governance, and its EPI.

The purpose of this study is to empirically evaluate the nexus between carbon emission and macroeconomic variables in Pakistan. Our paper differs from other similar studies [34,54,57] in the sense that the focus of the paper is not on establishing the environmental Kuznet curve (EKC) but to estimate the threshold effect of energy consumption and the magnitude effects of trade openness and financial development on carbon emission. More specifically, we formulate carbon emission as a function of energy consumption, trade openness and financial development. Unlike previous studies, we exclude per capita income, since the latter is directly related to energy consumption, as noted from the huge literature on energy-growth nexus. In estimating the model in this manner, we derive, based on the threshold level of energy consumption, the dominating effects between technology, scale, and composition, where the former is considered to enhance the environment. Moreover, by showing the basic mathematical derivations, we highlight that the coefficients of non-linear estimation for variable which is associated with the squared-term should not be interpreted as elasticity coefficients (as in [57]) and should only be used for computing threshold values.

The rest of the paper is set out as follows. Section 2 provides literature review. Section 3 presents econometric methodology. Section 4 presents the estimated results. The final section concludes the paper.

2. Literature survey

The economic studies relating to cointegrating and causality in relation to carbon emission and macroeconomic factors are growing, see e.g. [39,40,56,3,19,49,28]. There are also studies which have focussed Pakistan [34,54]. However, the findings are at odds. The differences in the studies are due to differences in sample size, model specification, estimation technique, among other things. While the goal of most of these studies is to establish EKC hypothesis, only few studies quantify the threshold effects. Moreover, these studies consider energy consumption and income as independent variable in the model specification ignoring their 'obvious' multicollinearity. Tables 1–3 provide a list of studies that have examined the causality nexus. Literature review reveals that the research related to the effect of financial development on carbon emission and environmental degradation is still new and has been encouraged for further policy [47,58]. We use these studies as a guide to specify the relationship between carbon emission and energy consumption.

3. Econometric methodology

3.1. Model

Our model for estimation is as follows:

$$\ln CO2_t = \alpha_0 + \alpha_1 \ln ENG_t + \alpha_2 (\ln ENG_t)^2 + \alpha_3 \ln TRD_t + \alpha_4 \ln FIN_t + \alpha_5 T + \varepsilon_t \quad (1)$$

where $T \in \{TB_x, Trend\}$, such that TB_x is structural break in series x

Table 1
A sample of studies supporting CO_2-energy consumption causality.

Country/Region	Reference	Country/Region	Reference
CO2→ENG		***ENG↔CO2***	
China	Zhang [63]	ASEAN	Lean and Smith [28]
Tunisia	Farhani and Ozturk [16]	Brazil, Russia, India, China	Pao and Tsai [39]
23 European countries	Al-Mulali et al. [5]	MENA countries	Al-Mulali [1]
MENA (Middle East and North African) region	Al-Mulali and Ozturk [2]	19 Selected Countries	Al-Mulali and Sab [3]
Latin America and the Caribbean countries	Al-Mulali et al. [6]	Sub-Saharan African Countries	Al-Mulali and Sab [4]
		Indonesia	Shahbaz et al. [52]
		Portugal	Shahbaz et al. [53]
ENG→CO2		***CO2 $\nleftrightarrow$ ENG***	
United States (US)	Menyah and Rufael [31]	Newly Industrialized countries	Hossain [19]
Russia	Pao et al. [41]	Brazil	Pao and Tsai [40]
14 MENA countries	Omri [36]	UAE	Sbia et al. [49]
EU member countries	Kasman and Duman [23]	Saudi Arabia	Alshehry and Belloumi [7]
		Pakistan	Nasir and Rehman [34]

Note: CO_2=carbon emission; ENG=energy consumption.

Table 2
A sample of studies supporting CO2-trade causality.

Country/Region	Reference	Country/ Region	Reference
CO2→TRD		***TRD↔CO2***	
Tunisia	Farhani and Ozturk [16]	Middle Eastern countries	Al-Mulali [1]
		Indonesia	Shahbaz et al. [52]
TRD→CO2		***CO2 $\nleftrightarrow$ TRD***	
BRIC Countries	Tamazian et al. [59]	Turkey	Halicioglu [18]
Newly Industrialized countries	Hossain [19]	China and India	Jayanthakumaran et al. [20]
China	Michieka et al. [32]	Turkey	Ozturk and Acaravci [38]
South Africa	Shahbaz et al. [52]	South Africa	Kohler [24]
India	Yang and Zhao [62]	Brazil, India, South Africa	Sebri and Ben-Salha [50]
12 MENA countries	Omri et al. [37]	Tunisia	Farhani et al. [17]
MENA (Middle East and North African) region	Al-Mulali and Ozturk [2]	India	Boutabba [10]
EU member countries	Kasman and Duman [23]	23 European countries	Al-Mulali et al. [5]
		Pakistan	Nasir and Rehman [34]

Note: CO_2=carbon emission; TRD = trade openness.

identified through break point tests, and ε is error term; α_1 and α_2 is the coefficient of $lneng$ and $(lneng_t)^2$, respectively.

