Environmental Science and Pollution Research (2019) 26:29307–29315
https://doi.org/10.1007/s11356-019-06116-8

RESEARCH ARTICLE

Energy consumption and environmental quality in South Asia: evidence from panel non-linear ARDL

Kashif Munir[1] · Nimra Riaz[1]

Received: 10 January 2019 / Accepted: 29 July 2019 / Published online: 8 August 2019

Abstract

The objective of this study is to estimate the non-linear effect of energy consumption i.e. oil, gas, electricity, and coal consumption on CO_2 emission in South Asian countries. The study uses annual panel data of three South Asian countries i.e. Bangladesh, India, and Pakistan from 1985 to 2017 and applies panel non-linear ARDL methodology to examine the long-run and short-run relationship. Results show that an increase in gas, electricity, coal, and electricity consumption leads to an increase in the carbon dioxide emission, whereas decrease in electricity and coal consumption reduces the carbon dioxide emissions in the long run. Non-linear relationship exists between electricity consumption and CO_2 emissions as well as between coal consumption and CO_2 emissions in South Asian countries in the long run. Results of short run dynamics of individual countries show that non-linear relationship exists between oil consumption and CO_2 emissions, electricity consumption and CO_2 emissions, and coal consumption and CO_2 emissions in Bangladesh and Pakistan. Research and development centers are required to control pollution through new technologies, while discourage to use higher electricity and coal consumption as a source of energy for a healthier environment.

Keywords Energy consumption · Oil · Gas · Coal · Electricity · Carbon Dioxide Emissions · South Asia

Introduction

Majority of the environmental problems are due to energy usage because it is impossible to transport, produce, and consume energy without having harmful impact on environment. Production of energy from non-renewable resources has dangerous effects on environment because it produces intense type of harmful toxic gasses, which is very dangerous for environment as well as biotic component. Ecosystem consists of biotic and abiotic components which interact with each other to sustain balance surrounding environment. Nowadays, many environmentalists believe that society lies among three E's i.e. energy, economy, and environment which are directly or indirectly linked with each other. In developing economies such as Bangladesh, India, and Pakistan, the industry and household consumers use energy in large amount, which impacts the environmental quality. Developing economies depend on coal, gas, and oil for fulfilling the requirements of energy. These emerging economies can maximize energy efficiency by reducing the environmental wastes.

There are different stances on the impact of energy consumption on environmental quality. First stance advocates that oil is one of the most abundant energy resource which promotes sustainable economic growth, reduce business cost, increase the demand and supply of commodities, promotes free trade, and intends to improve the employment conditions in the countries (Meadows et al. 1972; Akbostanci et al. 2009; Al-Amin et al. 2009; Akin 2014). Carbon taxes levied on fossil oil, and coal utilization provides an incentive for industries to develop more friendly environmental production processes (UNCTAD 2010). Second stance argues that energy consumption has serious effects on environment. Environmentalists and economists argued that energy consumption through oil, coal, gas, and electricity produces a large amount of waste because of high rate of consumption and destroys environmental condition of the world. They also oppose the carbon tax idea because it is

Responsible editor: Philippe Garrigues

✉ Kashif Munir
kashifmunirdr@gmail.com; kashif_ok@hotmail.com

[1] Department of Economics, University of Central Punjab, Lahore, Pakistan

quite difficult to measure how much carbon is produced, and therefore difficult to know what level of carbon tax to charge. Saidi and Hammami (2015) argued that energy combustion has positive impact on CO_2 emissions, while Irfan and Shaw (2017) described the nonlinear but positive impact of energy combustion on CO_2 emissions.

In sum, previous studies discussed the impact of the energy consumption on environment of emerging countries. The relationship between disaggregate energy consumption and carbon dioxide emissions was examined very frequently, but there is precise work on the non-linear relationship between energy consumption and environmental degradation in South Asian countries. This study aims at fulfilling this gap by examining the non-linear association among the consumption of energy and environmental quality. The major goal of this study is to examine the non-linear impact of energy consumption i.e. oil, gas, coal, and electricity consumption on carbon dioxide emissions in South Asian countries. This study provides necessary information, evidence, and better understanding to policy makers, individual, and researchers. This study is useful for government, policy makers, and civilian in evaluating and understanding how energy combustion affects environmental quality. This study provides the policy makers and environmentalists for making the environment-friendly policy for short run as well as for long run.

