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Improving environmental quality through renewable energy: evidence from South Asian economies

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Abstract

Environmental degradation led climate change is jeopardizing sustainable development. To ensure sustainable development, environment-friendly resources should be harnessed. Among these resources, renewable energy has the potential to mitigate environmental degradation. This study investigates the relationship between renewable, nonrenewable energy consumption, and carbon dioxide emissions by utilizing the panel data of South Asian countries over the period 1990–2014. The study used cross-sectional dependence test, Pedroni co-integration, fully modified ordinary least square, dynamic ordinary least square, and Dumitrescu and Hurlin (2012) panel causality test to find the relationships among the variables. Furthermore, the study used panel threshold regression to estimate the amount of renewable energy required for carbon dioxide mitigation. An increase in the share of renewable energy by 4.5143% of total energy will mitigate carbon emissions. The results suggest that renewable energy leads to an improved environment whereas nonrenewable energy contributes to environmental degradation. Finally, the findings of this study imply that the substitution of fossil fuel energy resources with renewable resources is an appealing alternative for sustainable development of the South Asian economies.

Keywords Clean energy · Environmental degradation · Nonrenewable energy · Urbanization

Introduction

The global patterns of climate change have awakened the thought for green technologies in both developed and developing countries that are required to sustain development. Green technologies such as renewable technology help to conserve the environment. Renewable energy consists of solar, wind, hydropower, geothermal, tidal, biomass and biogas (World Bank 2019).

With the development of economies energy demand to support the social and economic welfare of societies has increased. Energy is used to fulfill human basic needs however this energy usage has led to increased emissions. According to IPCC (2011, 2014) since 1850 global use of fossil fuel has increased to support energy production which resulted in increased emissions of carbon dioxide.

Environmental degradation resulted because of anthropogenic activities (IPCC 2011).

South Asia is experiencing rapid growth (Siddique and Majeed 2015) which was 7.5% in 2007 (World Bank 2019). Data suggest an upward trend of GDP in South and East Asia (Perera and Lee 2013). South Asian economies are facing pressure on energy resources, as they are experiencing high growth rates (Zakaria and Bibi 2019). Srivastava and Misra (2007) pointed out that the majority of the population in South Asian countries lacks access to clean and advance sources of energy and relies on conventional sources, which are not only inefficient but also generate several environmental and health problems. Thus, the region needs improvements in energy access, energy security as well as clean forms of energy.

Renewable energy can contribute to environmental mitigation and energy security through diversification of energy sector which boosts growth (Shukla et al. 2017) and development. Furthermore, increased emissions and volatility of fossil fuel prices have encouraged the demand for renewable energy and led to a rise in renewable energy capacity of the world (IPCC 2011). Furthermore, increased levels of

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emissions cause global warming and result in climate change (Majeed and Mumtaz 2017).

Ensuring the availability of environmentally friendly technologies is the goal of the economies around the globe (UN General Assembly 2015). Similarly, as South Asia is also aiming at achieving these goals, the tasks are to replace fossil fuel with renewable energy. Renewable energy deployment is a safe, reliable and affordable solution that can reduce CO_2 emissions by 90% (IRENA 2019b). Furthermore, cooperation among South Asian economies can solve energy trilemma of "energy security, affordability, and sustainability" (UN ESCAP 2018) and can increase job opportunities which ensure regional prosperity as renewable energy deployment led to 11 million jobs in 2018 (IRENA 2019a).

Advancement in technologies make renewable energy affordable, ensure energy security, and improve environmental quality. However, some studies also highlight the demerits of renewable technologies (Apergis et al. 2010; Boluk and Mert 2014; Al-Mulali et al. 2016; Jebli and Youssef 2017; Majeed 2018). These studies found out that renewable energy is a source of land and water inefficiencies that comprises environmental quality. Moreover, renewable energy also increases ecological footprint at the cost of the environment. Therefore, it is imperative to estimate the net effect of renewable energy on the environment of South Asian economies.

The study is novel in its approach as it incorporates the most relevant factors affecting emissions. Limited empirical evidence is available on the environmental mitigating effect of renewable energy particularly in South Asian economies. To the best of our knowledge, this is the first study that examines the environmental mitigating role of renewable energy in South Asian economies. The study confirms the environmental mitigating role of renewable energy in South Asia. To combat emissions in the South Asian region the share of renewable energy in total energy should exceed 4.5143%. Furthermore, the study also estimated the rate of substitution between fossil fuel and renewable energy in the South Asian economies to be 5.824% per annum.

The study analyzed the effect of renewable energy, fossil fuel energy consumption, economic growth, urbanization, and agriculture land on environmental degradation in South Asian economies. The study used cointegration techniques and incorporated fully modified ordinary least square (FMOLS), dynamic OLS (DOLS), vector error correction mechanism (VECM) results, Dumitrescu and Hurlin (2012) panel causality tests and panel threshold regression (PTR).