Note that α_1 cannot be interpreted directly as the respective share of$\hat{eng}$. The first order partial derivative of Eq. (1) with respect to energy consumption then becomes$\frac{\partial(lny\hat{Co}2_t)}{\partial(ln\hat{eng}_t)}=\alpha_1+2\alpha_2(ln\hat{eng}_t)$. Thus, after setting the first derivative equal to zero and solving for the amount of energy consumption per capita, we get $eng^{*}=e^{\frac{-\alpha_1}{2\alpha_2}}$ as a candidate for an optimum. Further, if the respective second order derivative evaluated at $\hat{eng}^{*}$ exceeds zero $\left(\frac{\partial^2(ln\hat{Co}2_t)}{\partial(ln\hat{eng})^2}=2\alpha_2>0\right)$ then $\hat{eng}^{*}$ represents a minimum and implies a U-shaped relationship between $\hat{Co}2_t$ and $\hat{eng}$, and $\hat{eng}^{*}$ represents a threshold. By the same token, if $\frac{\partial^2(ln\hat{Co}2_t)}{\partial(ln\hat{eng})^2}=2\alpha_2<0$ evaluated at $\hat{eng}^{*}$, then an inverted U-shaped relationship results, implying a maximum. Nevertheless, if $\frac{\partial^2(ln\hat{Co}2_t)}{\partial(ln\hat{eng})^2}=2\alpha_2=0$, then the relationship is monotonic and$\hat{eng}^{*}$ represents a saddle point. In statistical sense, where α_2 is not statistically significant within the conventional levels, then we reject non-linear relationship and accept a linear relationship between energy consumption and carbon emission (see [26]). Further, the $\alpha_3>0$ and $\alpha_4>0$ are the elasticity coefficients of trade openness and financial development, respectively.

Table 3
A sample of studies supporting CO2-financial development causality.

Country/Region	Reference	Country/Region	Reference
CO2→FIN		***FIN↔CO2***	
Tunisia	Farhani and Ozturk [16]	19 Selected Countries	Al-Mulali and Sab [3]
		Latin America & Caribbean countries	Al-Mulali et al. [5]
FIN→CO2		***CO2 $\nleftrightarrow$ FIN***	
BRIC Countries	Tamazian et al. [59]	Turkey	Ozturk and Acaravci [38]
China	Zhang [63]	South Africa	Shahbaz et al. [56]
Sub-Saharan African Countries	Al-Mulali and Sab [4]	India	Boutabba [10]
Tunisia	Shahbaz and Lean [51]	23 European countries	Al-Mulali et al. [5]
Indonesia	Shahbaz et al. [52]	12 MENA countries	Omri et al. [37]
Portugal	Shahbaz et al. [53]	GCC countries	Salahuddin et al. [48]

Note: CO_2=carbon emission; FIN=financial development.

3.2. Unit root tests

The reliability of statistical inference depends on the distinction between stationary and non-stationary (or integrated) time series. Shocks to a stationary time series are momentary due to constant mean and variance over time. In turn, non-stationary time series has time dependent mean and variance giving rise to permanent fluctuations after shock. Keeping in view the importance of peculiar characteristics of time series, it is necessary to check the stationarity properties of the variables using appropriate unit root tests. In literature, various time series unit root tests have been proposed to check the stationary properties of the variables. However, this study has applied some important unit root tests such as ADF, Phillips-Perron and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit roots tests. Further, to examine the break points in the series, we will use the single break unit root tests of Perron [42] and Zivot and Andrews [64].

3.3. Cointegration analysis

To investigate long-run cointegrating relationship among the variables several econometric techniques have been proposed in the literature. Univariate cointegration examples include Engle and Granger [15] and the fully modified OLS procedures of Phillips and Hansen [46]. With regard to multivariate cointegration, Johansen [21] and Johansen and Juselius [22] full information maximum likelihood procedures are widely used in empirical research. Johansen cointegration technique is preferred over other techniques as it is not only a multivariate technique, it also gives more than one cointegrating relations and overcomes small sample bias. However, one common problem with these cointegration techniques is that they require that all variables should be integrated of the same order.