Literature review

Noor and Siddiqi (2010) investigated the association among energy use and economic growth for five South Asian countries from 1971 to 2006. They found that unidirectional causality exists from GDP per capita to per capita energy consumption. They concluded that existence of energy shortage is due to excessive use of energy in South Asian countries. Hossain (2011) analyzed the association among CO_2 emissions, economic growth, trade openness, energy consumption, and newly industrialized urbanized economies from 1971 to 2007. Study found that unidirectional causality exists from urbanization and trade openness to economic growth, while unidirectional causality also exists from economic growth to energy consumption and from trade openness to urbanization. Sheng et al. (2012) investigated the effect of energy consumption of household on environment in rural as well as in urban areas of China. Results showed that different amount of energy is consumed at rural as well as in urban areas, while rural household consumed more energy as compared to urban household.

Omri (2013) examined the relationship among CO_2 emissions, economic growth, and consumption of energy in 14 MENA countries from 1990 to 2011. Results depicted that bidirectional causality exists between energy consumption and economic growth, while unidirectional causality exists from energy consumption to CO_2 emissions. Kasman and Duman (2015) analyzed the association among trade openness, urbanization, energy consumption, CO_2 emissions, and economic growth from 1992 to 2010 in EU member countries. They found that unidirectional causality exists from GDP to energy consumption and from urbanization to trade openness. However, unidirectional causality exists from trade openness, urbanization, and energy consumption to CO_2 emission in the short run. Saidi and Hammami (2015) investigated the effect of economic growth and CO_2 emission on energy consumption for panel of 58 countries from 1990 to 2012. They found that positive relationship exists among energy consumption and CO_2 emissions.

Destek et al. (2016) examined the association among real GDP, energy consumption, trade openness, CO_2 emission, and urbanization for selected Eastern and Central European countries from 1991 to 2011. They found evidence of environmental Kuznets curve (EKC) hypothesis in these economies. Dogan and Turkekul (2016) examined the association among CO_2 emission, energy consumption, real output, trade openness, financial development, and urbanization in the USA from 1960 to 2010. They found that urbanization and energy consumption lead to increase in environmental degradation. Ali et al. (2017) analyzed the casual association among renewable and non-renewable source of energy, per capita output, population density, and environment quality in South Asian countries from 1980 to 2013. They found that CO_2 emission has positive relation with per capita output, population density, and non-renewable energy source, while renewable energy has negative relation with CO_2 emission.

Irfan and Shaw (2017) analyzed the association among energy consumption, environmental pollution, and level of urbanization in South Asian economies from 1978 to 2011. They found that carbon dioxide emission and energy consumption have non-linear relationship, while energy consumption is positively related with carbon dioxide emission in these emerging economies. Kisswani (2017) examined the long- as well as short-run nexus of GDP-energy consumption for five ASEAN economies from 1971 to 2013. Study used nonlinear autoregressive distributed lag (NARDL) model for individual country analysis as well as for panel data analysis. Results depicted that long-run asymmetry exists in Singapore and Thailand, while short-run asymmetry exists in Thailand for individual country analysis. Moreover, panel data analysis showed that nonlinear asymmetry exists among energy consumption and GDP. Causality tests showed mixed results in both panel data analysis and individual country analysis.

Munir and Ameer (2018) analyzed the long- and short-run effect of trade openness, urbanization, and technology on environmental degradation in Asian emerging economies. They found that environmental Kuznets curve hypothesis exists among SO_2 emission and economic growth. Shahbaz et al. (2018) analyzed the association among economic growth, foreign direct investment, innovation of energy research, and financial development in France. Results depicted that energy innovation and financial development have inverse relation with CO_2 emissions, while foreign direct investment and energy use have positive relation with CO_2 emissions. Arminen and Menegaki (2019) analyzed the causality among energy consumption, economic growth, and CO_2 emissions in high and upper middle economies from 1985 to 2011. Results depicted that bidirectional causality exists among GDP and energy consumption but evidence of environmental Kuznets hypothesis does not exist.

Khan et al. (2019) analyzed the asymmetric impact of environmental regulation on carbon dioxide emissions in China from 1991 to 2015. Results depicted that significant and negative relationship exists among carbon dioxide emissions and environmental regulation in short as well as in long run. They concluded that technological innovation through research and expansion helps to reduce the carbon emission in China. Toumi and Toumi (2019) analyzed the asymmetric causality among renewable energy, CO_2 emission, and real GDP from 1990 to 2014 in the Kingdom of Saudi Arabia by employing non-linear ARDL model. Results depicted that asymmetry exists in the long run between renewable energy, CO_2 emissions, and real GDP. However, asymmetric causality test shows that negative and positive shocks to renewable energy consumption have adverse impact on carbon dioxide emission in the long run, while negative shock in CO_2 emissions has positive impacts on real GDP.