The present study is an attempt to explore the quest by providing a regional analysis of the impact of renewable energy on emissions in the case of South Asian economies during the period 1990 till 2014, which can provide useful insight into the relationship and can help in the formulation of policies related to environmental mitigation.

The study is organized as follows: second section incorporates the literature review. The next section is comprised of methodology and techniques applied. The following section is based on results and discussion and the last section will conclude the work.

The literature

Sustainable development requires meeting the need of the current generation without compromising the ability of future generations to meet their demands. Economies around the globe are concerned about climate change resulting from deteriorated environmental quality which resulted from anthropogenic activities. To support the development and improve living standards, the role played by the environment is indispensable. As most of the services to support and sustain life are provided by an ecosystem whose sustainability depends on a clean environment. Deteriorating environmental quality threatens the sustainability of life on earth. Economic growth and energy consumption are considered to be the major culprits behind deteriorating environmental quality. The relationship between growth and environmental degradation is quite elaborated in the growth environment nexus.

The available literature documents and support the Environmental Kuznets curve hypothesis which explains environmental deterioration at the early stages of development while improved environmental quality is achieved after a threshold level of income. Improved environmental quality is achieved through innovations, technological development, and sectoral shifts. This supports improvement in institutional quality and increases awareness and knowledge enhancing demand for improved environmental quality (Grossman and Krueger 1991; Dinda 2004). Thus Grossman and Kreuger (1995) supported increased environmental quality as a result of economic development. In contrast, Apergis et al. (2010), Farhani and Ozturk (2015), Salahuddin et al. (2018) and Kahia et al. (2019) reported an increased level of emissions from economic growth.

Environmental transition theory poses that during the transition of economies from traditional economies to industrial economies deterioration of environmental quality takes place as it is supported through increased demand of energy however this relationship improves with development when clean technologies are utilized to improve environmental quality respectively.

The literature is divided into two sections: the first section incorporates literature regarding the relationship between non-renewable energy consumption and environmental

degradation, the second section explores the relationship between renewable energy and environmental degradation.

Non-renewable energy and environmental degradation

Energy is required for development, however, this energy is generated from fossil fuels leads to environmental degradation. The literature supports a higher level of emissions caused by energy use. The findings of Alam et al. (2007), for Pakistan during the period 1971–2005, suggests a higher level of CO_2 emissions caused by energy intensity. Similarly, the results of Shahbaz et al. (2012), for Pakistan for 1971–2009 and Shahbaz et al. (2013), for Indonesia over the period 1975Q1–2011Q4 suggest an increased level of carbon dioxide emissions because of energy use. Rauf et al. (2018), for China from 1968 to 2016 reported increased energy consumption leads to environmental degradation however growth and urbanization ensure better environmental quality.

Similarly, Gorus and Aydin (2019), for 8 MENA countries support decreased environmental quality from energy consumption. In the case of developed economies like Europe union member countries, Kasman and Duman (2015) supported increased environmental degradation caused by energy consumption. Similarly, the findings of Dogan et al. (2017) for OECD countries and Ozokcu and Ozdemir (2017) for high income and emerging economies support the literature of energy-environment nexus. Recently, Majeed and Mazhar (2019) also provide evidence for a panel of 131 countries indicating increased emissions from energy consumption from 1971 to 2017. The evidence whether country-specific, region-specific or global panel highlights the environmental deteriorating role played by energy consumption. Thus, there is a consensus on the environmental deteriorating role of fossil fuel energy consumption.

Renewable energy and environmental degradation

Renewable energy (RE) is clean energy than fossil fuel as it leads to decreased emissions. Furthermore, renewable energy ensures energy security and is inexhaustible, unlike fossil fuels that exhaust (Tsoutsos et al. 2005). To reduce the effect of fossil fuel energy consumption, countries are shifting towards environmentally friendly energy resources. Solar energy being the cleanest form of energy is not vulnerable to weather conditions and does not generate any waste (solid, liquid or gaseous) thus enhancing the environmental quality (Solangi et al. 2011).

Renewable energy ensures energy security (Prandecki 2014; IRENA 2019a) along with the least environmental impact. As the availability of solar energy is not constrained, therefore, it can be exploited to fulfill the increased demands of energy and control climate variability without compromising environmental quality (Devabhaktuni et al. 2013).

Renewable energy sources are sustainable and also reduce dependence on fossil fuels whose prices are volatile. The costs associated with renewable energy deployment are decreasing (especially in solar photovoltaic and onshore wind power) (IRENA 2018). Through renewable energy deployment, water pollution can be controlled which results from using fossil fuels for energy generation (Akella et al. 2009).