The Autoregressive Distributed Lag (ARDL) procedure of Pesaran and Smith [44] and Pesaran et al. [45] has some advantages over other cointegration techniques. Firstly, it provides fairly robust results even when all the variables are endogenous. Secondly, it enables long and short-run parameters of the model to be estimated simultaneously. Thirdly, it can be applied regardless of whether the underlying variables are I(0), I(I), or fractionally integrated. Finally, it is suitable for small sample sizes [35,45]. We apply the ARDL model to check cointegration among carbon emissions (CO_2), energy consumption (ENG), trade openness (TRD) and financial development (FIN).

The following ARDL equation will be estimated to examine the cointegration relationship:

$$\Delta \ln CO2_t = \beta_0 + \beta_1 \ln CO2_{t-1} + \beta_2 \ln ENG_{t-1} + \beta_3 (\ln ENG_{t-1})^2 + \beta_4 \ln TRD_{t-1} + \beta_5 \ln FIN_{t-1} + \beta_6 T + \sum_{i=1}^{p} \alpha_i \Delta \ln CO2_{t-i} + \sum_{j=0}^{q} \alpha_j \Delta \ln ENG_{t-j} + \sum_{k=0}^{r} \alpha_k \Delta \ln TRD_{t-k} + \sum_{l=0}^{s} \alpha_l \Delta \ln FIN_{t-1} + \varepsilon_t \quad (2)$$

To identify co-integration among variables, two steps are involved. First, Eq. (2) is estimated using the ordinary least squares technique. Second, testing the null hypothesis of no co-integration ($H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$) is tested against the alternative hypothesis of the existence of a long run relationship ($H_1: \beta_1 \neq 0; \beta_2 \neq 0; \beta_3 \neq 0; \beta_4 \neq 0; \beta_5 \neq 0$),. The existence of a long run cointegrating relationship is examined by the corresponding F- and W-statistics. We reject the null hypothesis of no co-integration when F-statistics is above the upper bound critical values $\{F - stat > I(1)_{critical}\}$ and do not reject the null when F-statistics is below the lower bound critical values $\{F - stat < I(0)_{critical}\}$. However, if the F-statistics is within the upper and lower bound critical values, $\{I(0)_{critical} < F - stat < I(1)_{critical}\}$, then the outcome is inconclusive. We compute the bounds using Microfit (Mfit) 5.0 [43] tool, which is the successor of Mfit 4.1 [45]. The advantage of the former is that one can compute the critical F- and W-statistics at the corresponding 90% and 95% bounds by stochastic simulations using 20,000 replications with the given sample size, thus providing a sample adjusted outcome. Moreover, we also use the bounds reported by Narayan [33] for small sample size $30 \leq n \leq 80$ to support the decision regarding cointegration. Once the cointegration is confirmed within the conventional levels of significance, the next step is to estimate the long-run and short-run results, and to examine the diagnostic tests to ensure that the model is stable.

3.4. Causality analysis

To examine the direction of causality, we use the Granger non-causality test of Toda and Yamamoto [60]. This method has some advantages: (a) one can examine causality among variables which are I(0), I(1) or I(2), not co-integrated or co-integrated of an arbitrary order; and (b) the method fits well with the ARDL procedure as the part of the information such as lag-length and maximum order of integration are used to carry out this analysis. To examine the causality, the equations are expressed in the following vector autocorrelation regression (VAR) form:

$$\ln CO2_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} \ln CO2_{t-i} + \sum_{j=k+1}^{d\max} \alpha_{2j} \ln CO2_{t-j} + \sum_{i=1}^{k} \eta_{1i} \ln ENG_{t-i} + \sum_{j=k+1}^{d\max} \eta_{2j} \ln ENG_{t-j} + \sum_{i=1}^{k} \varphi_{1i} \ln TRD_{t-i} + \sum_{j=k+1}^{d\max} \varphi_{2j} \ln TRD_{t-j} + \sum_{i=1}^{k} \pi_{1i} \ln FIN_{t-i} + \sum_{j=k+1}^{d\max} \pi_{2j} \ln FIN_{t-j} + \lambda_{1t} \quad (3)$$

$$\ln ENG_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} \ln ENG_{t-i} + \sum_{j=k+1}^{d\max} \alpha_{2j} \ln ENG_{t-j} + \sum_{i=1}^{k} \eta_{1i} \ln CO2_{t-i} + \sum_{j=k+1}^{d\max} \eta_{2j} \ln CO2_{t-j} + \sum_{i=1}^{k} \varphi_{1i} \ln TRD_{t-i} + \sum_{j=k+1}^{d\max} \varphi_{2j} \ln TRD_{t-j} + \sum_{i=1}^{k} \pi_{1i} \ln FIN_{t-i} + \sum_{j=k+1}^{d\max} \pi_{2j} \ln FIN_{t-j} + \lambda_{1t} \quad (4)$$