Data and methodology

Majority of the studies in the literature used environmental Kuznets curve (EKC) hypothesis to explore the non-linear association between environment and economic growth. However, this study utilizes EKC hypothesis to find the non-linear association among environment and energy consumption. The EKC hypothesis states that an increase in energy consumption leads to increase in production activities which is directly proportional with economic growth, while higher level of energy consumption eventually leads to environmental deterioration.

This study uses the following models to analyze the association among energy consumption and environmental quality, while energy is disaggregated into oil, coal, gas, and electricity consumption:

$$CO_2 = f(OC^+, OC^-) \quad (1)$$

$$CO_2 = f(GC^+, GC^-) \quad (2)$$

$$CO_2 = f(EC^+, EC^-) \quad (3)$$

$$CO_2 = f(CoalC^+, CoalC^-) \quad (4)$$

where, CO_2 is carbon dioxide emissions, OC is oil consumption, GC is gas consumption, EC is electricity consumption, CoalC is coal consumption, and superscript + and – are decomposition of partial positive and negative sums of variable respectively.

This study uses annual panel data of three South Asian courtiers i.e. Bangladesh, India, and Pakistan from 1985 to 2017. Due to unavailability of data for all the South Asian countries, the study focuses on only three countries. Environmental degradation is measured by carbon dioxide (CO_2) emissions metric tons per capita and collected from "World Development Indicators," published by the World Bank. Oil consumption (OC), gas consumption (GC), coal consumption (CoalC), and electricity consumption (EC) are measured in million tons and collected from "Statistical Review of World Energy," published by the BP Global.

Panel data is more worthy as compared to time series and cross-sectional data because heterogeneity and specific impacts of cross section are illustrated by panel data. Due to large sample size data, reliability of the results increases and estimation will be more robust. On the other hand, panel data is more useful due to more information, less collinearity, and more efficiency (Wooldridge 2010; Gujarati 2005; Baltagi 2013).

Stationarity of the variables are checked in the first step to avoid misleading results and spurious regression. Stationarity of a variable is examined by LLC, IPS, and Fisher-ADF panel unit root tests. Panel unit root test of Levin, Lin, and Chu (LLC) is used for pooled data and given by Levin et al. (2002). If time period ranged from 5 to 250 and number of countries are 10 to 25, then LLC test is preferred. Im, Pesaran, and Shin (IPS) panel unit root test assumes that variables are normally distributed with finite heterogeneous variance and zero mean (Im et al. 2003). Fisher-ADF unit root test is illustrated by Maddala and Wu (1999) with the idea of Fisher (1932).

Pesaran and Shin (1995) and Pesaran et al. (1999) came with a technique to estimate non-stationary dynamic panels and called it as pooled mean group (PMG) or panel auto regressive distributed lag (ARDL) model. PMG is used to estimate the long- and short-run association among the variables as well as to investigate heterogeneous dynamic issue across countries. The general form of PMG model or panel ARDL can be specified as:

$$Y_{it} = \sum_{j=1}^{p} \lambda_{ij} Y_{i,\ t-j} + \sum_{j=0}^{q} \delta_{ij}^{'} X_{i,\ t-j} + \mu_i + \varepsilon_{it} \quad (5)$$

where, Y_{it} is dependent variable, X_{it} is $(k \times 1)$ vector of explanatory variables, μ_i represents the fixed effects, λ_{ij} is the coefficient of the lagged dependent variable, δ_{ij} is ($k \times 1$) coefficient vector of independent variables, ε_{it} is the error tern, i (1, 2, ….., N) is number of cross section, and t (1, 2, ……T) is number of time.

Equation (5) can be re-parameterized as a vector error correction model as:

$$\Delta Y_{it} = \theta_i \mathrm{ECT}_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta Y_{i,\ t-j} + \sum_{j=0}^{q-1} \delta_{ij}^{*\prime} \Delta X_{i,\ t-j} + \mu_i + \varepsilon_{it} \quad (6)$$

where, $\mathrm{ECT}_{it} = \phi_i\ Y_{i,t-1} - \beta_i^{\prime} X_{i,t}$

Error correction term (ECT) parameter θ_i provides the speed of adjustment. ECT depicts the rate of adjustment of variable towards the long-run equilibrium, while negative sign provides the convergence in the short run.