Global warming causing climate change can be controlled by changing energy mix increasing renewable energy consumption and decreasing fossil fuel dependence. A study of Algeria for the period 1980–2012 by Belaid and Youseef (2017), suggests an increased level of emission because of conventional energy use to support growth whereas the decreased level of emission through the use of renewable energy. Similarly, Dogan and Ozturk (2017) for the USA over the period 1980–2014 also supported the environmental mitigating role of renewable energy. Sulaiman et al. (2013) also support the environmental mitigating role of renewable energy sources for Malaysia during the period 1980–2009 whereas Al-Mulali et al. (2015), reported a higher level of emissions because of conventional energy use in Vietnam over the period 1981–2011 while the effect of renewable energy on emissions was insignificant.

The study of Bilgili et al. (2016) for OECD countries and Ito (2017) for the 42 developed economies over the period 2002–2011 and Balsalobre-Lorente et al. (2018), for Germany, Italy, France, Spain, and the United Kingdom, over the period 1985 till 2016 support the role of renewable energy in environmental mitigation. However, the study of Boluk and Mert (2014), for EU economies over the period 1990–2008 reported an increased level of greenhouse gases caused by renewable energy however the contribution of renewable energy to increased emission is less than conventional energy.

The findings of Hu et al. (2018) for 25 developing economies over the period 1996–2012, Zoundi (2017) for 25 African countries, over the period 1980–2012 and the study Kahia et al. (2019) for 12 MENA countries over the period 1980–2012 and Acheampong et al. (2019) for 46 Sub Saharan African economies over the period 1980–2015 highlight the importance of renewable energy in carbon dioxide mitigation. However, the study of Jebli and Youssef (2017), for 5 North African economies for the period 1980–2011 reported an increase in emissions from REC (combustile and water).

The study of 74 nations by Sharif et al. (2019) and Majeed and Luni (2019) for a panel of 166 countries suggests improved environmental quality because of renewable energy, whereas Apergis et al. (2010), supported increased emissions from renewable energy for 19 economies (developed and developing) during the period 1984–2007.

Similarly, the results of Farhani and Shahbaz (2014), also support higher CO_2 from renewable and fossil fuel energy for 10 MENA countries (1980–2009).

Thus the literature is mixed as some studies suggest insignificant (Al-Mulali et al. 2015) influence of renewable energy in environmental mitigation whereas other suggest positive effect (Apergis et al. 2010; Boluk and Mert 2014; Farhani and Shahbaz 2014; Jebli and Youssef 2017) while others suggest negative effect (Sulaiman et al. 2013; Bilgili et al. 2016; Belaid and Youseef 2017; Dogan and Ozturk 2017; Ito 2017; Zoundi 2017; Balsalobre-Lorente et al. 2018; Hu et al. 2018; Sharif et al. 2019; Acheampong et al. 2019; Kahia et al. 2019) of renewable energy on emissions.

Materials and methods

The current study extracted the data of South Asian economies from the World Bank (2019) and British Petroleum (2018). The variables used for the study are "carbon dioxide emissions (metric tons per capita) used for environmental degradation", "GDP per capita (constant 2010 US$) used for economic growth", "renewable energy consumption (% of total final energy)" for clean energy, "fossil fuel energy consumption (% of total energy)" for conventional energy sources resulting in emissions, "urban population" used for urbanization, "agriculture land (sq.km)" for the agriculture sector and "crude oil prices (US$ per barrel)". Most of the studies focused on the influence of energy produced from fossil fuels on environmental degradation however limited evidence is available on the environmental mitigating role of renewable energy. The present study incorporates both renewable energy and nonrenewable energy to examine their combined effect on emissions. Due to data limitation analysis is based on the period between 1990 and 2014 (carbon emission data is available till 2014 while renewable energy data is available from 1990 to 2015 and data of crude oil prices is taken from 1989 to 2014):

$$CO_{2it} = f\left(Y_{it}, RE_{it}, FE_{it}, UP_{it}, AL_{it}\right). \qquad (1)$$

CO_2 represent carbon dioxide emissions, Y is "GDP per capita", RE is "renewable energy", FE is" fossil fuel energy", UP is "urbanization" and AL is "agriculture land" respectively. To control for multicollinearity and heteroscedasticity variables are transformed into logarithmic form (Al-Mulali et al. 2016). After log transformation equation can be written as,

$$lCO_{2it} = \propto_0 + \propto_1 lY_{it} + \propto_2 lRE_{it} + \propto_3 lFE_{it}$$
$$+ \propto_4 lUP_{it} + \propto_5 lAL_{it} + \varepsilon_{it}, \qquad (2)$$

i indicates cross-sectional units (1, 2, 3, 4, 5) and t represent the time period (1, 2,…, 25). As growth results in higher emissions, therefore, the coefficient $(\propto_1)$ is expected to appear with a positive sign. RE is expected to decrease emissions, therefore, $\propto_2$ is expected to appear with a negative sign. FE leads to higher emissions, so $\propto_3$ is expected to appear with a positive sign. UP leads to an upsurge in demand for transportation, energy and resource exploitation, however, environmental awareness among the people lead to take such measures which decrease environmental degradation, therefore, $\propto_4$ is expected to be negative. Similarly, as more land is used for agriculture it will lead to more emissions (FAO 2016, 2018; Amjath-Babu et al. 2019) therefore, $\propto_5$ is expected to be positive, $\propto_0$ and ε_{it} is the intercept and error term.