$$\ln TRD_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} \ln TRD_{t-i} + \sum_{j=k+1}^{d\max} \alpha_{2j} \ln TRD_{t-j} + \sum_{i=1}^{k} \eta_{1i} \ln CO2_{t-i} + \sum_{j=k+1}^{d\max} \eta_{2j} \ln CO2_{t-j} + \sum_{i=1}^{k} \varphi_{1i} \ln ENG_{t-i} + \sum_{j=k+1}^{d\max} \varphi_{2j} \ln TRD_{t-j} ENG + \sum_{i=1}^{k} \pi_{1i} \ln FIN_{t-i} + \sum_{j=k+1}^{d\max} \pi_{2j} \ln FIN_{t-j} + \lambda_{1t} \quad (5)$$

$$\ln FIN_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} \ln FIN_{t-i} + \sum_{j=k+1}^{d\max} \alpha_{2j} \ln FIN_{t-j} + \sum_{i=1}^{k} \eta_{1i} \ln CO2_{t-i} + \sum_{j=k+1}^{d\max} \eta_{2j} \ln CO2_{t-j} + \sum_{i=1}^{k} \varphi_{1i} \ln TRD_{t-i} + \sum_{j=k+1}^{d\max} \varphi_{2j} \ln TRD_{t-j} + \sum_{i=1}^{k} \pi_{1i} \ln ENG_{t-i} + \sum_{j=k+1}^{d\max} \pi_{2j} \ln ENG_{t-j} + \lambda_{1t} \quad (6)$$

The term $(\ln ENG_t)^2$ is not included in the above the specifications to avoid making the equation(s) cumbersome. However, we included this term during estimation. In Eq. (3), causality runs from $\ln ENG$, $\ln TRD$and $\ln FIN$ to $\ln CO2$, which implies that $\eta_{1i} \neq 0 \forall\ i$, $\phi_{1i} \neq 0 \forall\ i$ and $\pi_{1i} \neq 0 \forall\ i$. Similarly, in equation (4)$\ln CO2$, $\ln TRD$ and$\ln FIN$Granger cause $\ln ENG$ if $\eta_{1i} \neq 0 \forall\ i$, $\phi_{1i} \neq 0 \forall\ i$ and $\pi_{1i} \neq 0 \forall\ i$. In Eq. (5) $\ln CO2$, $\ln ENG$ and $\ln FIN$ Granger cause $\ln TRD$ if $\eta_{1i} \neq 0 \forall\ i$, $\phi_{1i} \neq 0 \forall\ i$ and $\pi_{1i} \neq 0 \forall\ i$. In equation (6) $\ln CO2$, $\ln TRD$ and $\ln ENG$ Granger cause $\ln FIN$ if $\eta_{1i} \neq 0 \forall\ i$, $\phi_{1i} \neq 0 \forall\ i$ and $\pi_{1i} \neq 0 \forall\ i$. The maximum lag length for the Toda-Yamamoto [60] Granger non-causality test is calculated as the sum of the maximum order of integration and the lag length selected for the ARDL estimation. Further, in conducting the causality tests, it is important to examine the properties of the inverse roots of the AR (auto-regressive) characteristics polynomial diagram to ensure dynamic stability of the ARDL model. For causality test robustness, the inverse roots, I_R, should lie within the positive and negative unity i.e. $-1 \leq I_R \leq 1$. If the inverse roots lie outside the unit circle, this can be corrected by using either (a) appropriate lags greater than those of endogenous variables, (b) a trend variable and/or (c) structural break dummies as exogenous (instruments) variables in the VAR system.

4. Data and estimation

4.1. Data overview

We use annual data for the period 1971–2011 for empirical analysis. The data is taken from World Development Indicators and Global Development Finance Database [61]. Carbon emission (CO_2) is taken in per capita metric tons, energy consumption (ENG) is in