However, the objective of this study is to analyze the non-linear impact of energy consumption on carbon dioxide emissions in panel form. Shin et al. (2014) provided the framework for nonlinear ARDL (NARDL) based on linear ARDL model of Pesaran and Shin (1999) and Pesaran et al. (2001). Shin et al. (2014) followed the methodology of Granger and Yoon (2002) and Schorderet 2003for decomposition of a stationary variable into positive and negative variations. Thus, for a variable X, the two components which is partial sum of the variables are:

$$X^{+} = \sum_{j=1}^{t} \Delta X_j^{+} = \sum_{j=1}^{t} \max\left(\Delta X_j, 0\right) \quad (7)$$

$$X^{-} = \sum_{j=1}^{t} \Delta X_j^{-} = \sum_{j=1}^{t} \min\left(\Delta X_j, 0\right) \quad (8)$$

The long-run association among Y and X in a nonlinear framework is represented as:

$$Y_t = \beta^{+} X_t^{+} + \beta^{-} X_t^{-} + \mu_t \quad (9)$$

$$X_t = X_0 + X_t^{+} + X_t^{-} \quad (10)$$

where, β^{+} and β^{-} are long-run parameters, and $X^{+}$and X^{-} are scalars of decomposition partial sums.

This study combines the methodology of NARDL of Shin et al. (2014) and panel ARDL methodology of Pesaran et al. (1999) and estimates the panel non-linear ARDL model to achieve the objectives of this study. Hence, this panel non-linear ARDL methodology has the following three superior features over NARDL and panel ARDL. First, it measures the non-linear asymmetries in the data. Second, it measures the heterogeneity effect in the data. Lastly, it is more appropriate in the presence of mixed order of integration of variables. Brun-Aguerre et al. (2017) used panel non-linear ARDL model to examine the exchange rate pass through on import prices, while Salisu and Isah (2017) used panel non-linear ARDL model to examine the association among stock prices and oil prices.

Hence, panel non-linear ARDL model can be specified as:

$$\Delta Y_{it} = \theta_i ECT_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta Y_{i,\ t-j} + \sum_{j=0}^{q-1} \left(\delta_{ij}^{*\prime +} \Delta X_{i,\ t-j}^{+} + \delta_{ij}^{*\prime -} \Delta X_{i,\ t-j}^{-} \right) + \mu_i + \varepsilon_{it} \quad (11)$$

where, $\mathrm{ECT}_{it} = \phi_i\ Y_{i,t-1} - \left(\beta_i^{\prime +} X_{i,t}^{+} + \beta_i^{\prime -} X_{i,t}^{-} \right)$

The study has also applied diagnostic tests for reliability of the results. Jarque-Bera test is applied for normality (Jarque and Bera 1980), while Breusch-Pagan LM test (Breusch and Pagan 1980), Pesaran scaled LM test (Pesaran 2004), and Pesaran CD test (Pesaran 2004) for cross-sectional dependence. However, Granger causality test is used to find the short-run asymmetric causal association among the variables.

Results

Order of integration of the variable is checked by Im, Pesaran, and Shin (IPS), Levin, Lin, and Chu (LLC), and Fisher-ADF (F-ADF) panel unit root tests, while Schwarz information criteria (SIC) is used for lag length criteria, and results are reported in Table 1. Results show that all the variables are integrated of order one except electricity consumption, which shows mix order of integration. However, none of the variable is integrated of order two.

The long- and short-run parameters are estimated as proposed by Pesaran and Shin (1999) and Pesaran et al. (2001). The results of combine effects of long-run coefficients of panel non-linear ARDL are reported in Table 2 panel A, while panel B of Table 2 describes the short-run dynamics. Results of combine effects of asymmetric long-run coefficients of model-I show that partial positive sum of oil consumption has significant and positive effect on carbon dioxide emissions, while partial negative sum of oil consumption has positive and insignificant impact on carbon dioxide emissions. Oil consumption is an important source of obtaining energy. An increase in consumption of oil leads to environmental pollution, and this pollution contains high concentration of CO_2 emissions and other gases that lead to increase in environmental degradation and cause different types of diseases as well. Partial positive sum of gas consumption has positive and significant effect on carbon dioxide emissions, while partial negative sum of gas consumption has positive and insignificant impact on carbon dioxide emissions in the long run in model-II. An increase in gas consumption produces smoke, which has different types of dangerous chemical particles and damages the environmental quality.