Due to data limitations Afghanistan, Bhutan and Maldives were dropped. The economies analyzed were; "Bangladesh, India, Nepal, Pakistan, and Sri Lanka" respectively.

The present study used the "panel cointegration technique" to explore the long-run relationship among the variables. For this purpose initially, data were examined for cross-sectional dependence tests, to fulfill this purpose Breusch-Pegan LM test (BP-LM), Pesaran scaled LM (PLM) test and Pesaran cross-sectional dependence tests (PCD) are employed.

For panel cointegration, it is necessary that the series should be integrated of order one (Narayan and Narayan 2010), therefore unit root test is applied to check for the stationarity. The panel unit root test (PURT) by Levin et al. (2002) "examine for homogeneity of autoregressive coefficient across countries while", Im et al. (2003), "test allow for heterogeneity of autoregressive coefficient for the whole panel. Maddala and Wu (1999), nonparametric panel unit root tests calculate unit root for each individual by using Fisher–ADF and Fisher–PP tests and combine the p values (Apergis et al. 2010)."These tests assume cross-sectional independence.

After determining stationarity, the next step is to examine cointegration among the variables. Pedroni, Kao, and Westerlund cointegration (WC) techniques are used for the determination of cointegration among the variables.

As the analysis is based on panel data, therefore, the application of ordinary least square (OLS) provides biased results. Pedroni (2001) argued that because of biased results from OLS, the problem of simultaneity and serial association (correlation) between the variables arises. Therefore to tackle this problem "fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS)" have been applied to analyze the long-run relationship among the variables. The FMOLS technique is based on a nonparametric approach to tackle the problem of serial correlation and simultaneity respectively. Results obtained from vector error correction mechanism (VECM) are also reported which has the advantage of separating short and long-run effects among the variables in the presence of cointegration.

To know the share of renewable energy in total energy that is necessary to mitigate CO_2 PTR is used which was introduced by Hansen (1999).

Results and discussion

Cross-sectional dependence and unit root tests

Table 1 reports the results obtained from the cross-sectional dependence test. BP-LM and PLM test accept the alternate hypothesis of cross-sectional dependence whereas the PCD test accepts the null. Therefore it is concluded that cross-sectional dependence (CD) exists.

After cross-sectional dependence test stationarity of the variables is determined. Table 2 reports the results of the unit root test. From the table, it could be noticed that all of the variables are difference stationary.

Panel cointegration test

Table 3 reports the findings of Pedroni, Kao and Westerlund cointegration tests. The H_0 (null hypothesis) of no cointegration is rejected at a conventional level of significance

by Panel PP statistics, Panel ADF, Group PP statistics and group ADF statistics. Therefore, four tests indicate the existence of a long-run relationship among the variables. Furthermore, Kao and Westerlund's test also rejects the null hypothesis. Therefore the results obtained suggest that series are cointegrated.

Fully-modified OLS results

FMOLS and DOLS are employed to explore the long-run relationship among the variable. FMOLS was introduced by Phillips and Hansen (1990), and later on, improved by Pedroni (2001). The reason behind the incorporation of this technique is its usefulness in tackling the problem of serial correlation and endogeneity and the provision of robust results (Jebli and Youseef 2017).

The results suggest a positive effect of Y, FE, and land under agriculture on emission whereas renewable energy and urbanization contribute to environmental mitigation through a decrease in emissions (Table 4). All the coefficients are highly significant.

1% increase in Y, FE, and AL will lead to 0.63%, 0.34%, and 0.67% rise in CO_2 respectively. However, a 1% increase in the share of RE and UP will decrease CO_2 by 1.433 percentage points and 0.68% respectively.

The results of the model suggest that FE consumption contributes to an increased level of CO_2 whereas RE decreases CO_2 over the long run. The results indicate the importance of RE in environmental mitigation and based on the above results, it could be emphasized that countries should invest in RE and work in collaboration to promote environmental improvement through technological advancement and promotion of renewable energy deployment.