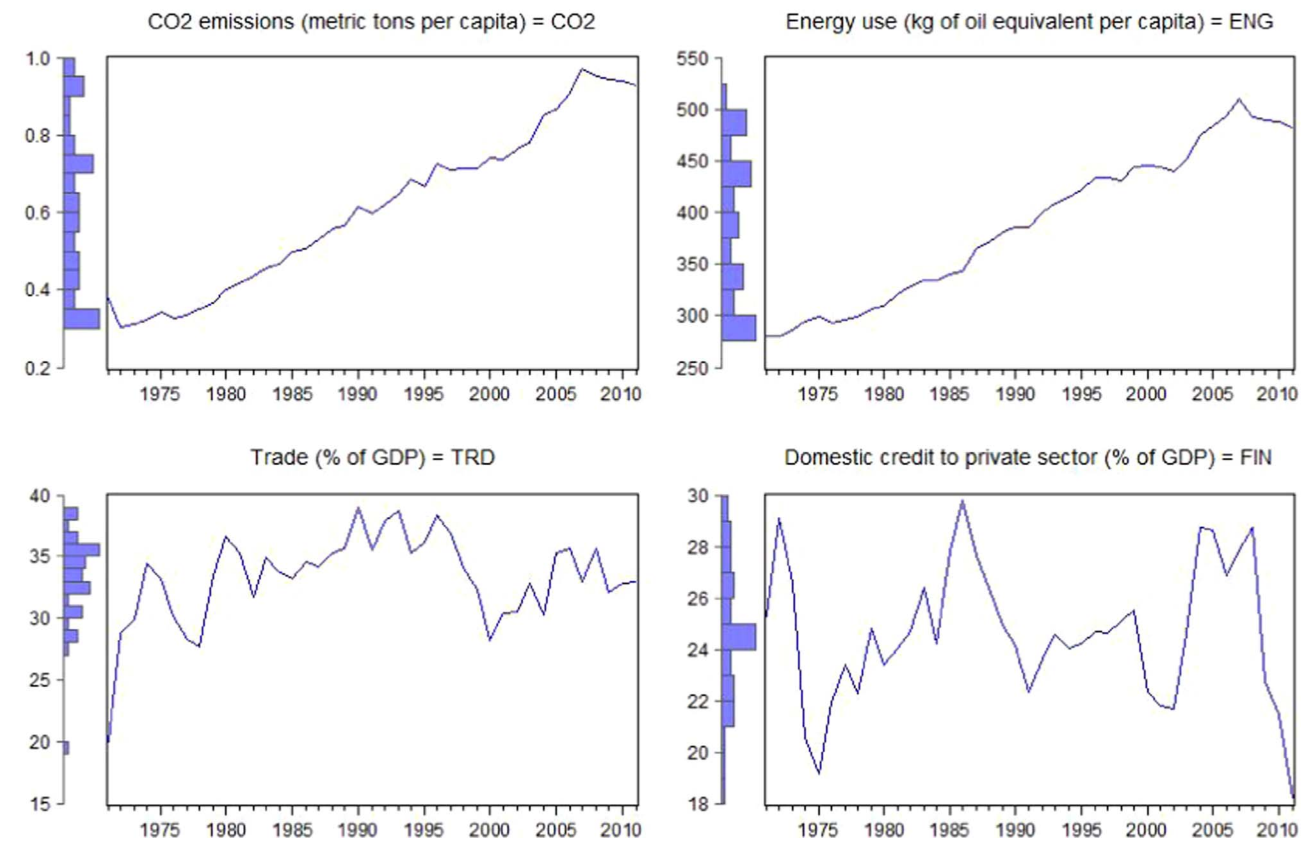

Fig. 1. Plots of study variables for the case of Pakistan (1971–2011).

Table 4
Descriptive statistics and correlation matrix (1971–2011).

Statistics	Carbon emission (CO_2)	Energy consumption	Trade openness	Financial development
Mean	0.60	388.00	33.28	24.59
Median	0.61	385.78	33.69	24.59
Maximum	0.96	509.98	38.90	29.78
Minimum	0.30	279.72	19.93	18.12
Std. Deviation	0.21	73.25	3.60	2.69
Skewness	0.15	0.00	−1.24	−0.10
Kurtosis	1.81	1.62	5.86	2.74
Jarque-Bera	2.58	3.21	24.56	0.18
Probability	0.27	0.20	< 0.01	0.91
Carbon Emission	1			
Energy Consumption	0.99*** (< 0.01)	1		
Trade Openness	0.25* (0.10)	0.29* (0.06)	1	
Financial Development	0.06 (0.67)	0.06 (0.68)	0.06 (0.66)	1

Note: ***(*) denotes that the correlation coefficient is statistically significant at 1% (10%) level of significance. The *p*-values are in parenthesis.

kilogram of oil equivalent per capita, trade openness (TRD) is measured by export plus imports as percentage of GDP and financial development (FIN) is measured by domestic credit as percentage of GDP. Fig. 1 presents trend analysis of the variables, which clearly indicates that energy consumption and hence CO2 emission has increased in Pakistan. Table 4 provides descriptive statistics and correlation matrix. Carbon emission has high correlation with energy consumption followed by trade openness and financial development.

Table 5
Unit root tests results.