Model-III and model-IV show that non-linear relationship exists between electricity consumption and carbon dioxide emissions as well as between coal consumption and carbon dioxide emissions in South Asian countries. Partial positive

Table 1 Results of LLC, IPS, and F-ADF panel unit root test

Var	LLC		IPS		F-ADF		Order of integration		
	Level	1st difference	Level	1st difference	Level	1st difference	LLC	IPS	F-ADF
$LnCO_2$	− 0.8791	− 3.2985***	0.8385	− 4.5237***	10.273	32.361***	I(1)	I(1)	I(1)
LnOC	0.0720	− 2.1878**	1.2183	− 2.0894**	0.2338	7.0791**	I(1)	I(1)	I(1)
LnGC	5.1655	− 3.3110***	− 0.1931	− 3.2602***	1.7005	13.4674***	I(1)	I(1)	I(1)
LnEC	4.4090	− 4.2683***	− 1.3160*	----	2.7005	16.0416***	I(1)	I(0)	I(1)
LnCoalC	− 0.9755	− 5.6726***	0.1071	− 4.8831***	1.1646	21.958***	I(1)	I(1)	I(1)

***, **, and * show significance at 1%, 5%, and 10% level respectively

sum of electricity consumption and coal consumption has positive and significant impact on carbon dioxide emissions, while partial negative sum of electricity consumption and coal consumption has negative and significant impact on carbon dioxide emissions in model-III and model-IV respectively. Panel non-linear ARDL model is transformed into error correction model (ECM) for measuring the short-run dynamics. Error correction term (ECT) is the rate of adjustment that indicates how quickly variables adjust towards long-run equilibrium, and its negative sign represents the convergence in the short run. The results of combine effects of short-run dynamics of all the four models are reported in Table 2 panel B. The negative and significant ECT term in all the four models shows that long-run relationship exists among the variables.

Table 3 reports the results of diagnostic tests. Diagnostic tests are applied for normality (Jarque-Bera test) and cross-sectional dependence (Breusch-Pagan LM test, Pesaran scaled LM test, and Pesaran CD test). These tests are applied to avoid misleading results. Results of normality test and cross-sectional dependence indicate that none of the model is suffering from these problems.

The results of asymmetric short run dynamics of individual countries for all the four models are reported in Table 4. The results of Bangladesh show that partial positive sum of oil,

Table 2 Asymmetric long- and short-run dynamics of oil, gas, electricity, and coal—combine effects

Var	Model-I: oil consumption	Model-II: gas consumption	Model-III: electricity consumption	Model-IV: coal consumption
Panel A: long-run dynamics				
$LnOC^+$	1.5028***	----	----	----
	(0.2881)			
$LnOC^-$	5.5816	----	----	----
	(4.8253)			
$LnGC^+$	----	1.5550**	----	----
		(0.6812)		
$LnGC^-$	----	− 10.5489	----	----
		(6.7789)		
$LnEC^+$	----	----	0.5524***	----
			(0.1055)	
$LnEC^-$	----	----	− 0.5709*	----
			(0.3404)	
$LnCoalC^+$	----	----	----	0.4446***
				(0.04829)
$LnCoalC^-$	----	----	----	− 0.9113***
				(0.1923)
Panel B: short-run ECM				
ECT(-1)	− 0.1016**	− 0.0807***	− 0.3072***	− 0.0653***
	(0.0502)	(0.0173)	(0.1344)	(0.0322)

Standard errors are in parenthesis

***, **, and * show significance at 1%, 5%, and 10% respectively

Table 3 Diagnostic tests

Model	Test	Statistics (p value)	Null hypothesis
Model-I: oil consumption	Normality test: Jarque-Bera test	2.6906 (0.2605)	Normally distrusted
	Cross-sectional dependence: Breusch-Pagan LM test	0.5607 (0.9054)	No cross-sectional dependence
	Cross-sectional dependence: Pesaran scaled LM test	− 0.9958 (0.3193)	No cross-sectional dependence
	Cross-sectional dependence: Pesaran CD Test	0.5369 (0.5913)	No cross-sectional dependence
Model-II: gas consumption	Normality test: Jarque-Bera test	1.8109 (0.4043)	Normally distrusted
	Cross-sectional dependence: Breusch-Pagan LM test	0.3093 (0.9583)	No cross-sectional dependence
	Cross-sectional dependence: Pesaran scaled LM test	− 1.0985 (0.2720)	No cross-sectional dependence
	Cross-sectional dependence: Pesaran CD test	− 0.3957 (0.6923)	No cross-sectional dependence
Model-III: electricity consumption	Normality test: Jarque-Bera test	0.6905 (0.7080)	Normally distrusted
	Cross-sectional dependence: Breusch-Pagan LM test	0.8204 (0.8446)	No cross-sectional dependence
	Cross-sectional dependence: Pesaran scaled LM test	− 0.8898 (0.3736)	No cross-sectional dependence
	Cross-sectional dependence: Pesaran CD test	− 0.5900 (0.5552)	No cross-sectional dependence
Model-IV: coal consumption	Normality test: Jarque-Bera test	0.9359 (0.6263)	Normally distrusted
	Cross-sectional dependence: Breusch-Pagan LM test	0.0954 (0.9924)	No cross-sectional dependence
	Cross-sectional dependence: Pesaran scaled LM test	− 1.1858 (0.2657)	No cross-sectional dependence
	Cross-sectional dependence: Pesaran CD test	− 0.2033 (0.8389)	No cross-sectional dependence