Table 1 Results of CD test

Test	Statistic	Probability
BP-LM test	63.11263	0.0000
PLM	11.87635	0.0000
PCD	− 0.084499	0.9327

Table 2 Results of panel unit root test

Variable	Level	(1) LLC	(2) BS	(3) IPS	(4) ADF-χ^2	(5) PP-χ^2
LCO_2	Levels	− 0.83589	0.35423	− 0.47099	16.4921	19.5143
	1st differences	− 4.5812***	− 2.3972***	− 6.4530***	73.2691***	342.12***
LY	Level	− 0.4437	− 0.3424	0.1604	18.3504	33.6324
	1st differences	− 7.8692***	− 6.1849***	− 7.1904***	74.0198***	93.0203***
LRE	Level	0.4577	2.5566	1.1367	10.7756	20.6514
	1st differences	− 5.2167***	− 5.0921***	− 7.0976***	74.0087***	332.734***
LFE	Level	− 1.1478	0.7084	0.2747	8.2978	5.3761
	1st differences	− 7.3374***	− 4.0410***	− 6.5313***	53.7740***	66.7016***
LUP	Level	− 1.0516	3.3098	− 1.5259*	30.6304**	19.5654
	1st differences	− 21.0012***	− 0.9229	− 8.6967***	272.292***	5.9817
LAL	Level	− 2.3997***	− 0.6295	− 1.7754**	24.9074*	23.2499
	1st differences	− 6.5687***	− 6.40557***	− 8.3528***	87.4720***	328.999***

*LLC (Levin, Lin & Chu), BS (Breitung t-stat), IPS(Im, Pesaran & Shin W stat), ADF-χ^2 (ADF-Fisher chi2), PP-χ^2 (PP-Fisher chi2)

Probabilities *p < 0.1, **p < 0.05, ***p < 0.01

VECM is used to find the direction and nature of causality in the presence of cointegration among the variables and hence separates the short and long-run relationships (Belaid and Youssef 2017). Table 5 presents the findings of VECM.

There exists short-run causality from Y to Up, from RE to Y. The coefficient of ECt-1 is negative and significant at a 1% level for the RE equation in the long run. This indicates that the deviation of RE from the long run will be corrected at 4.2% per annum, respectively.

Country-specific effects

South Asian economies can have diverse experiences concerning renewable energy and environment relationships. Therefore, it is also important to explore how individual

countries implement renewable energy practices and respond to emission reduction strategies. For this purpose, time series analysis of each country is conducted and results of FMOLS and DOLS are reported in Table 6.

The results suggest that RE decreases emissions in all countries except Nepal while Y and FE lead to higher emissions. Moreover, in the case of Nepal cross-price elasticity of substitution is not negative implying that renewable energy is not yet treated as a substitute for non-renewable energy.

Dumitrescu–Hurlin causality test

The study employed the "Dumitrescu–Hurlin panel causality test" after Dumitrescu and Hurlin (2012). The test considers that all coefficients differ across cross-sections and results

Table 3 Results of cointegration test

Estimates	Stats	Probability
Pedroni panel cointegration test Ho: no cointegration		
Panel v-statistics	− 2.628494	0.9957
Panel rho-statistics	1.734789	0.9586
Panel PP statistics	− 5.016132	0.0000
Panel ADF statistics	− 7.017366	0.0000
Alternate hypothesis: individual AR coefficients		
Group rho-statistics	2.322256	0.9899
Group PP statistics	− 4.95611	0.0000
Group ADF statistics	− 5.226754	0.0000
Kao cointegration test Ho: no cointegration		
ADF	− 4.444974	0.0000
Westerlund cointegration test Ho: no cointegratio		
Variance ratio	− 1.5929	0.0556

Table 4 Results of fully modified and dynamic OLS

Variable	FMOLS			DOLS		
	Coefficients	T-Stats	Probabilities	Coefficients	T-Stats	Probabilities
LY	0.634425	72.05569	0.0000	0.5184	3.7149	0.0008
LRE	− 1.433321	− 88.99971	0.0000	− 1.2002	− 3.9094	0.0005
LFE	0.341416	20.87503	0.0000	0.6924	2.6756	0.0118
LUP	− 0.508520	− 43.50865	0.0000	− 0.5217	− 2.8105	0.0085
LAL	0.679428	62.32987	0.0000	− 0.6976	− 1.58782	0.1225

Table 5 Results of VECM

	ΔCO_2	ΔY	ΔRE	ΔFE	ΔUP	ΔAL	ECt-1
ΔCO_2	–	0.31478	− 0.2707	0.0965	1.9255	0.1125	0.0028
ΔY	0.0187	–	− 0.1934*	− 0.0456	− 0.9278	0.1156	0.0096***
ΔRE	− 0.0255	− 0.0492	–	0.0412	− 0.3311	0.2729*	− 0.0422***
ΔFE	0.0577	0.2475	− 0.17758	–	− 0.9339	− 0.3318	− 0.0013
ΔUp	0.0035	− 0.0119*	− 0.0012	− 0.0006	–	− 0.004	0.0016**
ΔAL	0.0002	0.06281	0.0438	− 0.0127	0.5677	–	0.0032