Variables	Intercept		Intercept & Trend	
	Level	1st Diff.	Level	1st Diff.
Augmented Dickey Fuller (ADF)				
lnCO2	−1.45[1]	−10.24[0]***	−3.66[0]**	−10.16[0]***
lnENG	−1.23[0]	−5.32[0]***	−0.89[0]	−5.49[0]***
lnTRD	−5.82[0]***	−8.08[0]***	−5.39[0]***	−7.97[0]***
lnFIN	−3.34[1]**	−5.31[0]***	−2.12[0]	−5.26[0]***
Phillips and Peron (PP)				
lnCO2	−0.12[1]	−10.07[3]***	−4.13[4]**	−10.57[2]***
lnENG	−1.20[1]	−5.33[1]***	−1.12[1]	−5.49[2]***
lnTRD	−5.62[2]***	−8.98[3]***	−5.26[2]***	−8.82[3]***
lnFIN	−2.46[3]	−5.33[2]***	−2.38[3]	−5.28[2]***
Kwiatkowski-Phillips-Schmidt-Shin (KPSS)				
lnCO2	0.76[5]	0.14[1]***	0.14[4]*	0.13[0]**
lnENG	0.77[5]	0.22[0]***	0.16[4]*	0.10[1]***
lnTRD	0.32[3]***	0.28[3]***	0.20[3]*	0.10[4]***
lnFIN	0.07[1]***	0.14[5]***	0.07[1]***	0.08[5]***

Note: The ADF and PP critical values are based on Mackinnon [29] and KPSS critical values are based on Kwiatkowski et al. [27]. The null hypothesis for ADF and Phillips-Perron tests is that a series has a unit root (non-stationary) and for KPSS, the series is stationary. ***, ** and * denote that the series is stationary at 1%, 5% and 10% level of significance, respectively. Values in [] provide the lag-length automatically determined by Eviews 9.

4.2. Unit root tests

Table 5 provides the results of three traditional unit root tests i.e. ADF, PP and KPSS. Table 6 provides the results of unit root with single break point tests of Perron [42] and Zivot and Andrews [64]. The results of all unit root tests show that the variables have mixed order of

Table 6
Unit Root Tests with Structural Break.

Test	Perron [42]				Zivot and Andrews [64]			
Var. (x)	Level		1st Diff.		Level		1st Diff.	
	T_{stat}	TB_x	T_{stat}	TB_x	T_{stat}	TB_x	T_{stat}	TB_x
lnCO2	−5.64 [4]**	1994	−10.86 [0]***	2003	−5.69 [4]***	1995	−11.02 [0]***	2004
lnENG	−2.73 [0]	2005	−6.68[0] ***	2002	−2.67 [0]	1987	−6.76[0] ***	2004
lnTRD	−7.15 [0]***	1998	−5.80[2] **	2000	−7.07 [0]	1998	−5.52[2] ***	2003
lnFIN	−2.96 [0]	2004	−6.46[0] ***	2002	−3.20 [0]	2004	−6.56[0] ***	2003

Note: The critical values are obtained from Perron [42] and Zivot and Andrews [64]. The null hypothesis for the two tests is that a the series has a unit root with a structural break in both intercept and trend. *** and ** denote that a series is stationary at 1% and 5% level of significance, respectively.

integration i.e. some variables are stationary at levels and some are stationary at their first differences.

4.3. Lag length test

The lag order selection results are presented in Table 7. We note that four (LR, FPE, SC and HQ) out of the five criteria (including AIC) indicates lag-length of one as desirable. Thus, we select the lag-length of one for ARDL estimation.

4.4. Bounds test

Incorporating the information from structural break test and lag-length test we examine the critical F- and W- statistics against the respective upper and lower bounds of Pesaran and Pesaran [43] and Narayan [33]. Notably, we excluded the structural break dummy from the estimation because it was not statistically significant. The trend and constant were statistically significant at 1% level so they were included in the estimation. Results of Bounds test are provided in Table 8. Calculated values of both F-statistics (30.93) and W-statistics (154.66) are more than their respective 95% upper bound critical values. It shows that there is long run cointegrating relationship between carbon emission, energy consumption, trade openness and financial development.

4.5. Short-run and long-run estimates

The short-run and long-run estimations are provided in Tables 9 and 10, respectively. The results reveal that there is an inverted U-shaped relationship between energy consumption and carbon emission both in the short-run and the long-run. Moreover, we note that the maximum threshold of energy use (kilogram of oil equivalent per capita) is 640 kg. The value is calculated by solving the the first derivate

Table 7
Results of Lag Order Selection Criteria.

Lag	LL	LR	FPE	AIC	SC	HQ
0	245.95	–	1.52e−12	−13.02	−12.80	−12.94
1	420.66	292.76*	4.71e−16*	−21.11	−19.81*	−20.65*
2	446.98	36.99	4.74e−16	−21.18	−18.79	−20.34
3	468.04	23.89	7.25e−16	−20.97	−17.49	−19.74
4	506.91	33.61	5.42e−16	−21.72*	−17.15	−20.11

Note: LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.
* Indicates lag order selected by the criterion at 5% level of significance.