p values are in parenthesis

electricity, and coal consumption have positive and significant effect on carbon dioxide emissions, while partial negative sum of oil, electricity, and coal consumption have negative and significant impact on carbon dioxide emissions in the short run. An increase in oil, gas, and coal consumption enhance carbon dioxide emissions in the short run, while a decrease in oil and electricity consumption reduce the carbon dioxide emissions in India in the short run. Partial positive sum of oil, gas, electricity, and coal consumption have positive and significant impact on carbon dioxide emissions in Pakistan, while partial negative sum of oil, electricity, and coal consumption have negative and significant impact on carbon dioxide emissions in the short run.

After estimating the asymmetric long-run and short-run dynamics, the results of asymmetric Granger causality tests are reported in Table 5. Results show that unidirectional causality runs from CO_2 emission to partial positive sum of gas consumption, partial negative sum of gas consumption, partial positive sum of coal consumption, and partial negative sum of coal consumption. However, bidirectional causality exists among carbon dioxide emissions and partial positive sum of electricity consumption.

Conclusion

It is impossible to transport, produce, and consume energy without having harmful impact on environment. Developing economies depend on coal, gas, and oil for fulfilling the requirements of energy, while industry and household consumers use energy in large amount and damage the environment. This study analyzes the non-linear impact of energy consumption i.e. oil, gas, coal, and electricity consumption on carbon dioxide emissions in South Asian countries. Environmental Kuznets curve (EKC) hypothesis is used as a theoretical basis for non-linear relationship. The study uses annual panel data of three South Asian countries i.e. Bangladesh, India, and Pakistan from 1985 to 2017 and applies panel non-linear ARDL methodology to examine the long-run and short-run relationship.

Table 4 Asymmetric short-run dynamics of oil, gas, electricity, and coal—individual country effects

Model	Var	Bangladesh	India	Pakistan
Model-I: oil consumption	D(LnOC⁺)	1.6239*** (0.0940)	0.3152*** (0.0435)	0.7747*** (0.0442)
	D(LnOC⁻)	− 0.0470** (0.0086)	− 1.6407*** (0.5373)	− 1.2313** (0.4800)
	ECT(-1)	− 0.0490*** (0.0005)	− 0.0258*** (0.0004)	− 0.3258*** (0.0037)
Model-II: gas consumption	D(LnGC⁺)	0.0686 (0.0394)	0.1262*** (0.0081)	0.0860*** (0.0002)
	D(LnGC⁻)	− 1.0809 (9.8160)	− 0.8943 (0.7522)	− 0.8943 (0.7522)
	ECT(-1)	− 0.0201*** (0.00009)	− 0.0119*** (0.00016)	− 0.0119*** (0.0001)
Model-III: electricity consumption	D(LnEC⁺)	0.1321*** (0.0172)	0.0297 (0.0228)	0.0634** (0.0229)
	D(LnEC⁻)	− 1.0645*** (0.1713)	− 0.0419** (0.0878)	− 0.5512** (0.0977)
	ECT(-1)	− 0.4566*** (0.01252)	− 0.0003 (0.0007)	− 0.3769*** (0.0107)
Model-IV: coal consumption	D(LnCoalC⁺)	0.0345*** (0.0019)	0.0835*** (0.0030)	0.0195*** (0.0026)
	D(LnCoalC⁻)	− 0.0587*** (0.0003)	− 0.0193 (0.0106)	− 0.0639*** (0.0085)
	ECT(-1)	− 0.0016*** (0.0012)	− 0.0050*** (0.0002)	− 0.1893*** (0.0023)