Probabilities represented by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

Table 6 Results of country-specific FMOLS and DOLS"

	FMOLS					DOLS				
	LY	LRE	LFE	LUP	LAL	LY	LRE	LFE	LUP	LAL
BGD	0.11 (0.73)	−1.47*** (−8.8)	−0.09 (−0.44)	0.13 (0.85)	0.15 (0.93)	2.72** (2.09)	−2.69*** (−3.57)	2.58** (2.47)	−5.08*** (−3.45)	−1.09 (−0.9)
IND	0.33* (1.70)	−0.91*** (−4.67)	1.02*** (3.51)	−0.43 (−1.35)	0.38 (1.55)	−3.83*** (−4.92)	−1.51*** (−6.04)	−4.86*** (−3.51)	7.83*** (4.6)	−39.01*** (−26.08)
NPL	1.98*** (7.72)	16.2** (4.96)	3.15*** (7.75)	−0.89*** (−5.94)	−7.62*** (−5.35)	36.28*** (132.58)	68.19*** (31.08)	5.33*** (16.19)	−15.86*** (−73.81)	121.15*** (150.56)
PAK	0.44*** (3.76)	−0.31 (−1)	1.41*** (4.24)	0.00 (0.04)	−0.61** (−2.52)	1.27*** (6.79)	−2.92*** (−4.17)	−1.76*** (−2.53)	−1.27*** (−17.07)	2.13*** (5.98)
LKA	0.70*** (5.56)	−0.27 (−0.39)	0.86*** (2.85)	−0.08 (−0.18)	−0.68 (−1.23)	−2.57*** (−52.69)	−3.92*** (−15.55)	3.48*** (39.86)	−8.41*** (−54.4)	15.14*** (64.09)

BGD Bangladesh, *IND* India, *NPL* Nepal, *PAK* Pakistan, *LKA* Sri Lanka

Probabilities represented by *$p<0.1$, **$p<0.05$, ***$p<0.01$, t values in parenthesis

are reliable in the presence of CD (cross-sectional dependence). Furthermore, this causality test can be used in both cases when the time period is greater than cross-sectional units or less than cross-sectional units and even in case of unbalanced heterogeneous panels. The results suggest unidirectional causality from Y to CO_2, CO_2 to RE, FE, and UP while bidirectional causality is reported between CO_2 and AL respectively (Table 7).

Panel threshold regression

Table 8 presents the results obtained from PTR. Initially, estimation is conducted to determine the number of thresholds. The values of F statistics obtained from bootstrap are F1(γ) 28.19 and F2(γ) 15.12, respectively, suggesting that a single threshold effect exists in the model.

The point estimate of threshold (95% confidence interval (CI)) $\widehat{\gamma}_1$ takes the value of 4.5136 in the empirical distribution of the threshold variable with the CI estimates of 4.5077–4.5143. This finding is consistent with the study of Chiu and Chang (2009) that renewable energy mitigates emissions after reaching a threshold (Table 9).

The graphs shed light on the construction of CI for single and double threshold models, respectively. The horizontal axis presents the 1st and 2nd threshold parameter and the vertical axis presents the "individual likelihood-ratio (LR) functions, LR1 r (γ) and LR2 (γ)". The estimates are the values of $\widehat{\gamma}_1$ and $\widehat{\gamma}_2$, "where the LR intersects the zero-point of the X-axis, which is in the right section of the graph. The 95% CI for γ_1 and γ_2 can be found from LR1 (γ) and LR2 (γ) based on the values of γ_1 and γ_2, for which the LR lies below the dotted line at 7.35". This critical value is calculated using the formula $(c(\alpha) = -2\log(1 - \sqrt{1 - \alpha}))$. The results obtained from the threshold analysis suggest the presence of a single threshold (Fig. 1).

Cross elasticity of demand

Energy price is also important to promote investment in renewable energy. The volatile oil prices jeopardize energy security (Chiu and Chang 2009; Majeed and Luni 2019). A rise in oil price increases the cost of energy generation and incentives for substitution of non-renewable energy with renewable energy increase. With the advancement and innovations in technologies the cost of deployment of RE decreases (Table 10). Moreover, RE has certain fixed costs and experience economies of scale. The elasticity of substitution between FE and RE is estimated to be −0.05824, implying that one percent increase in prices of crude oil the RE will be substituted at a rate of 5.824% per annum in South Asia.