Table 8
Results of Bounds Test: ARDL (1,0,0,1,1).

Dependent Var.| Independent Var. Critical Bounds	***lnCO2*** | ***lnENG***, ***lnTRD***, ***lnFIN*** 95% Lower Bound	95% Upper Bound	90% Lower Bound	90% Upper Bound
F-stat.= 30.93	3.94	5.12	3.30	4.37
W-stat.=154.66	19.72	25.63	16.53	21.88
Narayan [33]	3.95	5.22	3.33	4.43

Note: Critical Bounds and the respective F-stat and W-stat are computed with inclusion of intercept and trend. Narayan [33] bounds are reported at n=40.

Table 9
Short-run: dependent variable (Δ***lnCO2***).

Regressor	Coefficient	Standard Error	t-ratio
$\Delta lnENG$	7.992***	1.924	4.153
$\Delta lnENG^2$	−0.618***	0.161	−3.823
$\Delta lnTRD$	0.122**	0.053	2.299
$\Delta lnFIN$	0.087**	0.041	2.128
Trend	0.016***	0.002	6.255
ECM_{t-1}	−0.868***	0.071	−12.237

R^2=0. 87;$\bar{R}^2$=0. 84; $\bar{x}_{\Delta \ln CO2}$=0. 02; $\hat{\sigma}_{\Delta \ln CO2}$=0. 05; $F-Stat.$ (6, 33)=36. 44
Note: *** and ** refer to 1% and 5% level of statistical significance, respectively.

Table 10
Long-run: dependent variable (***lnCO2***).

Regressor	Coefficient	Standard Error	t-ratio
lnENG	9.201***	2.120	4.340
$lnENG^2$	−0.712***	0.179	−3.957
lnTRD	0.247***	0.063	3.872
lnFIN	0.165***	0.045	3.672
Constant	−31.858***	6.175	−5.159
Trend	0.018***	0.002	7.124

R^2=0.87;$\bar{R}^2$=0.84; χ^2_{SC}: χ^2(1)=4.38, F(1, 30)=3.69; χ^2_{ff}: χ^2(1)=2.96, F(1, 30)=2.40; χ^2_n: χ^2(2)=0.3^2; χ^2_{hc}: χ^2(1)=1.23, F(1, 38)=1.20; SER=0.02; SSR=0.01; $\bar{x}_{\ln CO2}$=−0.55; $\hat{\sigma}_{\ln Co2}$=0.36; AIC=9
4.16; SBC=86.56; LL=103.16; $F-Stat.$=1506.7; $DW-stat.$=2.53
Note
*** Refers to significance at 1% level.

of CO_2 with respect to energy consumption equated to zero. Upon solving the maximum energy consumption, we obtain 6.46 which is in log form and then taking an exponential, we get the optimum quantity [26].

This implies that beyond this level of energy consumption (640 kg of oil equivalent), the economy is expected to realize negative effect of energy consumption on carbon emission (technology effect). However, as noted from the sample, the actual maximum energy consumption per capita is around 510 kg (in 2007), which is below the threshold level and hence implies that the overall effects of energy consumption thus far is dominated by scale and composition effects.

Both trade openness and financial development have positive impacts on carbon emission both in short and long run. One percent increase in trade openness will increase carbon emission by 0.122% in short run and by 0.247% in long run. Similarly, one percent increase in financial development will increase carbon emission by 0.087% in short run and by 0.165% in long run. The positive impact of trade openness on carbon emission relationship is in contrast with Shahbaz et al. [54] but coincides with Nasir and Rehman [34]. Notably, the result from short-run and long-run are consistent and does not present any ambiguity (mixed outcomes) as noted in earlier papers [34,54]. Finally, the coefficient of the error-correction term is negative and statistically significant, which implies that roughly 87% of the dis-

Table 11
Granger non-causality test based on χ^2.

	Dependent Variable (Y)					
	X	*lnCO2*	*lnENG*	*lnENG*^{2}	*lnTRD*	*lnFIN*
$X \xrightarrow[causes]{} Y$	*lnCO2*	–	4.52	4.62*	2.58	0.94
	lnENG	21.71***	–	10.45***	0.07	5.25*
	lnENG^2	22.56***	11.40***	–	0.08	5.42*
	lnTRD	11.28***	3.54	3.60	–	0.70
	lnFIN	12.13****	7.58**	7.25**	0.94	–
	Combined	43.86***	18.35**	17.46**	9.24	14.07*

Note: ***, ** and * indicate presence of causality at 1%, 5% and 10% level of significance, respectively; degrees of freedom=2.

equilibrium in the previous years is corrected within one year. It shows a relatively speedy convergence to the long-run equilibrium.