Standard errors are in parenthesis

***, ***, and * show significance at 1%, 5%, and 10% respectively

Results of panel non-linear ARDL model of combine effects show that partial positive sum of oil, gas, electricity, and coal consumption has significant and positive impact on carbon dioxide emissions in the long run. On the other hand, partial negative sum of oil and gas consumption has positive and insignificant impact on carbon dioxide emissions, while partial negative sum of electricity and coal consumption has negative and significant impact on carbon dioxide emissions in the long run. Results show that non-linear relationship exists between electricity consumption and carbon dioxide emissions as well as between coal consumption and carbon dioxide emissions in South Asia countries in the long run.

Table 5 Results of asymmetric Granger casualty test

Model	F-statistics	Causality
$\mathbf{GC^+} \rightarrow CO_2$	0.10838	No
$CO_2 \rightarrow \mathbf{GC^+}$	7.6241***	Yes
$\mathbf{GC^-} \rightarrow CO_2$	0.8483	No
$CO_2 \rightarrow \mathbf{GC^-}$	2.8673*	Yes
$\mathbf{EC^+} \rightarrow CO_2$	3.2389**	Yes
$CO_2 \rightarrow \mathbf{EC^+}$	14.3981***	Yes
$\mathbf{EC^-} \rightarrow CO_2$	0.4110	No
$CO_2 \rightarrow \mathbf{EC^-}$	0.1120	No
$\mathbf{CoalC^+} \rightarrow CO_2$	0.9073	No
$CO2 \rightarrow \mathbf{CoalC^+}$	3.8742**	Yes
$\mathbf{CoalC^-} \rightarrow CO_2$	0.4271	No
$CO_2 \rightarrow \mathbf{CoalC^-}$	4.0477**	Yes
$\mathbf{OC^+} \rightarrow CO_2$	0.0693	No
$CO_2 \rightarrow \mathbf{OC^+}$	0.8797	No
$\mathbf{OC^-} \rightarrow CO_2$	0.0171	No
$CO_2 \rightarrow \mathbf{OC^-}$	0.00956	No

***, **, and * show significance at 1%, 5%, and 10% respectively

However, the results of asymmetric short run dynamics of individual countries show that non-linear relationship exists between oil consumption and CO_2 emissions, electricity consumption and CO_2 emissions, and coal consumption and CO_2 emissions in Bangladesh and Pakistan in the short run. Moreover, asymmetric short-run relationship exists between oil consumption and CO_2 emissions in India. Bidirectional causality exists among carbon dioxide emissions and partial positive sum of electricity consumption, while unidirectional causality exists from CO_2 emission to partial positive sum of gas consumption, partial negative sum of gas consumption, partial positive sum of coal consumption, and partial negative sum of coal consumption.

Policy implications

An increase in coal and electricity consumption deteriorates the environment of South Asian countries in the long run, while a reduction in consumption of coal and electricity improves the environmental condition of South Asian countries. On the basis of results, following policy recommendations are suggested by the study: firstly, it is important to control the pollution with new technologies by enabling the research and development centers more productive and secondly, discouraging to use higher electricity and coal consumption as a source of energy for a healthier environment.

References

Akbostanci E, Turut-Asik S, Tunc GI (2009) The relationship between income and environment in Turkey: is there an environmental Kuznets curve? Energy Policy 37(3):861–867

Akin CS (2014) The impact of foreign trade, energy consumption, and income on CO_2 emissions. Int J Energy Econ Policy 4(3):465–475

Al-Amin SC, Huda N, Hamid A (2009) Trade, economic development and environment: Malaysian experience. Bangladesh Dev Stud 32(3):19–39

Ali S, Anwar S, Nasreen S (2017) Renewable and non-renewable energy and its impact on environmental quality in South Asian countries. Forman Journal of Economic Studies 13:177–194

Arminen H, Menegaki AN (2019) Corruption, climate and the energy-environment-growth nexus. Energy Econ 80:621–634

Baltagi BH (2013) Econometric analysis of panel data. John Wiley & Sons Inc, Hoboken

Breusch TS, Pagan AR (1980) The Lagrange multiplier test and its application to model specifications in econometrics. Rev Econ Stud 47(1):239–253

Brun-Aguerre R, Fuertes A-M, Greenwood-Nimmo MJ (2017) Heads I win; tails you lose: asymmetry in exchange rate pass-through into import prices. J R Stat Soc A 180(2):587–612