Table 7 Results of Dumitrescu–Hurlin causality test

H_0 hypothesis	W-statistics	p value	Decision	Conclusion
LY heterogeneously cause LCO_2	6.1095	0.0007	$LY \rightarrow LCO_2$	$LY \rightarrow LCO_2$
LCO_2 heterogeneously cause LY	1.1753	0.3472	–	
LRE heterogeneously cause LCO_2	2.1844	0.9541	–	$LCO_2 \rightarrow LRE$
LCO_2 heterogeneously cause LRE	4.3720	0.0629	$LCO_2 \rightarrow LRE$	
LFE heterogeneously cause LCO_2	1.6400	0.5929	–	$LCO_2 \rightarrow LFE$
LCO_2 heterogeneously cause LFE	4.8642	0.022	$LCO_2 \rightarrow LFE$	
LUP heterogeneously cause LCO_2	4.0080	0.1234	–	$LCO_2 \rightarrow LUP$
LCO_2 heterogeneously cause LUP	5.2620	0.0083	$LCO_2 \rightarrow LUP$	
LAL heterogeneously cause LCO_2	4.4257	0.0565	$LAL \rightarrow LCO_2$	$LAL \leftrightarrow LCO_2$
LCO_2 heterogeneously cause LAL	9.8939	2.00E-11	$LCO_2 \rightarrow LAL$	

Table 8 Results of PTR and threshold estimates

Threshold variable	Threshold estimator (level = 95% CI)	$F(\gamma)$ (10%, 5%, 1%)
$\hat{\gamma}_1$	4.5136** (4.5077, 4.5143)	28.19 (21.0478, 25.6254,, 34.9894)
$\hat{\gamma}_2$	4.3212 (4.3066, 4.4067)	15.12 (33.2833, 52.3706, 68.2561)

Probabilities *p < 0.1, **p < 0.05, ***p < 0.01

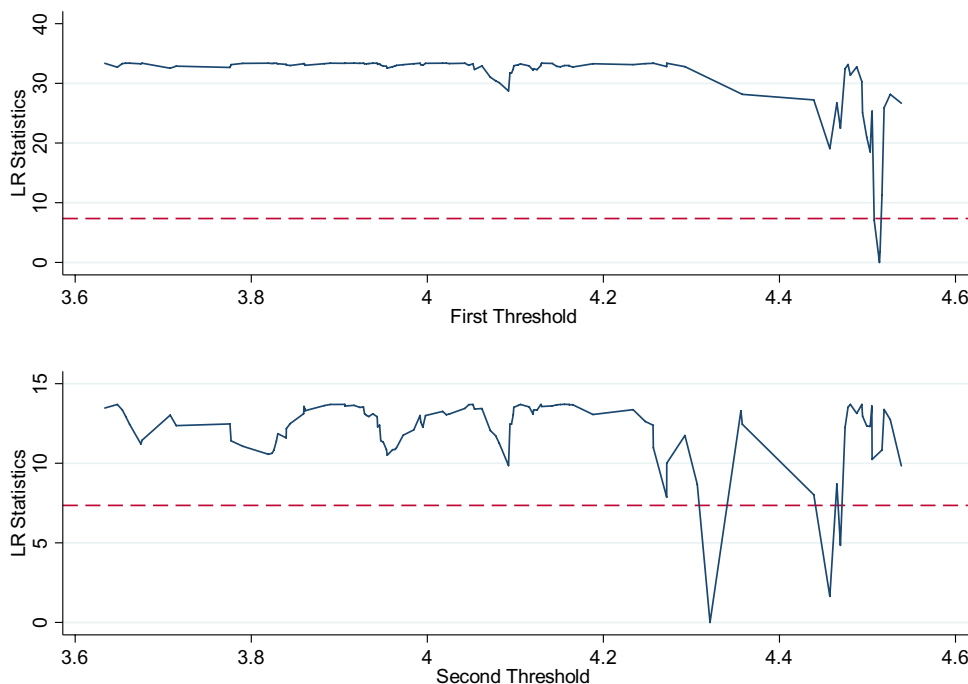**Fig. 1** Confidence interval construction of single and double threshold

Table 9 Regression results of single threshold model

Threshold estimator (level = 95%)

Variable	Coefficient	SE	t value
Lag lCO_2	0.3801***	0.0638	5.96
LY	0.2544***	0.0582	4.37
LRE	−0.4556*	0.2608	−1.75
LFE	0.9649***	0.1029	9.37
LUP	0.0150	0.0535	0.28
LAL	−0.2210	0.2375	−0.93

Probabilities *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

Conclusion

As South Asian economies are facing rapid growth, this growth is accompanied by higher emissions as energy is generated from fossil fuels. Therefore for continued growth and sustainable development, such resources are required that do not deplete or degrade environmental quality. With this objective to support growth and improved environmental quality and ensure energy security, the current study investigated the effect of renewable and non-renewable energy consumption on CO_2 in a panel of South Asian economies over