4.6. Diagnostic tests

Next, we proceed to estimate the long-run and short-run relationship between carbon emission (*CO2*), energy consumption (*ENG*), trade openness (*TRD*) and financial development (*FIN*). The initial step requires the examination of the diagnostic test statistics from the lag-estimate results which precedes the long-run estimation and the short-run dynamics. For the diagnostic test statistics, we examine the Lagrange multiplier test of residual serial correlation (χ^2_{sc}); Ramsey's RESET test using the square of the fitted values for correct functional form ($\chi^2{}_{ff}$); normality test based on a test of skewness and kurtosis of residuals ($\chi^2{}_n$); and heteroscedasticity test based on the regression of squared residuals on squared fitted values ($\chi^2{}_{hc}$). In case where the respective diagnostic tests are statistically significant, this implies presence of the respective biasness in the estimated results. We note that the diagnostic tests pass all the tests (serial correlation, functional form, normality and heteroscedasticity) thus implying absence of biasness (bottom panel of Table 10). We included the $lnENG^2$ term to correct for functional form biasness. To support robustness of the results, we examine the dynamic stability of the parameters in the model using cumulative sum of the recursive residuals (CUSUM) and cumulative sum of the recursive residuals squared (CUSUMQ) [11]. If the estimated model is valid, the recursive residuals will be independently and normally distributed with zero mean and constant variance. Both the results of CUSUM and CUSUMQ show that the parameters of the model are stable.

4.7. Granger causality

From the unit root results we note that the maximum order of integration is 1 i.e. d_{max} =1, and the lag used for the ARDL estimation is 1 (l =*1*). Hence, the maximum lag that can be used to carry out the non-causality test is d_{max} + l =2. Further, we ensured that the causality model is dynamically stable by adhering to the condition $|I_R| \leq 1$ (Figure. The results of the causality tests are presented in Table 11.

The causality results show a unidirectional causality from energy consumption, trade openness and financial development to carbon emission. There is bi-directional causality between energy consumption and financial development which indicates that financial development and energy use are mutually reinforcing (or has a feedback effect) on each other.

5. Conclusion

The paper examines the non-linear relationship between carbon emission and energy consumption in Pakistan using data for the period 1971–2011. The paper also examines the threshold level of energy consumption. Other variables included are trade openness and financial development. The results of unit root tests indicate that all variables do not have same order of integration. Therefore, we have applied ARDL cointegration technique. The results of ARDL bounds test confirm the presence of a long run cointegrating relationship among variables. Both the short-run and long-run estimates show that energy consumption has non-linear (inverted U-shape) effect on carbon emission with maximum threshold level of 640 kg of oil equivalent. Further, carbon emission increases both with the increase in trade openness and financial development. The causality analysis shows that energy consumption, trade openness and financial development Granger cause carbon emission, and that energy consumption and financial development have a mutually reinforcing (bi-directional) effect. Besides providing the threshold level of energy consumption, the study notes that the current level of energy consumption is not sufficient to reach a tipping-off point. In other words, the current level of energy consumption is still below the point of technology effect, and is largely dominated by scale and composition effects. In this regard, we argue that increasing energy consumption with an objective of green growth is underscored.

While we underscore the findings, we concur that the results are country- and model-specific. In this regard, caution is warranted when generalizing the outcomes of the study to other countries because countries are heterogeneous in the way they generate and use energy in different sectors of the economy. Moreover, the pace of development in terms of the energy mix will situate a country differently in regards to the scale, composition and technology effects. Therefore, further research needs to be done in this regard. In fact, country specific studies of this nature will provide specific policy levers. Additionally, it is important to emphasize that when a variable (in our case it is energy) is specified both in linear and non-linear (squared) form in the model, their coefficients should not be directly interpreted as elasticities and should be only used to compute the threshold values.

Finally, an outcome of the paper is that energy consumption should be increased in Pakistan as currently the usage is below the threshold. However, since financial sector and trade activities contribute to the carbon emission, policy focus need to be on productive use of energy. Our study can be used as a basis to conduct a micro-level study on the use of energy and consumers' willingness to pay for energy use. Studies of the latter types are expected to provide more insights. It is vital to highlight that a shift in consumer attitude towards the use of renewable energy dependent commodities and transportation services can create an effective and efficient society. In due course, once the threshold is reached, which is not too far from the current maximum, any further increase in energy use therefore should consider renewable sources of energy. Nevertheless, we have shown that energy in its current configuration and use is expected to add, albeit gradually, to the carbon emission for some time, until the threshold level is reached.

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