Destek MA, Balli E, Manga M (2016) The relationship between CO_2 emission, energy consumption, urbanization and trade openness for selected CEECs. Research in World Economy 7(1):52–58

Dogan E, Turkekul B (2016) CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res 23(2): 1203–1213

Fisher RA (1932) Statistical methods for research workers. Oliver and Boyd, Edinburgh

Granger CWJ, Yoon G (2002) Hidden cointegration. Economics. No. 2002-02. University of California

Gujarati DN (2005) Basic Econometrics (4th ed.). McGraw-Hill, New York

Hossain MS (2011) Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized economy. Energy Policy 39:6991–6999

Im KS, Pesaran MH, Shin Y (2003) Testing for unit roots in heterogeneous panels. J Econ 115(1):53–74

Irfan M, Shaw K (2017) Modeling the effects of energy consumption and urbanization on environmental pollution in South Asian countries: a nonparametric panel approach. Qual Quant 51(1):65–78

Jarque CM, Bera AK (1980) Efficient tests for normality, homoscedasticity and serial independence of regression residuals. Econ Lett 6(3):255–259

Kasman A, Duman YS (2015) CO_2 Emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. Econ Model 44:97–103

Khan Z, Sisi Z, Siqun Y (2019) Environmental regulations an option: asymmetry effect of environmental regulation on carbon emission using non-linear ARDL. Energ Source Part A 41(2):137–155

Kisswani KM (2017) Evaluating the GDP–energy consumption nexus for the ASEAN-5 countries using nonlinear ARDL model. OPEC Energy Rev 41(4):318–343

Levin A, Lin CF, Chu CJ (2002) Unit root tests in panel data: asymptotic and finit-sample properties. J Econ 108(1):1–24

Maddala GS, Wu S (1999) A comparative study of unit root rests with panel data and a simple new test. Oxf Bull Econ Stat 61(S1):631–652

Meadows DH, Meadows DL, Randers J, Behrens WW (1972) The limits to growth. Universe Books, New York

Munir K, Ameer A (2018) Effect of economic growth, trade openness, urbanization, and technology on environment of Asian emerging economies. Management of Environmental Quality: An International Journal 29(6):1123–1134

Noor S, Siddiqi MW (2010) Energy consumption and economic growth in South Asian countries : a cointegrated panel analysis. International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering 4(7):1731–1736

Omri A (2013) CO_2 Emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equation models. Energy Econ 40:657–664

Pesaran MH (2004) General Diagnostic Test for Cross Section Dependence in Panels. No. 1240, Institute for the Study of Labor

Pesaran MH, Shin R (1995) Estimating long-run relationships in dynamic heterogeneous panels. J Econ 68(1):79–113

Pesaran MH, Shin Y (1999) An autoregressive distributed-lag modelling approach to cointegration analysis. In: Strom S (ed) Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium. Cambridge University Press, Cambridge, pp 371–413

Pesaran MH, Shin Y, Smith RJ (1999) Pooled mean group estimation of dynamic heterogeneous panels. J Am Stat Assoc 94(4):621–634

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econ 16(3):289–326

Saidi K, Hammami S (2015) The impact of CO_2 emissions and economic growth on energy consumption in 58 countries. Energy Rep 1:62–70

Salisu AA, Isah KO (2017) Revisiting the oil price and stock market nexus: a nonlinear panel ARDL. Econ Model 66:258–271

Schorderet Y (2003). Asymmetric Cointegration. No. 2003.01. University of Geneva

Shahbaz M, Nasir MA, Roubaud D (2018) Environmental degradation in France: The effects of FDI, financial development, and energy innovations. Energy Econ 74:843–857

Sheng ZC, Wen NS, Xin Z (2012) Effects of household energy consumption on environment and its influence factor in urban and rural areas. Energy Procedia 14:805–811

Shin Y, Yu B, Greenwood-Nimmo MJ (2014) Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In: Horrace WC, Sickles RC (eds) Festschrift in honor of Peter

Schmidt: econometric methods and application. Springer Science & Business Media, New York, pp 281–314

Toumi S, Toumi H (2019) Asymmetric causality among renewable energy consumption, CO_2 emissions, and economic growth in KSA: evidence from non-linear ARDL model. Environ Sci Pollut Res 26(16):16145–16156

UNCTAD (2010) Trade and environment review: promoting poles of clean growth to foster the transition to a more sustained economy. United Nations Conference on Trade and Development

Wooldridge JM (2010) Econometric analysis of cross section and panel data. MIT Press, Cambridge