Table 10 Cross elasticities

Year	CN	Es	CN	Es	CN	Es	CN	Es	CN	Es
1990	BGD	−0.07452	IND	−0.0484	NPL	−0.02392	PAK	−0.05151	LKA	−0.07174
1991	BGD	−0.13294	IND	0.113892	NPL	0.062388	PAK	−0.06548	LKA	0.010304
1992	BGD	0.600467	IND	0.19039	NPL	0.008587	PAK	1.064029	LKA	1.008915
1993	BGD	0.126657	IND	0.035525	NPL	0.05376	PAK	0.269438	LKA	0.118769
1994	BGD	0.328661	IND	0.367979	NPL	0.183154	PAK	−0.01292	LKA	0.715243
1995	BGD	−0.9898	IND	−0.25472	NPL	−0.09248	PAK	−0.26108	LKA	−0.12003
1996	BGD	−0.12261	IND	−0.0613	NPL	−0.01102	PAK	−0.08361	LKA	−0.36822
1997	BGD	0.454156	IND	0.312065	NPL	0.115625	PAK	0.05858	LKA	−0.30325
1998	BGD	−0.01304	IND	−0.01279	NPL	0.007178	PAK	0.019211	LKA	0.07954
1999	BGD	0.01207	IND	−0.04568	NPL	−0.06522	PAK	−0.0642	LKA	−0.03405
2000	BGD	−0.04304	IND	−0.00455	NPL	0.004501	PAK	0.024629	LKA	0.024526
2001	BGD	0.383152	IND	−0.02834	NPL	0.042066	PAK	−0.04945	LKA	0.134711
2002	BGD	−1.11291	IND	−0.99212	NPL	1.051348	PAK	−0.18763	LKA	−0.55505
2003	BGD	−0.20377	IND	0.035526	NPL	−0.03657	PAK	−0.17741	LKA	−0.08453
2004	BGD	−0.02986	IND	−0.06724	NPL	0.029183	PAK	−0.13527	LKA	0.015329
2005	BGD	−0.06086	IND	−0.05438	NPL	−0.02032	PAK	0.000293	LKA	−0.05855
2006	BGD	−0.18938	IND	−0.11956	NPL	0.099525	PAK	−0.10829	LKA	0.179215
2007	BGD	−0.261	IND	−0.29867	NPL	0.005814	PAK	−0.43243	LKA	−0.28593
2008	BGD	−0.11658	IND	−0.14184	NPL	−0.02689	PAK	0.112947	LKA	0.066444
2009	BGD	0.113463	IND	0.179274	NPL	0.046579	PAK	0.013169	LKA	−0.08604
2010	BGD	−0.20894	IND	−0.10942	NPL	−0.0636	PAK	0.071788	LKA	−0.09081
2011	BGD	−0.09835	IND	−0.03485	NPL	−0.00995	PAK	−0.03488	LKA	−0.10494
2012	BGD	−5.62142	IND	−3.73237	NPL	−6.94695	PAK	2.637587	LKA	6.537942
2013	BGD	−0.14195	IND	0.522644	NPL	−0.68119	PAK	−0.74748	LKA	0.500468
2014	BGD	0.324998	IND	0.3541	NPL	0.243626	PAK	0.201876	LKA	0.427353

BGD Bangladesh, *IND* India, *NPL* Nepal, *PAK* Pakistan, *LKA* Sri Lanka

the period 1990–2014. The study used FMOLS and DOLS to explore the relationship among the variables VECM is used to separate short-run effects from the long run in the presence of cointegration. "Dumetriscu and Hurlin" test is used to examine the direction of causality. Furthermore, PTR is conducted to find out the level of renewable energy required to mitigate emissions. The results suggest a higher level of emissions caused by nonrenewable energy consumption which is well addressed in the literature and improved environmental quality from renewable energy consumption. Similarly, urbanization supports environmental improvement whereas agricultural land leads to deteriorated environmental quality.

To the best of our knowledge, this is the first study that examined the contribution of renewable energy in emission reduction in South Asian economies. Due to their geographical location, South Asian economies have an advantage in renewable energy availability which is further supported by advancement in technologies to store and deploy energy. Through cooperation among South Asian economies, energy trilemma (energy security, affordability, and sustainability) can be solved (UN ESCAP 2018), which promotes

prosperity in the region by increasing job opportunities (IRENA 2019b).

Based on results obtained it could be suggested that South Asian countries should reduce their reliance on energy produced from fossil fuels and shift towards renewable energy as it will not only improve their environment but will also bring stability caused by fluctuations in fossil fuel prices. The share of renewable energy in total energy mix should be more than 4.5143% to combat emissions. The rate of substitution between fossil fuel and renewable energy is 5.824% per annum for South Asian economies. Collaboration among countries could be a helpful step in this direction. As South Asian economies are expanding and agrarian economies, therefore, they should consider and incorporate such policy measures that promote growth and development without compromising environmental quality and policy measures such as advancement in agriculture should be promoted.

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